ESSAYS IN ECONOMICS OF SCIENCE, INNOVATION, POLICY AND GROWTH

by

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ABSTRACT

In this thesis we study the effect of scientific research on economic growth of the EU27 countries for 1981-2010, finding that scientific research determines national growth through patents with a ten-year lag. We also study the effect of funding on scientific research output of researchers and find that national competitive funding and other funding are positively and significantly related to research quality. National competitive funding seems to affect positively research quantity. Internal and EU funding matter only in specific scientific fields. We investigate whether past research productivity determines success in securing competitive funding at the individual level finding a significant and positive association of past cumulative citation-related indicators with the funding decision. We also examine the effect of research output and resources on FP7 applications and success at the country level for the EU28 countries in 2007-2013. We find that for research followers both scientific publications and international collaboration matter for FP7 applications and success and for research leaders, publications matter for FP7 applications and citations matter for FP7 success rates. Finally, we use the principal-agent theory framework to discuss the choices and trade-offs that research policy-makers and researchers face and find that balance in bureaucracy and research orientation within funding schemes can produce optimal results.

DEDICATION:

This PhD thesis, and all the years of effort devoted to it, is wholeheartedly dedicated to:

- My loving wife Kyriaki and my precious son Soteris for both being the light in my life
- My mother for her boundless love and for being my shepherd all these years
- My father who I miss so much for always being an example to me with his ethos and selfless actions

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GLOSSARY

CIP: Competitiveness and Innovation Programme of the EU
CMLE: Conditional Maximum Likelihood Estimator
DGEPCD : Directorate General for European Programmes, Coordination and Development
EC: European Commission
EPO: European Patent Office
EU: European Union
EU28: All EU member states
EU27: All EU member states except Croatia
FE: Fixed Effects
FP or EU FP: European Union Framework Programme for Research and Technological Development
FP6: Sixth Framework Programme for Research and Technological Development
FP7: Seventh Framework Programme for Research and Technological Development
FTE: Full-Time Equivalent
GMM: Generalised Method of Moments
Horizon 2020: The EU Horizon 2020 Programme for Research, Technological Development and Innovation (2014-2020)
H2020: See "Horizon 2020"
ICT: Information and Communication Technologies
OLS: Ordinary Least Squares
PC: per capita
PPP: Purchasing Power Parity
PTR: per thousand residents
QCMLE: Quasi Conditional Maximum Likelihood Estimator
R&D: Research and Development
RE: Random Effects
RPF: Research Promotion Foundation of Cyprus
RTD: Research and Technological Development
RTDI: Research, Technological Development and Innovation
S&T: Science and Technology
SME: Small- Medium Enterprise
SS: Social Sciences
UCY: University of Cyprus
WoS: Institute of Scientific Information Web of Science

1 INTRODUCTION

1.1 Background

Economic growth has been the subject of intense study over the past seventy years. Numerous studies have tried to identify the determinants of economic growth and the most common finding has been that technology is the strongest determinant of economic growth (Aghion and Howitt, 1998; Zachariades, 2004). However, there is little agreement over the mechanism through which technology contributes to this growth. Many studies have identified scientific research as the main driver of technological progress (Stephan, 2008; Gibbons and Johnston, 1975). This finding has driven both scientists and policy-makers to investigate further the process by which scientific research enhances technological progress. These investigations have included the economic aspects of the process, such as the funding and productivity of scientific research, sometimes referring to endogenous growth. It is therefore important to understand the mechanisms through which research policy affects economic growth. Figure 1:1 illustrates the possible interactions at different points in the process. This thesis serves as an exploration on the importance of scientific research to economic growth. This includes the study of the contribution of research funding to research output alongside an investigation of the effect of the latter on competitive research funding allocation. The analysis will be based on data for past research productivity for both individual researchers and EU countries. The analysis will be framed within the framework of the principal-agent model.

1.2 Motivation

Four motives have driven the choice of this strand of economics as the focus of this thesis. The first two relate to the field of the economics of science and the related applied econometrics literature. The third and fourth motives reflect issues in applied economics, such as policy design and implementation. More specifically, the third motive originates from an increasing interest in the European Union's research policy and the fourth from the corresponding framework for Cyprus. The thesis concentrates to a significant extent on the field of economic growth. This is a critical field and its necessity is heightened by the financial crisis of 2008 to find alternative economic growth policies more robust to exogenous shocks. Achieving this task may mitigate the negative effects of future crises such as high unemployment and poverty. In this light, scientific research can be instrumental for constructing new knowledge-based models of economic growth. For this to be achieved, studies should switch attention to research able to provide answers to the ambiguity surrounding the mechanisms of economic growth, scientific research funding and productivity. Particularly, countries presently affected by the crisis such as a number of EU member states, including Cyprus, can benefit directly from studies that a) investigate the association of scientific research with subsequent economic growth and b) provide insights as to how scientific research funding allocation and productivity can be optimised. The present thesis follows this direction as explained in subsequent sections.

1.2.1 The emerging field of the "Economics of Science"

In recent years, the economics of science, an evolving field in economics, has studied a wide range of issues related to science. These comprise scientific research productivity at the individual and institutional levels, scientific research funding, the relation and impact of science on innovation, the role of science in shaping economic activity and others (Stephan, 1996; Dasgupta and David, 1995; Diamond, 1994). Recent works discuss the contribution of scientific research to economic growth (Stephan, 2008; Antonelli, 2012). However, there is a significant gap on this subject in the literature and addressing this gap is one of the core contributions of the thesis. Our understanding of the constituents of the economics of science and the path towards its impact on growth, are depicted in Figure 1:1.

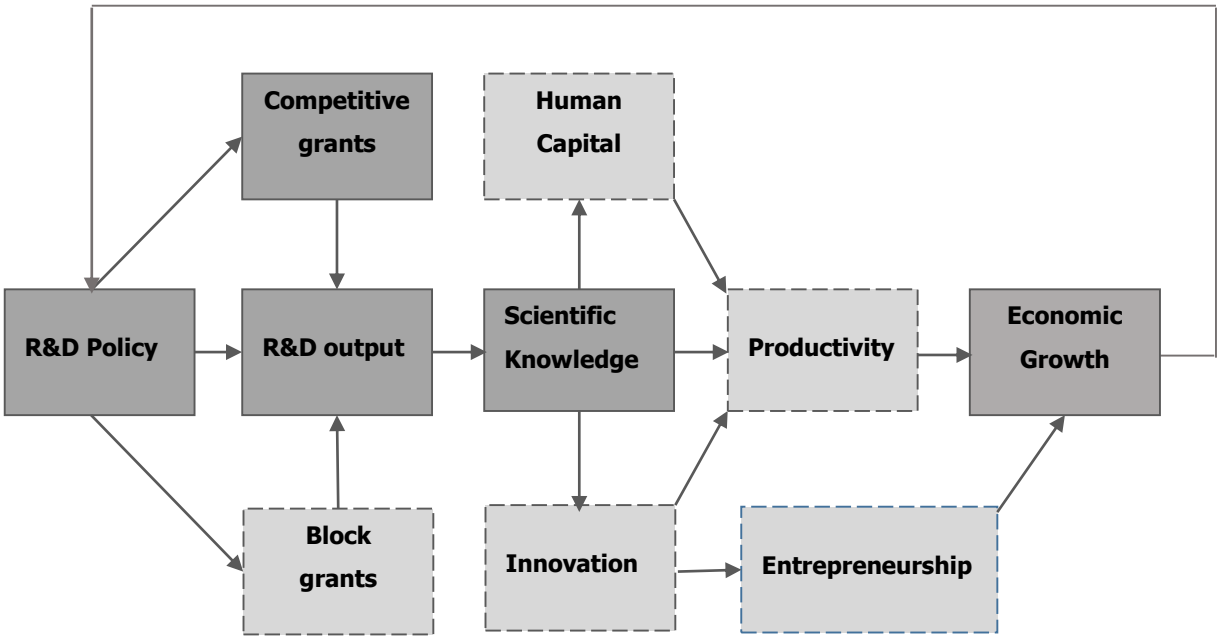


Figure 1:1: The system from R&D policy to economic growth

The end product of the system illustrated in Figure 1:1 is economic growth. In a Cobb-Douglas production function, the technology term *A* is represented by

innovation and productivity in Figure 1:1. The steps that lead to technological advancements that enhance either productivity or lead to new products through entrepreneurship compose the focal point of the thesis. How we measure research output to proxy scientific knowledge, and how we allocate competitive funding efficiently so that the probability of achieving the optimal levels of scientific knowledge is maximised, are subjects of high interest in the economics of science and of the present thesis.

So far, these topics had been a subject of concern for fields other than economics. There is a considerable non-economics literature related to research output and research funding at the individual and institutional levels. Evidently, the economics of science has attracted interest from scientists of all fields but relatively limited interest from economists. Some disciplines have approached the issue either from a sociological or even from a philosophical angle while other thematically-oriented studies focused on the analysis of attributes of specific fields or sub-fields. However, while these studies offer useful insights, they lack rigour in approaching important economic concepts such as productivity, policy, human capital and others. Equally, these studies use very basic statistical methods that are far from the thorough econometric techniques needed to accommodate the features of economic actions and concepts. As a result, important characteristics of economic models such as endogeneity and heterogeneity are systematically ignored. This is a limitation that a new wave of economists has tried to reverse.

The present thesis aims to contribute a better understanding of this system by carrying out mostly empirical work in a number of subfields. In particular, reviewing

the relevant literature led to the realisation that there these significant gaps needed to be addressed:

1. The association of country-specific scientific research productivity in different fields with subsequent economic growth.
2. The determinants of application and success at the country-level for the EU FP7
3. The effects of competitive grants from different funding agencies on subsequent research productivity at the researcher level
4. The assessment of competitive funding schemes as to the optimality of the grant allocation and whether the best researchers get the money
5. A theoretical framework with micro-foundations that explains the interactions of policy-makers as principals and the researchers as agents in the context of research funding-output nexus

This thesis tries to fill, or at least narrow, gaps in the literature and in our current understanding. The first gap is addressed by Chapter 2 in the study of how scientific research has affected subsequent economic growth in the EU countries for the period 1980-2010. The second gap is closed by Chapter 5, which, to the best of our knowledge, is the first study to investigate the determinants of research funding application and success at the country level in any EU FP. Chapters 3 and 4 contribute to the literature by using data from the Research Promotion Foundation and the University of Cyprus to examine the determinants of funding success and research productivity, filling the third and fourth gaps. Lastly, a principal-agent model is constructed to facilitate a better understanding and discussion of the trade-offs and choices of policy-makers and researchers in their interaction within research

policy and funding schemes. In what follows we discuss the different motives for choosing to address these gaps.

1.2.2 Applied econometrics challenges

Empirical studies carried out within the economics of science use standardised econometric methods. The predominant approach is to consider the existence of a research talent or ability that drives both research productivity and success in securing competitive research grants. Hence, the main concern of econometric models is how to deal with endogeneity caused due to the simultaneity of research talent with research excellence. Therefore, the use of the fixed effects approach both in cross-section data (individual dummies) and panel models (within transformation) is very often encountered in the literature. This method controls for unobserved heterogeneity among individuals and, partially, for simultaneity due to a potentially time-invariant talent. However, in order to account fully for endogeneity, instrumental variable estimation is preferred and thus we use it at some instances. Our approach obtained consistency and unbiasedness in the models to a satisfactory extent, but at the cost of efficiency due to higher standard errors caused by the non-use of the between variation in the data. In most cases, the results seemed accord to intuition but either low magnitudes or low levels of statistical significance moderated the validity of the inference. It can be argued though that a more detailed approach to the econometric modelling of such studies is missing from this strand of the literature. Examining alternative assumptions other than research talent could result in a more efficient method of estimation, given that plausible justification can be provided. Therefore, albeit using the mainstream

econometric methods in this thesis as well, we enrich the analysis by considering unconventional approaches such as multilevel modelling. Multilevel modelling allows for different levels of econometric analysis and in our case the levels concern departments, individuals and research output. By exploiting more of the variation in the data, it is a very efficient estimation method. However, its assumptions of normality and strict exogeneity may jeopardize the consistency of the estimators. To address this, we examine the source of endogeneity on a case-by-case basis and construct, where applicable, assumptions that can rationalise departure from restrictions that hinder the full employment of efficient econometric methods. We use instruments conditional on attributes of actual procedures such as the evaluation of research funding proposals or the talent built through a PhD and a post-doc fellowship, with the disclaimer that these assumptions are at least as plausible as the traditional econometric assumptions.

Also, along with separating research output per scientific field, we include in the same models research output indicators from different thematic fields and search for acceptable ways of harmonising them to include them collectively in the analysis. To this end, and unlike in previous studies, we construct a series of indicators that underline different aspects of research output. Journal publications, citations, journal impact factors, h-index, domestic and international co-authorship and length of research output are the main determinants differentiating the various indicators. Looking for robustness among different indicators equips the findings with reliability and validity.

The econometric treatment of these composite indicators is on its own a non-trivial challenge. Publications and citations are usually treated as count variables through either Poisson or Negative Binomial but their composite variations are more difficult to define in terms of their appropriate treatment as dependent variables. The Journal Impact Factors are greater than zero and therefore can be log-transformed but the same technique is not applicable for a variable such as "Amount of funding secured" in a specific time interval since there is a large number of zero observations which are lost in the log-transformation. The use of censored models such as Tobit is problematic due to the normality-homoskedasticity requirements for consistency and either we apply ad-hoc transformation and use linear regression or we use count models such as Poisson and Negative Binomial that can accommodate non-count variable due to the Gamma factorial.

1.2.3 The European Union

Patterns of growth and R&D policies in the EU are of great interest to economists. The EU is a unique combination of countries implementing the majority of their economic policies in a collective manner, albeit addressed to largely heterogeneous member states. Policies highly relevant to a number of countries may be remotely related to other countries' capacity or characteristics and this contradiction deserves more attention, all the more so if it has not been examined empirically. This is the case with the R&D policy of the EU. No single economics study (or in any other field) exists that focuses on the determinants of the success of countries in the EU funding framework and especially from a productivity perspective such as the scientific

capacity of countries in per capita terms. This is a striking gap in the literature and this is the first study to attempt such an analysis.

1.2.4 Cyprus

Interestingly, in the case of Cyprus the need to restructure the productive constituents of GDP is more relevant than ever. The high reliance on financial services brought the country close to economic disaster in 2013 when the two major banks of the country were judged insolvent. This unfortunate event dictated signing a memorandum of austerity with the EU and the International Monetary Fund to get a loan in order to recapitalise the banking system as the markets would not buy Cypriot bonds. Among other austerity measures, the memorandum imposed an unprecedented 'haircut' of all deposits above €100.000 in the two problematic banks, bringing immense uncertainty and lack of trust in the banking sector and the country as a whole. The "haircut" caused many firms to undergo major losses in terms of both operating cycle and liquidity, leading the country to a deep recession and unemployment reaching 17%. With this background in mind, one can understand why finding new economic sectors that can become profitable within a short to medium-term horizon is critical for the country.

Along with renewables such as solar energy, R&D is one of the potential growth paths examined. A significant share of the EU Structural Funds has been channelled to R&D and policy-makers in Cyprus believe that it can make the difference in opening new growth horizons by exploiting the potential of knowledge-intensive sectors. However, this may prove to be merely wishful thinking if relevant policies and the research and innovation system are not thoroughly designed towards

producing results commensurate with driving the knowledge-intensive sectors. Here is where the motivation for a number of chapters of the present thesis lies. A two way relationship between funding and scientific research output exists and this should be appraised as to its efficiency. When allocating research funding, it is of paramount importance to have deep knowledge of the impact of the grants on scientific research productivity and have credible metrics to reflect upon. On the other hand, there should be efficiency in the competitive funding allocation mechanisms so that the probability that funding goes to the best researchers is maximised. These are issues that have never before been investigated for Cyprus and this is one of the contributions of the thesis. It is linked to normative economics as it provides policy suggestions for an ideal research and innovation system in the country. In no case is this the only contribution of the thesis to the economics literature but rather the realisation of an applied economics related motive. Exploring the attributes of the case of Cyprus can result in carrying out, *inter alia*, economic analysis that can be directly taken into account by policy makers for welfare purposes in the country and other countries with similar characteristics facing analogous challenges.

These four motives drive the thematic orientation of the thesis. In what follows, we discuss this thematic orientation of the thesis reviewing the scope of each of the chapters.

1.3 Thematic orientation

The second chapter goes deeper into exploring the effect of scientific research on growth rates for the countries of the European Union. It utilises publications in three

broad thematic fields, namely Science and Technology, Social Sciences and Humanities for each country for the period 1981-2010, the lagged values of which are used as the explanatory variables of interest. Economic growth is proxied by growth rates of GDP per capita in PPP Fixed Prices. Other national accounting measures are also deployed to study the effect of scientific publishing activity, citations thereof and patent applications on economic growth. We construct a theoretical model based on the foundations of endogenous growth theory and then use a panel data model to estimate it. The findings show that, at least quantitatively, the scientific research of a country in the fields of Science and Technology and Social Sciences is a key determinant for growth for through its effect on patents. Patents are found to be highly important for growth in our results. Thus the lag of the effect of Science and Technology and Social Sciences publications on economic growth is estimated to be around ten years. These results are in line with endogenous growth theory and a number of empirical studies in the field. For Arts and Humanities there are no implications that publications thereof are influential for growth. This could be due to differences in research output produced in arts and humanities but also due to a probable longer lag needed to affect growth which is not covered by the present chapter.

In the third chapter we provide insights regarding the effect of different types of funding on research output discussing the multiple econometric challenges towards that end and applying various methods to tackle them. We examine this relation by adopting two mutually exclusive assumptions for researchers: either they have a fixed effect related to their ability to produce research output or they have a random

effect unrelated to their ability where the latter is fairly homogeneous among them due to a presumed threshold level of sophistication. Two datasets were utilised: a) a panel data of 172 tenure-track faculty researchers employed at the University of Cyprus from 1999 until 2013 with information regarding their personal characteristics and research funding and output and b) a dataset of 1909 publications for the same researchers for 2008-2013 where publications are the main response variable and their quality is the metric utilised. We separated funding into several types such as internal grants, national competitive funding, European Union funding, prestigious funding, culturally-adjacent funding and other funding, with the latter covering all other funding sources not included in the first five categories. Using both linear and non-linear estimation techniques for panel as well as cross-section data, including multilevel modelling, we find that national competitive funding along with other funding are the only types that seem to be significantly related to better output as represented by citations and impact factor related measures. In the panel setting, national competitive funding seems to affect positively the quantity of research output as well, with both three-year and six-year lags. The other types of funding seem to matter only in specific scientific fields whereas in some cases the sign of the coefficient is counter to intuition. The explanation for these findings may lie in the levels of bureaucracy and the collaborative orientation of each funding scheme-especially EU funding- and the role that these features play for either enhancing or hindering research productivity.

In the fourth chapter we examine competitive research funding allocation by analysing if success in securing funding is determined by a number of research

output indicators at the individual level. We utilise data from the Research Promotion Foundation of Cyprus from 2003 to 2011 to explore the case of the faculty members of the University of Cyprus. Employing various econometric estimation methods, the results show a direct and positive association of past research performance to the funding decision for cumulative output mainly in citation-related indicators. However, lagged 3-year average and career average research output of researchers do not appear to be significant determinants of success in securing funding. These findings imply that reputation is likely to be more important than research productivity for the outcome of the funding allocation decision. Policy implications derived from the magnitude of the estimates include the need for a more efficient evaluation system for research proposals. Ideally, this evaluation system should place more emphasis on past performance rather than other criteria given the role this determinant can play as a signal for the policy-makers.

In the fifth chapter we examine the effect of research output and resources on competitive funding applications and success rates at the country level. To this end, data from the Seventh Framework Programme of the European Union for Research and Technological Development (FP7) for the EU28 countries in 2007-2013 were utilised. Accounting for both country- and year-specific effects, the results show that past research output in science and technology matters for FP7 applications while in the social sciences and the humanities it does not. However, the effect of most inputs, such as research intensity and research personnel, on FP7 applications and success is ambiguous. Comparing countries of low or high research capacity (research followers or leaders as defined by the EU), we find that for research

followers both scientific publications and international collaboration matter for FP7 applications and success. In contrast, for research leaders, publications matter for FP7 applications and citations matter for FP7 success rates.

Finally, the sixth chapter discusses policy implications derived from the findings of chapters two to five, using the principal-agent theory framework. The aim is to formulate a plausible theoretical background that approximates the process of research funding allocation and scientific research productivity. Moreover, we discuss the trade-offs of the scientist and the policy-maker and the dilemmas they face in the production of scientific research and the design of programs for optimal earmarking of research grants respectively. The chapter also elaborates upon the concepts of moral hazard and adverse selection to highlight the importance of addressing all aspects of the interaction between the policy-maker and the researcher before formulating funding mechanisms for research.

1.4 Research questions

The areas and the specific issues that the present thesis addresses are identified in the following research questions:

1. Does scientific research enhance economic growth? How was this association reflected empirically on the EU member states in the last 30 years?
2. Do different types of competitive research funding enhance individual research productivity and to what extent?
3. Is competitive research funding allocated efficiently to researchers? Do the best researchers get the money?

4. How is common pot funding for research and innovation earmarked to the members of a partnership such as the EU FP for RTD at the macro level? Does per capita research performance play a role?

5. What is the theoretical background for the motivation of policy-makers and researchers to engage in transactions within the research funding-output context?

6. What are the policy implications for optimal funding allocation and research productivity?

We discuss potential answers to the above research questions within the chapters and also in the conclusions section of the thesis.

1.5 Structure of the thesis

Though each chapter is presented as a distinct article each provides a progressive exploration of the factors linking scientific research and economic growth.

The second chapter brings the aim of thesis into perspective: the relevance of scientific research to the achievement of higher economic growth rates. The third chapter goes deeper in examining the impact of research policy on research productivity at the individual level. Chapters 4 and 5 are concerned with whether the competitive funding allocation is optimal with respect to the most promising proposals. This is analysed at the individual level in Chapter 4 and at the country level in Chapter 5. Subsequently, Chapter 6 reflects upon the results of the four empirical chapters to add theoretical texture to the thesis, using the principal-agent model to address all surrounding interactions between the policy-makers and the scientists and to form the basis to discuss policy implications and suggestions.

Finally, Chapter 7 concludes, whilst discussing the limitations of the thesis and providing suggestions for future research.

2 SCIENTIFIC RESEARCH AS A DETERMINANT OF ECONOMIC GROWTH

We explore the effect of scientific research on economic growth for the countries of the European Union. To that end, we utilise publications in three broad thematic fields, namely science and technology, social sciences and the arts and humanities along with patents and schooling data for each country for the period 1981-2010. We construct a theoretical model based on the foundations of endogenous growth theory and then use a fixed effects panel data model to estimate it. The findings show that, at least quantitatively, a country's research output in Science and Technology and Social Sciences is a key determinant for growth with an average lag of 10 years. This effect is indirect and passes on to growth through technology as represented by patent applications. Publications in the Arts and Humanities seem to have no impact on growth but this might be because our chosen 10-year lag is too short.

2.1. Introduction

Economic growth represented by the increase in real Gross Domestic Product (GDP) per capita is a measure of the change in economic activity of a country. With economic growth being one of the key macroeconomic objectives, policy-makers focus on selecting the best growth strategy.

Throughout the years, it has become clear that no magic recipe exists that generates economic growth. Consequently there is interest in finding the determinants of growth to assist in formulating effective growth policies. One of the widely studied determinants is 'knowledge', in all its different forms. The most prominent version of knowledge is the one used as an input in economic growth models, usually referred to as technology or technological change.

Economic growth and its determinants have been extensively studied in the last 60 years, ever since the Solow-Swan models were made known. Due to non-empirical verification of these models (Lucas, 1988), in the late 1980s and early 1990s, a new generation of models were introduced which endogenised knowledge in the growth model (Romer, 1986; Lucas, 1988; Romer, 1990; David

et al, 1992; Grossman and Helpman, 1991; Aghion and Howitt, 1992) either through vintages of technology or stock of human capital.

Endogenous growth has generated probably the most interesting and challenging part of the growth literature. It was a critical step towards explaining how technological progress was endogenously determined in a growth model, meaning that technological progress is a result of economic choices and actions rather than a process taking place outside the economy. Such a development in growth theory was very important since influential growth models (*e.g.* Solow, 1956; Swan, 1956), albeit underlining the contribution of technology in achieving high growth rates, considered this technology as exogenous to the growth process. On the other hand, the empirical evidence was not consistent with the pattern in growth suggested by endogenous growth theory. Aghion, David and Foray (2009) referred to the benefits of research and innovation on growth as too obvious to neglect despite the complications in proving empirically their existence and magnitude. Leonard (1971) believed that education and technology have a direct impact on growth with the effect from technology being far greater. Schumpeterian growth models offered a probable scenario as to how innovation can bring increasing returns to scale through the creative destruction effect of vertical innovations (Schumpeter, 1934; Aghion and Howitt, 1992). Vertical innovations refer to a process whereby newly-invented intermediate products render the previous ones obsolete, as opposed to the theory of expanding varieties of products suggested by a number of authors (Spence, 1976; Romer, 1990) in which there is an additive rather than replacing effect.

These growth theories were not able to combine the new theoretical background with the stylised facts. In particular, the main discrepancy was that while endogenous growth theory models suggested that endogenous technology can result in increasing growth rates, the data were not in line with this pattern. A wave of new studies followed that eased the restrictive assumption of increasing returns and created models that were endogenous but did not impose scale effects on the growth rate (Segerstrom, 1998; Dinopoulos and Thompson, 1998; Zachariades, 2003; Sener, 2008).

Despite being included in all contemporary growth models, technological progress is still a matter of debate as to how it is achieved. With theoretical premises ranging from vertical or horizontal innovation up to human capital and knowledge spillovers, many different models have claimed plausible paths for technological progress. We assert that scientific knowledge may provide an answer as to how technological progress is achieved not by exclusion but by combination with the paths explained above. It is nevertheless critical to examine the classification of different types of knowledge and discuss further the properties of scientific knowledge. Knowledge is a key component of contemporary economies encountered in different forms such as basic, scientific, technological and technical (Aghion and Howitt, 1992). Each of these categories of knowledge is linked to different stages of the production function of a country and fuels different actions. Superior knowledge has the advantage of providing a competitive advantage. Different levels of knowledge bring about different types of innovation, both in their nature and magnitude. In technical knowledge for instance, it suffices to have an experienced technician to apply changes in a

production line to introduce a small innovation, which reduces time needed, costs or improves quality. To introduce an innovation which relies on scientific progress, extensive research should be conducted so as to achieve general scientific breakthroughs but these take considerable time to materialise. However, when such discoveries are achieved, the impact on technological progress is usually substantive and in terms of increased exponential growth. One such example is in photonics and its multiple impact. Photonics is the science and technology of generating, controlling, and detecting photons, *i.e.* light particles (Butter et al, 2011). Photonics underlies a number of advanced technologies including *inter alia* lasers, computers, the Internet, smartphones, lighting technology and medical instruments.

In this chapter we are interested in how scientific knowledge contributes to the process of economic growth. How the dependence path between the two is established is also of interest as the linkage is not directly clear. If scientific knowledge is growth-enhancing then countries could compete to produce new science and leverage upon the potential benefits on growth. So, would any country able to differentiate itself with respect to the production of scientific knowledge achieve higher growth rates exploiting its superior knowledge? If this relationship holds, a relatively uniform progression of knowledge and economic growth across countries would be visible. However, there has been inadequate empirical evidence in growth economics to support this argument.

Scientific knowledge is presumably the form of knowledge that takes the longest to be transformed into added value in the production process (and thus growth) and the one that has had the least attention in the literature. Moreover, the

magnitude and lag of the contribution of scientific knowledge to growth seems to vary among sectors. It is important to distinguish between scientific knowledge and innovation. Scientific knowledge comes in the form of theoretical research (basic or applied) whereas innovation is practical insofar as once implemented it has an immediate impact on technology. Scientific research is the step that precedes innovation. Arguably, the more applied the nature of the scientific sector the less time it takes for research to materialise into innovations (Leonard, 1971). Howitt (2000) argued that universities are driving economic growth through both basic accessible research and applied research targeting technological innovations. But what is the actual impact of scientific knowledge on the output of the economy and what mechanism channels the results of research into production?

The implication is that different levels of knowledge are needed for different innovations to be introduced in the production process. Innovation is the obvious outcome but human capital is another side-product of this process. Human capital is either defined as a formative learning process through the choice of attending higher education (Lucas, 1988; Mankiw et al, 1992) as in Figure 2:1 or as a learning-by-doing effect (Arrow, 1962; Romer, 1990). Human capital is a likely bridge between ideas and the implementation of innovations (Nelson and Phelps, 1966; Aghion, David and Foray, 2009). Figure 2:1 shows a potential path that leads from scientific research to economic growth and how innovations and human capital play the role of intermediaries towards that end.

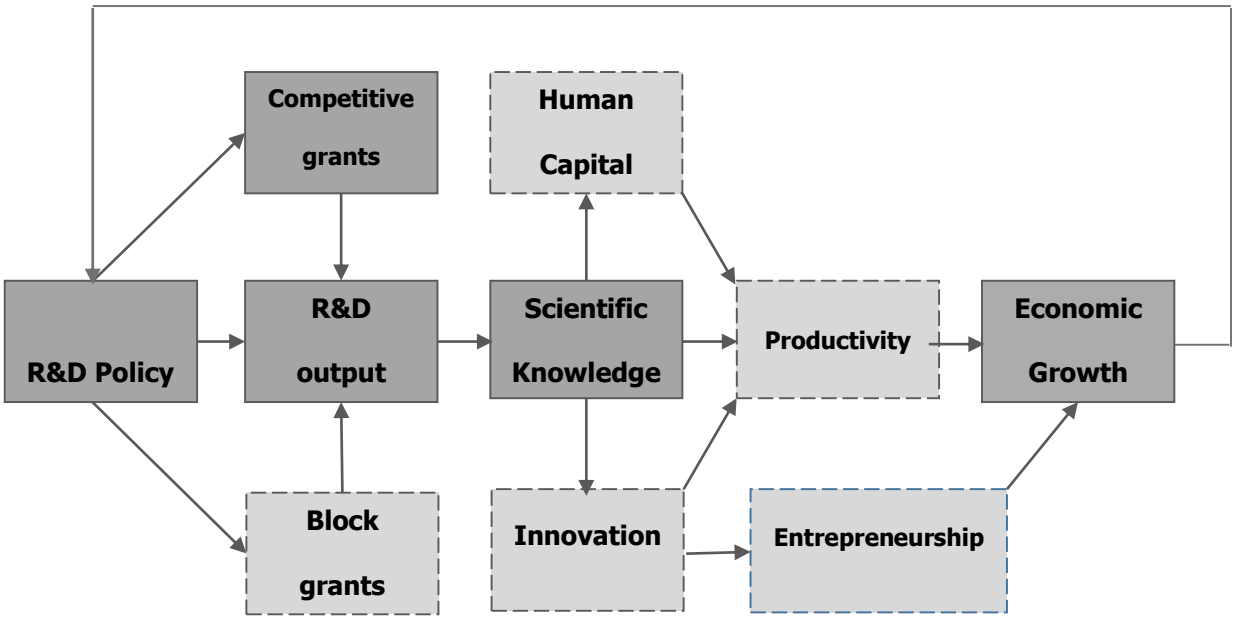


Figure 2:1: A potential path from R&D policy to economic growth

Based on the above background analysis, we try to test empirically the associations of input variables leading to growth as illustrated in Figure 2:1. We consider that policy, through R&D expenditure, enhances scientific knowledge and in turn this knowledge helps improve technological progress and the skills of individuals engaged in the production process. These enhancements are expected to bring improvements in the productivity of the factors of production and the introduction of new firms to the market, based on novel technologies. Finally, economic growth facilitates liquidity to reinvest in scientific research through policy, given that there is the political will to do so, and this helps the process to restart[1].

Based on the above explanation, the aim of the chapter is to test the validity of the growth path. We investigate the association and potential causality between

[1] For example, in the European Union a target was set where by 2020, on average, 3% of the GDP of the member states should be reinvested in R&D activities.

all variables of Figure 2:1 such as research policy, scientific knowledge, innovation, human capital and economic growth. More specifically, we are interested in answering the following questions using empirical evidence at the country level:

- Does scientific research have an impact on economic growth?
- Does scientific research have an indirect impact on economic growth through innovation?
- If any of the above effects on economic growth exists how long does it take to materialise?
- Is there an inverse relationship from economic growth to scientific research and innovation?

These questions have not been adequately addressed in the literature. The existing research has taken as given that scientific knowledge is globally available at a very low cost to innovators and a cross-country analysis of the production of such knowledge and its impact on growth could not offer useful information. This chapter aims to overturn this view by utilising empirical evidence for EU countries. Countries spend money funding universities either directly through block grants or indirectly through competitive grants. We claim that research and development activities are not exogenous to the whole growth process but are intentionally carried out to foster innovations and growth. Characteristically, in the Europe 2020 growth strategy, the European Union (EU) has set a target of achieving R&D spending levels of 3% of each member state's GDP until 2020. The provision of this strategy corroborates the findings of Jones and Williams (2000) who find that in free market economies, such as in the EU, investment in R&D is less than the social optimal.

Nevertheless, it may be the case that decisions taken within this context lack the background information necessary to allocate resources optimally among different scientific fields and institutions. In the era of the economic crisis every pound spent is important and perhaps indirect and long-term effects will not be included in the top priorities of policy-makers for the next few years. Therefore, a study on the contribution of scientific knowledge to economic growth at a country-year level is likely to fill this gap in the economic growth literature. In particular, it will be significant in revealing the importance of scientific research on output growth by differentiating between the thematic areas of research.

The present chapter addresses these gaps, providing an empirical investigation using data from a panel of 27 EU countries (EU27 - all EU member states excluding Croatia due to its very recent accession to the EU) and discussing policy implications.

To this end, the paper is organised as follows. In the next section, the relevant literature is reviewed, followed by the theoretical framework and the models to be estimated. Subsequently, the dataset along with the methodology are explained. The findings are analysed and discussed in section 5 and the final section concludes and offers suggestions for further study.

2.2. Literature Review

The literature on economic growth and its determinants is extensive and diverse. Since this chapter is an empirical study of the effect of scientific research on economic growth, we narrowed down the scope of the survey to the core endogenous growth models and related empirical studies. After a general

introduction on economic growth models, where we discuss exogenous growth and convergence, we focus on endogenous growth and the role of scientific research and innovation in driving growth, both at the theoretical and empirical level. We address implications for scientific research in all parts of the literature. In an early version of a growth model, Solow's (1956) seminal paper was the first in a class called exogenous growth models (Swan, 1956; Solow, 1957; Cass, 1965; Koopmans, 1965). The term "exogenous" refers to the fact that the Solow model concluded that the only way to achieve long-run growth was through exogenous technological change, that is, outside the model. The Solow model relied on a neoclassical production function which exhibited constant returns to scale and diminishing returns to each factor of production. The model stated that capital per capita was the main determinant of economic growth. The determining factors of capital per capita such as savings (positive) and depreciation and exogenous population growth rate (negative) were the determinants of the capital per capita growth rate and consequently the economic growth rate. However, the model predicted that capital accumulation could not increase the long-run growth rate of GDP per capita, as capital exhibits diminishing returns to scale. It could exhibit positive growth and perhaps sustain a stable rate of growth but it could not result in increasing the growth rate.

As technology is exogenously determined in the model, the implication of the Solow model for scientific research is that it is not purposefully conducted for contributing to technology and economic growth. A contribution of scientific research to economic growth would be a side-effect of scientific research policy according to the Solow growth model. In reality, scientific research policy is

largely oriented towards economic growth. An example is the European Union's research policy which is an indispensable part of its economic growth strategy. Research that followed afterwards focused greatly on explaining the "A" term of the production function of the economy, also referred to as the "Solow residual" (Solow, 1957) given its vagueness as to the process and the degree to which it contributes to output. The residual comes as a result of growth accounting, a non-econometric method, which deducts the growth rates of capital and labour, each weighted by their share in national income, from the growth rate of GDP. The remainder rate is the Solow residual and it is attributed entirely to exogenous technological change. Schultz (1960) linked this residual to human capital, finding that it was responsible for 20% of the growth rate of GDP. Subsequently Denison (1962) and then Jorgenson and Griliches (1967) estimated the impact of human capital on the "residual" to be in the neighbourhood of 33%, translated in an average of 0.5% increase in the overall growth rate. These developments were major steps in explaining the Solow residual[2]. The strand of the literature that followed focused more on explaining and proving the convergence property of the Solow model and did not engage in explaining how technology was determined, let alone the role of R&D in the process, given it was considered exogenous.

The convergence property stated that countries with low initial income would grow faster than countries with high initial income and thus they would all converge to the same levels of per capita income (Barro, 1991). This refers to absolute convergence. On the other hand, the theory of conditional convergence

[2] Griliches (1997) reviews these attempts in detail, along with other similar studies related to human capital.

maintains the inverse relationship of initial income with growth rates but instead predicts that each country would converge to their own particular steady-state, given country-specific conditions. Without looking at the empirics and only from general knowledge we could state that the theory of absolute convergence does not stand in reality. We should note that we discuss the convergence concepts and the theory-evidence discrepancies thereof, as their insights are valuable for understanding the necessity of subsequent models and empirical findings that examine the role of knowledge as a determinant of economic growth.

Islam (1995) used panel data to examine the convergence assumption for three different datasets referring specifically to OECD countries, non-oil economies and countries that belong to the latter group but not to the former. The countries used were similar to those in Mankiw et al (1992) in order to facilitate comparison of the findings but also of the cross section and the panel data settings. Islam found evidence of conditional convergence, which means that each country converges to its own steady state and not to some common ideal steady state for all countries. He claimed that had the theory of absolute convergence been valid we should have already seen a clear convergence of all developing countries to the levels of developed countries. Solow predicted a 17 year period to reach half of the way to convergence whereas Mankiw *et al* (1992) estimated 35 years, which is far more realistic. However, what is obvious is that other institutions have played a critical role in growth such as education systems, democracy and international openness. Such institutional variables exhibit very slow changes and their between variation is more likely to be captured in a cross-section model. Nonetheless, cross-section models suffer from unobserved heterogeneity, that is,

time-invariant variables relevant to growth that are not included as explanatory variables leading to omitted variable bias. This is the reason why a panel data approach is more suitable for exploring economic growth dynamics. Such an undertaking allows for heterogeneity among countries and does not presume common characteristics of growth determinants.

In contrast to Islam (1995), Mankiw *et al* (1992) did not provide for these idiosyncratic features and used cross-section based econometric methods to estimate their model that most probably produced results that suffer from omitted variable bias. The authors augmented the Solow model by including human capital in the production function and tested the degree to which the empirical findings matched the theoretical suggestions of the augmented model. The authors improved the predictive power of their empirical model coming to the conclusion that human capital differences can explain differences in economic growth rates. However, they did not account for other country-specific explanatory variables and this is a key pitfall of their cross-country models where unobserved heterogeneity is not provided for. This is something that panel data can handle. Moreover, using panel data to examine countries with similar characteristics can lead to an isolation of the effects of knowledge progress upon growth.

As discussed above, Islam (1995) examined this property in detail, incorporating various aspects of the growth process. Nonetheless, Islam's effort focused on the convergence phenomenon and inferred the existence of a conditional convergence pattern, that is, a convergence of each country to its own steady-state and not to some uniform steady-state. In our view, the most interesting

result of Islam's empirical study is that even with uniform population growth and saving rates across countries only technological progress can impact on long-term growth. He also underlined that human capital is likely to affect growth positively through technological progress, although he clarified that the mechanism through which this happens is unclear. Indeed, how this technology was improved and how it could contribute in achieving increasing growth rates in the long term leads to challenging research questions.

Scientific and technological research were credited with a significant share of growth of technological progress despite Denison's (1985) argument that only around 20% of the improvement of technology can be attributed to the progress of research. This divergence was mainly due to the uncertainty that characterises the research process and the difficulty in fully quantifying its benefits. Romer (1986) came to contrast this argument by stating that most accumulation of knowledge comes from profit-maximising firms, thereby resulting in a partially non-excludable and non-rival good.

In essence, Romer's paper was the first of many endogenous growth models to follow. He considered the creation of knowledge as part of the economic decision process of profit-maximising firms for the first time in modern growth studies, thus making it part of the growth model. As a result, a vast literature with influential studies about the endogenous nature of technology (and other related variables) in growth models followed in the late 1980s and in the 1990s. In what follows, we review and discuss the ones referring to technology as we considered them as more relevant for the purposes of our chapter. In particular, we will look mostly at theories that convey implications for the relationship of scientific

research and economic growth and then we will proceed to the empirical work done for this relationship.

2.2.1. **Endogenous growth models**

This class of models departs from Solow's neoclassical model endogenising knowledge, either in the form of technology or human capital. Endogenous growth theory is about providing the theoretical tools to determine the long-run growth rate within the model and knowledge serves as such a tool given the importance attached to it as an exogenous determinant of the long-run growth rate. The rewarming of interest in economic growth theory started in the late 1980s due to this class of models.

Romer (1986) presented a model where knowledge was a factor of production in the production function and could result in increasing economic growth rates. He diverged from the convergence theory by stating that big countries can always grow faster than small countries. He presented knowledge as a form of capital that, as opposed to physical capital, can have increasing marginal productivity and can increase boundlessly. The study underscored the importance of knowledge spillovers in the growth process claiming that intellectual property rights are not perfectly protected. This contention implied that more agents than just the knowledge monopolist can benefit from the arrival of inventions and Sveikauskas (2007) reinforced this point. We can consider the example of tablet computers which relied heavily on the patent of touch-screens. The know-how behind this technological advancement was transferred very soon to the competitors even though intellectual property rights are still in place. Today, one can find computer tablets in the market for a price ten times cheaper than the

corresponding price the original inventor had introduced. It is therefore clear that, in this case, social returns to R&D effort (i.e. lower prices and better quality for consumers) are far greater than private returns.

In addition, Romer (1986) held the view that while the inclusion of knowledge in the production function may lead to increasing growth rates, the production of knowledge exhibits diminishing returns. This implies that not all R&D expenses and the effort of the personnel will produce analogous returns. This point is very important as it gives a direction of what one should expect when examining the knowledge production function. The generation of new ideas that can result in being used as inputs in the production function and are capable of exhibiting increasing returns, is not a smooth and homogeneous process. It depends on rigorous R&D effort which in some cases may not produce any return due to the uncertainty inherent in the experimental phase of R&D. We claim that a strong scientific knowledge base can smooth this process but, unless a breakthrough idea is introduced, the diminishing marginal productivity in knowledge suggested by Romer is plausible.

Lucas (1988) introduced a model which moved along the lines of the Solow model but with one distinguishing feature that renders growth endogenous: that human capital stock is responsible for differences in the long-run growth rate. Lucas defines human capital as the ability of a worker to produce, in other words, labour productivity. He considers that a worker A that is twice as skilled as worker B, will produce double the output of worker B. Schooling and experience are highlighted as the two main measures of human capital and the author supports the view that differences in growth rates across different countries can be

explained by differences in the accumulation of human capital. Lucas argues that human capital is the driving force for the successful implementation of new knowledge and technologies in the production function.

Romer (1990) extended his initial study (Romer, 1986) with a model where technology was endogenously determined. This model was an extension of the neoclassical growth model with a convincing explanation on how technology was a product of intentional research efforts carried within the business sector. Romer identified that different levels of human capital across countries determine the differences in growth rates. He stated that research funding and human capital accumulation should be central priorities for economic growth policies and much preferred rather than subsidies given for physical capital. He concluded that the most important factor necessary to achieve increasing growth rates was human capital used for in-house research of business firms.

Aghion and Howitt (1992) introduced a model where vertical innovation is the driver of economic growth. A creative destruction effect is in place whereby new inventions render older ones obsolete. This framework draws significantly from Schumpeter and his theory on how innovation occurs. For this reason this model, along with other models based on quality ladders such as Grossman and Helpman (1991), are also known as Schumpeterian growth models (Barro and Sala-i-Martin, 2004, p.317). The authors discuss the existence of a competitive R&D sector where systematic effort takes place to produce new intermediate products that are of higher quality than their predominant counterparts. This theory suggests that the production of new products is highly dependent on existing products. We add that scientific knowledge is also critical in this respect and

many times a new scientific discovery is what renders the advancement of quality in intermediate products. There are many examples of products of higher quality that brought creative destruction effects to their predecessors due to scientific knowledge. Compact discs and digital versatile disks that replaced audio and video cassettes in the 1990s due to laser technology are such examples.

In the same vein as our example, Grossman and Helpman (1991) developed a model based on the improvement of products in a quality ladder mode, where products of higher quality introduced in the market by entrepreneurs replace older products which are less technologically advanced. Both Aghion and Howitt (1992) and Grossman and Helpman (1991) provided plausible explanations of how technology is improved but they did not address the possibility of having scientific research as an endogenous input in the R&D process.

Aghion, David and Foray (2009) discussed *inter alia* the ability of creative destruction based models of growth to accommodate the interactions in the system of science, technological progress and innovation. They highlighted that despite their attractiveness they convey some shortcomings as well. These are realised in the effort to connect endogenous theory with policy-making since the latter either bears political cost or it is too difficult to implement exactly as the theory dictates.

Lucas (2008) revisited the puzzle of economic growth underlining again the importance of human capital in achieving increasing growth rates. Lucas contradicted the arguments of Aghion and Howitt (1992) and Grossman and Helpman (1991) that increasing growth is a result of the efforts of a devoted

R&D sector. He claimed that there no collective knowledge exists either at the firm or economy level and that patents play only a trivial role in the growth process. Instead, it is the sum of the knowledge and, more importantly, the exchange of knowledge between these individuals and the process of problem solving that has driven productivity, innovation and, as a result, growth. Therefore, Lucas supports the view that high quality "minds" and their interaction in the production sector is what really improves productivity. In a subsequent paper Lucas, alongside other authors (Alvarez, Buera and Lucas, 2013), supported the view that this process of exchanging ideas takes place at random encounters with competitors or collaborators. In the same vein, Eaton and Kortum (1999) model the creation of new technological knowledge and distinguish between locally and internationally generated ideas. However, they recognise that this process affects patenting activity as well. The importance attributed to the knowledge spillover effect is widely evident in all these studies. Though the above assertions are sensible it is simplistic to attribute all growth only to the spillover effect. We believe all these forms of knowledge are important. In all likelihood, new industrial knowledge in the form of patents plays a significant role and we claim that so does scientific research but in a different way. In what follows, we review studies that focused on scientific knowledge as a determinant of economic growth and discuss further the evidence for its importance.

2.2.2. **Scientific knowledge and economic growth**

There are surprisingly few studies engaged in exploring the importance of scientific research in determining economic growth. The class of endogenous

growth models emphasised ideas and innovation, either in production or an industry-oriented R&D sector, where in-house researchers race against their competitors to discover novel products or product improvements. As science is implicit in these models, little attention has been given to the causal relationship of scientific research and growth. Advancements in scientific research are widely acknowledged to underlie technological progress (Stephan and Ehrenberg, 2007; Stephan, 1996; Dasgupta and David, 1994) but empirical work on this issue is lower than its pronounced importance. In what follows, we will firstly consider some theoretical insights and then review their related empirical studies.

Mokyr (2005) claimed that the main factor behind economic growth in the 17th century, through the industrial revolution, was the quest to extend existing knowledge and improve technologies. Evidently, this quest for knowledge started a long time ago and has evolved to become what we know it to be today. To that end, a number of studies have stressed the role of various forms of knowledge in determining economic growth.

Garner (2008) describes a theoretical model where long-term growth is highly reliant on the growth of scientific knowledge. His proposed model distinguishes between two types of innovations: break-through and augmenting innovations. The model implies that science lays the ground for break-through innovations to occur and these help improve productivity in a lasting manner, as opposed to augmenting innovations, the effect of which obscures with time. Indeed, innovation ideas can occur at different levels coming from employees in the production line or the best scientists. There are nevertheless a number of assumptions that are not plausible given intuition on knowledge generation.

Firstly, the model assumes that the growth rate of human capital, represented by the change in years of schooling, depends entirely and proportionally on the generation of new science, so that the two rates are equal. Investing in human capital is also a choice that rational individuals make rather than solely a causal effect of science. Introducing new scientific inventions does influence future human capital but does not automatically improve its quality. Such an improvement is likely to become evident with a considerable time lag. Besides, new scientific knowledge could enter the production function as an impact on the technology of capital goods and not necessarily in the form of human capital enhancement. Also, the assumption that human capital is inversely related to population growth is not necessarily justified by the "quantity-quality trade-off" argument. "More people-more ideas", was widely thought to result in "more and better knowledge" and thus, through the spillover effect, better human capital (Lucas, 2008). This effect is exemplified in places where research clusters had been established (*e.g.* Silicon Valley, Route 21, *etc*.) and the spillover impact that proximity offered.

Schofer *et al* (2000) have tried to explore the impact of research on growth by focusing on a panel of 18 countries for a 20-year period. They inferred a statistically significant positive effect of human capital measured by schooling and a significant negative effect of "socially relevant" scientific research output measured by publications on growth. Scientific research which is closer to technology was found to be statistically insignificant. The authors stressed the nature of science as more of a society-improving process rather than an output-enhancing mechanism. Nonetheless, there seem to be drawbacks in this

methodology. Specifically, the data are cross-sectional in nature and the authors use publication data from 1973 regressed against the average economic growth rate of the period 1970-1990. The authors do not provide for unobserved heterogeneity nor potential heteroskedasticity. Thus the standard errors of their estimates are probably downward biased. This approach does not capture the whole impact of the scientific research output on economic output as the year chosen to measure scientific research output is arbitrary and concerns only once specific time interval without intertemporal consideration.

Another strand of the literature focused on the importance of scientific research in enhancing innovation in the industry which in turn is said to fuel economic growth. Indeed, there is a considerable literature on the contribution of industrial R&D in economic growth (see Sveikauskas, 2007) which we do not review as it is beyond the scope of the chapter. As a result, a number of studies stressed the association of science with technology in the form of patents. Early on, Mansfield (1991) investigated whether an effect of academic research on subsequent innovations existed. Using a sample of 76 American enterprises, the study addressed which innovations would have not been possible without the use of the scientific research produced within a 15-year period before the introduction of the innovation. He found a social rate of return of around 28% from academic research and an average lag of 7 years needed for the effect to become evident. This background supports our decision to include 5 and 10 years lags of scientific research in our model. Likewise, Sveikauskas (2007) also reports that in the United States, the Bureau of Economic Analysis uses a five year lag for recording basic research as an input in the production function.

David *et al* (1992) examine the economic impact of fundamental research. They recognise that not all scientific fields can offer economic returns in the long term and that some fields can affect applied research at an increasing rate offsetting the lack of economic impact of other fields. They suggest that, to maximise its economic impact, scientific research should be directed towards fields that are closer to applied research and can become innovations more quickly. Aside from research output, the authors also trace three by-products of scientific research: human capital, social capital and technological progress of science-related capital (equipment, software, methodologies, *etc*.). In our approach we cover for the differences in thematic fields as these side-effects are likely to vary considerably from field to field.

There is little literature with respect to the relationship of scientific research and growth especially when compared to other strands of economic growth literature. Indeed, very few empirical studies considered scientific research as a determinant of economic growth and we discuss them below.

Jin (2009) focused on five Asian economies and studied the effect and causality of scientific publications on economic growth. Using Granger causality tests, he found that for Taiwan and Korea causality runs from economic growth to publications rather than the opposite way as found for Japan. The other two countries showed statistical insignificance of both explanatory variables. This result is not surprising given that some countries benefit from readily available scientific knowledge coming from other research-advanced countries. Should this stand, then there are significant implications for research funding policy in a number of countries with low R&D capacity. For example, Japan has been a

producer of scientific knowledge for many years, whereas for South Korea and Taiwan this is a more recent development. For their development in technology and innovation South Korea and Taiwan have been applying mostly scientific knowledge coming from leading research countries, such as the USA. Perhaps in the future, when these countries are at the frontiers of scientific research, the economies will follow causality patterns from scientific research to growth similar to the ones found by Jin (2009).

Jin and Jin (2013) examined the effect of research publications on growth for 34 countries and inferred a significant association between the two. The authors used the quantity of research as a proxy for the quality of tertiary education in each country. They repeat this rationale in a subsequent study (Jin and Jin, 2014) where they use the research output of professors as a proxy of education. There are considerable objections to these papers. Firstly, the methodology followed is one of a cross-section analysis with the known problems of not providing adequately for unobserved heterogeneity. Secondly, it is doubtful whether research publications of scholars form a reliable proxy for the quality of education provided in the respective institution. It is widely known that some academics may be brilliant researchers but not very good educators. This fact is substantiated through the results of a number of studies (Centra, 1983; Melland, 1996; Verburgh, 2007), in which no significant association was found between research productivity of academics and their teaching performance as evaluated by their students, peers and their institution. Therefore, according to these papers, education is not always the channel through which research affects economics growth. Even if it is assumed that excellence in research is associated

with excellence in teaching, there is a non-trivial time lag until scientific knowledge is incorporated in the syllabi of undergraduate courses. Hence, it is highly likely that the authors should have estimated their model considering a plausible lag. This provision is incorporated in our chapter where we allow for a reasonable lag for the effect of new knowledge on growth to appear.

Moscone *et al* (2013) examined the effect of scientific research on productivity, focusing only on the sector of health care. They used a number of OECD countries and found that scientific research in the field of medicine is positively correlated with productivity in the corresponding sector. This makes sense because medical doctors tend to utilise the scientific literature in their work much more than other professions. When medical doctors are making diagnoses for their patients an update on the literature should suffice to provide them with this knowledge. But in the case where more advanced treatments are needed (e.g. specialised diagnoses through ultrasound or Magnetic Resonance Imaging) then physical technology is relevant and the scientific literature is not sufficient. Another example in the life sciences comes from Toole (2012) who investigated the potential impact of basic research on industrial innovation in the pharmaceutical industry finding a positive and significant impact of the former on the latter. Not all scientific fields produce knowledge so close to the market though. It is no exaggeration to say that in medicine scientific knowledge may be playing the role of new technology in many cases. In other fields, we expect that scientific knowledge facilitates progress in technology and innovation and is not used directly as an input in the production function as may be the case with medicine. This will be reflected in our model and the findings.

Antonelli and Fassio (2012), approach the puzzle of academic research and its relation to growth through the use of the number of graduate students for the period 1998-2008 in 16 OECD countries and for four broad fields of knowledge. They find that the elasticity of each area of science is different for determining growth. They imply that caution should be exercised in earmarking funding among scientific areas since only pure sciences are found to be statistically significant for explaining growth. However, the methodological limitations of this paper may be critical for the validity of the results. Firstly, the data are in an annual structure not taking into account potential cyclical effects. Moreover, the number of graduates is a plausible proxy for human capital but the authors do not provide adequate time for its expected impact. A one-year lag is not adequate for the benefits derived from the introduction of more and better human capital in the production process to become evident. Another drawback is that the paper considers only the effect of academic knowledge upon human capital. It does not take into account the importance of this knowledge in generating new technologies in the long term, something that is provided for through the present chapter.

We aim to fill these gaps by showing the effect of scientific research on economic growth for the EU countries. This effect may be through technology, a possibility which we examine. Conversely, human capital could be a candidate vehicle for the impact of scientific research on growth but, unlike Antonelli and Fasio (2012), with a considerable lag. We do not examine this path in the chapter. We do examine though the possibility of an effect directly from scientific research to growth to see whether there is another path that we did not consider.

In summary, the current literature has not fully addressed the impact of scientific research on economic growth. Although the endogenous growth theory is now widely accepted, the fact that scientific research is a result of concerted economic effort and thus endogenous in the growth model has not been given the appropriate attention. The few studies that have examined empirically the effect of scientific research on growth retain noticeable shortcomings which we try to address in this chapter: Firstly, no study has used the European Union countries to examine this effect. Secondly, the lag allowed for scientific research to impact on growth is in most cases insufficient. Lastly, scientific research is likely to have a multidirectional effect on growth which is not limited to human capital as some studies suggest. In what follows, we start addressing the above issues by setting the theoretical premises and deriving the model specifications to be estimated.

2.3. Theoretical Background

In order to explore the effect of scientific research on growth, we use a Cobb-Douglas production function. We consider two ways through which scientific research may affect the technical knowledge term, A. The first way is the one supported by the Schumpeterian growth models. That is, the vertical innovation way- some sort of a creative destruction process. This pattern is likely to apply in scientific and technological themes, such as information science and engineering, but not to all areas of science. This type of science is expected to have a more direct impact on technology as its applied nature is easily transformed into innovations. The second way is horizontal innovation, similar to the expanding variety of products discussed before, whereas different types of scientific knowledge co-exist without necessarily imposing a creative destruction

effect. The latter phenomenon applies more in the social sciences and the humanities, whereby new knowledge does not automatically render all alternatives obsolete but serves rather as addition to existing knowledge. Intuitively, this type of knowledge needs more time to contribute to the production process and for arts and humanities it takes even more time than social sciences as the latter incorporate economics and business which are more directly linked to technology.

The Cobb-Douglas production function for a country in a specific year takes the usual form:

$$Y = A^{\beta} K_Y^{\alpha} L_Y^{1-\alpha} H_Y^{\gamma} \qquad (1)$$

where Y is GDP, K and L are capital and labour respectively, A is the level of technology available and H is human capital separate from physical capital as in Lucas (1988). The Y subscripts indicate that these are inputs used in the production of Y rather than the production of A as illustrated in equation (2) below. We do not include country or year subscripts at this point for simplification. The production function exhibits constant returns to scale with respect to capital and labour jointly but can produce increasing returns for technology, hence the β power term. Human capital represents an exogenous learning-by-doing effect, expressed by both experience, as described by Arrow (1962), Lucas (1988) and Romer (1990), and years of schooling as supported by a number of authors (Lucas, 1988; Griliches; 1997). This results in a faster and more efficient assimilation of new knowledge into the production process. This usually requires skilled labour. The level of technology A $(A > 0)$ in the production function is

the stock of all existing technologies. Technology is considered to be endogenous as in Aghion and Howitt (1992) and its growth entirely dependent upon new innovations.

In line with David *et al* (1992), scientific research is considered to have an indirect economic payoff regardless of its nature, basic or applied. Basically, we consider that scientific research does not have a straight impact on economic output but rather enables a process of gradual knowledge increase which eventually leads to market innovations (David *et al*, 1992). The new innovations and the improvement of human capital arrive in the economy through systematic effort, resulting in better technology and growth in output. The economy has two sectors: the production of final goods and the R&D sector which produces new technology. Therefore, the equation for technology is

$$A = B^{\theta} K_A^{\delta} L_A^{1-\delta} H_A^{\xi} \qquad (2)$$

where B is the pool of scientific knowledge which is used to produce new technologies and K, L and H are respectively, capital, labour and human capital used in the R&D sector. We follow Jones (2005) to set capital and labour as inputs with constant returns to scale and to distinguish the factors of production used in each of Equations (1) and (2) with the relevant constraints:

$$K = K_Y + K_A \qquad (3)$$

$$L = L_Y + L_A \qquad (4)$$

$$H = H_Y + H_A \qquad (5)$$

$$A = A_Y + B_A \qquad (6)$$

As equation (6) implies, at any point in time the pool of technology comprises all knowledge used for production along with the knowledge used for improving technology. For simplification we will assume that there is no knowledge overlap between the two components although in one of our econometric settings we consider their parallel inclusion as explanatory variables. Our results corroborate that scientific research is more likely to be used to produce technology and technology is used to produce final goods.

Now we focus on the impact of scientific knowledge on growth and will not model in much detail how scientific knowledge is produced, as this process is modelled in Chapter 3. We will instead show the accumulation process of scientific knowledge, as in Equation (7) and the corresponding production function in (7.a):

$$B_{At} = \sum_{t=n-k}^{n} w_t p_t \qquad (7)$$

Where Equation (7) states that new ideas p affect the pool of scientific knowledge through their relevance w where $0 < w \leq 1$ and they are cumulated to derive the aggregate measure of scientific knowledge. This can be also expressed as the degree of obsolescence $1 - w$ in a partial creative destruction context. We derive that for the marginal effect of a new idea to be positive, that is, for $\partial B / \partial p > 0$, the condition $w_n > w_{n-k}$ must apply. According to this condition an existing idea can become partially or completely obsolete by the arrival of a new idea. For simplification purposes, in the estimation of the model we will assume that $w = 1$, with no creative destruction effect in place. This assumption implies that new ideas expand scientific knowledge horizontally rather than vertically.

$$S_{i,t} = A_{St} K_{Si,t}^{a_s} L_{Si,t}^{\beta_s} H_{Si,t-k}^{\gamma_s} \quad (7.a)$$

where S is scientific knowledge produced and the subscript s denotes scientific knowledge-related inputs. Before we proceed to describe the dataset it is important to elaborate on the proxy we use throughout the chapter for scientific knowledge, that is, journal publications. We acknowledge that the number of journal publications is an imperfect measure of research output but it is structured, measurable, easily accessible, and undergoes credible scientific assessment (peer-review process). It is also important to use strictly published scientific knowledge since from the day of a journal publication the knowledge becomes widely accessible and can be used in the production of new technologies as discussed above. There are two caveats for journal publications as a proxy of scientific knowledge. The first is that due to the aggregate measures of publications per country and year, we cannot normalise the publications by an indication of their quality, i.e. citations and/or journal impact factors. We try to offset this weakness by tackling this shortcoming extensively at the individual level in Chapters 3 and 4 exploiting the availability of data at the micro level. Also the fact that our publications come from the Web of Science (WoS) secures a threshold quality for the publications. The second caveat is that in fields such as the Arts and Humanities, research output may come in other forms such as monographs, books or chapters in books which are not captured by journal publications. Also, journal articles take considerable time to publish. Peer review is an iterative process which, depending on the field, can last from a few months to a couple of years. Therefore, in our findings we must be careful when

calculating a potential lag from journal publications to growth to take into account sufficient time before the publication date.

Thus, the models to be estimated at the country-period level develop from log-transforming equation (1),

$$\ln Y_{it} = \beta \ln A_{it-1} + a \ln K_{Yit-1} + (1-a) \ln L_{Yit-1} + \gamma \ln H_{Yit-1} \quad (8)$$

and equation (2)

$$\ln A_{it} = \theta \ln B_{it-k} + \delta \ln K_{Ait-1} + (1-\delta) \ln L_{Ait-1} + \xi \ln H_{Ait-1} \quad (9)$$

Transforming equation (1) into per capita terms and then log-transforming gives

$$\ln y_{it} = \beta \ln A_{it-1} + \delta \ln k_{Yit-1} + \xi \ln H_{Yit-1} \quad (10)$$

where y_{it} is real GDP per capita and k_{it-1} is capital per capita. Similarly for technology,

$$\ln A_{it} = \theta \ln B_{it-k} + a \ln k_{Ait-1} + \gamma \ln H_{Ait-1} \quad (11)$$

We can also derive the relevant growth rates by first-differentiating equations (8)-(11)

$$\frac{\dot{Y}_i}{Y_i} = \beta_{g_1} \frac{\dot{A}_i}{A_i} + \alpha_{g_1} \frac{\dot{K}_i}{K_i} + (1-\alpha_{g_1}) \frac{\dot{L}_i}{L_i} + \gamma_{g_1} \frac{\dot{H}_i}{H_i} \quad (12)$$

$$\frac{\dot{y}_i}{y_i} = \beta_{g_2} \frac{\dot{A}_i}{A_i} + \alpha_{g_2} \frac{\dot{k}_i}{k_i} + \gamma_{g_2} \frac{\dot{H}_i}{H_i} \quad (13)$$

$$\frac{\dot{A}_i}{A_i} = \theta_{g_1} \frac{\dot{B}_i}{B_i} + \delta_{g_1} \frac{\dot{K_{A,i}}}{K_{A,i}} + \left(1-\delta_{g_1}\right) \frac{\dot{L_{A,i}}}{L_{A,i}} + \xi_{g_1} \frac{\dot{H_{A,i}}}{H_{A,i}} \quad (14)$$

$$\frac{\dot{A}_i}{A_i} = \theta_{g_2} \frac{\dot{B}_i}{B_i} + \delta_{g_2} \frac{\dot{k_{A,i}}}{k_{A,i}} + \xi_{g_2} \frac{\dot{H_{A,i}}}{H_{A,i}} \quad (15)$$

where the dot denotes derivative with respect to time, the g subscript is used to distinguish between the coefficients of the logged explanatory variables and their

growth rates and g_1 is for absolute and g_2 is for per capita growth. The A subscript represents inputs used in the production of technology.

We keep A_{it} and B_{it} intact in all per capita normalisations since the terms $\frac{A_{it}}{L_{it}}$ and $\frac{B_{it}}{L_{it}}$ are cumbersome to interpret in the context of economic growth theory. Technology is presupposed in the literature to be non-appropriable and non-excludable. So the outcomes of $\frac{A_{it}}{L_{it}}$ and $\frac{B_{it}}{L_{it}}$ are A_{it} and B_{it} respectively.

However, if a monopoly right for the exploitation of technologies is in place (Romer, 1990) and A_{it} refers to technology available to a country, then the term has the dimension of knowledge produced within a country (Muscone *et al*, 2013) and it is only partially non-rival and non-excludable (Romer, 1990). Our study examines this model at the country-year level and the outcomes above would hold if we had divided the global level A_t by the world population. Leaving A_{it} and B_{it} intact, results in neglecting this fact. Therefore we keep the theoretical framework as it is but in estimating some settings of the model we also divide knowledge and technology by population to explore the importance of the R&D productivity dimension.

We should also explain here that we use patent applications as an indicator of technology as they have been used widely as such in the literature. If inventors spend money to register a patent, it is likely that this patent has potential for commercial exploitation and brings a new innovation in technology. In our chapter, we use the first lag of patents (and in one case the second lag) in order to provide adequate time for their effect on production to become evident. This

choice also serves to provide time for patents registered by universities and research institutions to enter the market.

2.4. Data

The dataset consists of information gathered for all EU27 members plus Israel, Norway, Switzerland, USA and Japan. Data regarding national accounts of participating countries for the years 1981-2010 were drawn from the Penn World Tables (Heston et al, 2012) and for human capital variables from the Barro and Lee revised dataset (Barro and Lee, 2010). All information about scientific journal publications was collected by hand through the ISI Web of Science database for years 1981-2010. To this end, a straight count of publications per country and year were considered. The publications were grouped per theme according to the default grouping of the Web of Science; that is a) Science and Technology, b) Social Sciences and c) Arts and Humanities. We also collected information for patent applications to the European Patent Office (EPO) and R&D expenditure form Eurostat. The inclusion of patent applications led to the realisation that countries outside European Union could not be included in our dataset since the applications to EPO would be downward biased for them. Therefore, we maintained only EU27 countries in our dataset. We also wanted to include data on R&D personnel to compare our findings with the endogenous foundations of Romer (1990) and the empirical findings of Segerstrom (1998) but unfortunately the data covered only three periods and, given the lags used, the estimation of our model could not produce reliable estimates. We instead use R&D expenditure in the higher education and business sectors as proxies of R&D resources, including R&D personnel, to capture their seemingly divergent effects on

technology and growth. Although more time series observations were available than for R&D personnel, these variables still limit the length of our sample size as we will see below.

All variables were averaged across 5 years as in Islam (1995) so as to control for cyclical effects and explore the time-length of possible effects of scientific publications on growth, a feature identified by Durlauf et al (2005, p.635). This approach resulted initially in a dataset of 196 observations for 5-year averaged variables. For some variables, like publications, GDP and average years of schooling, data were available for some years before 1980 and we included them in the dataset so as to use their lags if needed. All variables were then log-transformed so as to be brought to a near-normal state and to match the functional forms in the previous section. Subsequently, growth rates for all averaged log-transformed variables were calculated. In total, a dataset of a maximum of 216 observations for 5-year averaged variables was created. Data for Estonia, Latvia, Lithuania, Slovenia Czech Republic and Slovakia were not available before 1992 so only data thereafter were utilised limiting the dataset to 133 observations. Due to the use of growth rates and lags in running the models we observe that these observations are further reduced. The exact number of observations is reported in each table of findings.

Table 2-1 presents summary statistics of the data on an annual scale. It is interesting to note that the mean value of the publications in science and technology per 1000 residents is less than unity whereas in social sciences and arts and humanities this value varies around zero. This is probably due to the very low research activity of many countries in the 1980s in these disciplines.

Table 2-1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
S&T publications	203	13,837.97	24,808.02	0.00	118,353.00
SS publications	189	566.07	1,406.15	0.00	12,794.00
HU publications	205	182.18	441.76	0.00	3,782.00
S&T publications ptr	203	0.65	0.75	0.00	3.17
SS publications ptr	189	0.03	0.03	0.00	0.21
HU publications ptr	205	0.01	0.01	0.00	0.06
Patents (author-normalised count)	146	1,562.13	3,635.32	0.50	23,620.46
Patents pmr	146	62.02	76.41	0.12	301.38
Average Years of tertiary schooling	216	0.47	0.29	0.07	1.71
Capital investment (% of GDP)	190	23.77	5.42	5.07	42.60
Government expenditure (% of GDP)	190	7.76	2.36	2.09	21.77
Trade Openness	190	75.58	53.60	3.78	307.71
GDP per capita in PPP 2005 fixed prices	190	19,604.09	10,735.30	2960.2	75,898.60
R&D Expenditure (in € million)	135	6,244.05	11,257.60	9.00	64,751.06
R&D Expenditure per capita	133	278.14	309.15	5.23	1,264.76
R&D Expenditure in the Business Sector (in € million)	135	3,990.20	7,520.06	1.34	44,491.80
R&D Expenditure in the Business Sector per capita	133	182.64	229.42	1.28	964.04
R&D Expenditure in the Higher Education Sector (in € million)	134	1,313.27	2,140.59	0.02	10,993.64
R&D Expenditure in the Higher Education Sector per capita	133	60.84	66.91	0.00	324.00

Notes: S&T: Science and Technology, SS: Social Sciences, HU: Arts and Humanities, pmr: per million residents, ptr: per thousand residents, PPP: Purchasing Power Parity, GDP: Gross Domestic Product

2.5. Methodology

In order to estimate the effect of scientific publications on economic growth we consider equations (8) to (15) of Section 3. We modify some of the elements of these equations in order to accommodate seemingly influential explanatory variables. For example, we proxy capital per capita with the percentage of investment on GDP. Although a flow instead of a stock variable, it is normalised

by GDP and, in the equations of growth rates it measures the change to potential capital formation. Also to allow for richer interpretation we also include the percentage of public expenditure on GDP. According to the relevant literature, the latter variable is expected to affect economic growth negatively as identified by Barro (1990) in a number of empirical studies (Grier and Tullock, 1989; Landau, 1983). This pattern is attributed by the authors to the opportunity cost that public spending conveys on the expense of investment or according to Barro (1991) and Rebelo (1991) to the income tax rate. In this light, we also add the Trade Openness Variable which captures the positive spillovers from international trade and also accounts for potential technology and knowledge spillovers (Alvarez et al, 2013). In the literature, it is widely acknowledged that such a trading approach enhances R&D spillovers and thus brings higher growth rates (Coe et al, 1995; Coe and Helpman, 1993). The first model we estimate is described in Equation (16):

$$\ln y_{it} = \ln k_{it-1} + \ln g_{it-1} + \ln F_{it-1} + \ln st_{it-k} + \ln ss_{it-k} + \ln hu_{it-k} + \ln p_{it-k} + \ln h_{it-1} + \alpha_i + \tau_t + \varepsilon_{it} \quad (16)$$

where y_{it} denotes Real GDP per Capita in Purchasing Power Parity (PPP) terms k_{it} is the Investment Share of Real GDP per Capita and τ_t is a time-specific dummy variable. In line with Mankiw *et al* (1992), a fixed depreciation rate is assumed for all countries which for simplification was set to zero. The variables denoted by st_{it-k}, ss_{it-k} and hu_{it-k} are lags of $k = 1,2$ periods of the logs of Scientific Publications in Science and Technology (S&T) fields, Social Sciences (SS) and Arts and Humanities (A&H) respectively, all in *per capita* terms. The

variable g_{it} is the log of Government Expenditure and the Trade Openness as a share of real GDP is expressed by F_{it}.

We also repeat the estimation of equation (16) using absolute values instead of per capita ratios of publications and patents to examine the effect of size of technology and science produced in a country on its GDP. This results in

$$\ln y_{it} = \ln k_{it-1} + \ln g_{it-1} + \ln F_{it-1} + \ln ST_{it-k} + \ln SS_{it-k} + \ln HU_{it-k} + \ln P_{it-k} + \ln h_{it-1} + \alpha_i + \tau_t + \varepsilon_{it} \quad (17)$$

The estimation of (16) and (17) is replicated using the growth rate of GDP as the dependent variable but leaving the explanatory variables in log-transformed or ratio form.

The models above imply that Scientific Research and Technology affect economic growth both separately and simultaneously. Since according to our theoretical model it is most likely that scientific research enhances technology and in turn technology affects growth we also consider an equation for the impact of scientific research on patents in accord with equations (9) and (11):

$$\ln P_{it} = \ln k_{it-1} + \ln gh_{it-1} + \ln gb_{it-1} + \ln F_{it-1} + \ln ST_{it-k} + \ln SS_{it-k} + \ln h_{it-1} + \alpha_i + \tau_t + \varepsilon_{it} \quad (18)$$

where gh is spending in the higher education sector and gb is spending in the business sector. These variables are used in separate estimations either in absolute or in per capita form. Since gh and gb are components of government expenditure, the inclusion of these separate variables means that total government expenditure has to be excluded as a regressor to avoid severe multicollinearity problems and poorly determined estimated parameters. We also

do not include Arts and Humanities for two reasons. Firstly, we do not expect this type of scientific knowledge to have an impact on new technologies and consequently patents as it is mostly theoretical. Secondly, when the models were initially estimated the coefficients were found to be statistically insignificant in explaining subsequent patenting activity. We retain the investment share on GDP and Trade Openness as these have previously been found to have a spillover effect on technology.

In estimating the model we take a number of issues into consideration. Firstly, we choose Fixed Effects over Random Effects as the primary estimation tool. The unobserved heterogeneity of countries is accounted for, without the need to be estimated which offers the significant advantage of avoiding strong assumptions such as strong exogeneity. All regressors can be related to the fixed effects error α_i but not with the random error ε_{it}. The assumption of weak exogeneity finds strong support in the fact that lags of 5-year averages are used as explanatory variables. It is more difficult for a random external shock to affect variables that have 5 years of difference in their realisation.

The elements of α_i include *inter alia* fixed factors of countries such as geographical position, cultural dimensions, robustness of the economy, the strength of the productive base, the degree of technological advancement, the structure of economic activity and others. More importantly, they include the initial stocks of all our variables so that we can use the flows as explanatory variables without ignoring them and securing additional degrees of freedom.

Nevertheless, we apply the converse regressions in order to infer the direction of causality between scientific research and economic growth and demonstrate that

this assumption is not necessarily valid (See Table 2-6). We estimate the following equations for scientific knowledge flow in each of the three fields of science both in absolute and per capita terms using the rationale of Equation (7a) but with the many limitations that will be outlined below:

$$\ln st_{it} = \beta_{st0} + \beta_{st1}\ln k_{it-1} + \beta_{st2}\ln gh_{it-1} + \beta_{st3}\ln F_{it-1} + \beta_{st4}\ln y_{it-1} + \beta_{st5}\ln p_{it-1} + \beta_{st6}\ln h_{it-1} + \alpha_i + \tau_t + \varepsilon_{it} \quad (19)$$

$$\ln ss_{it} = \beta_{ss0} + \beta_{ss1}\ln k_{it-1} + \beta_{ss2}\ln gh_{it-1} + \beta_{ss3}\ln F_{it-1} + \beta_{ss4}\ln y_{it-1} + \beta_{ss5}\ln p_{it-1} + \beta_{ss6}\ln h_{it-1} + \alpha_i + \tau_t + \varepsilon_{it} \quad (20)$$

$$\ln hu_{it} = \beta_{hu0} + \beta_{hu1}\ln gh_{it-1} + \beta_{hu2}\ln F_{it-1} + \beta_{hu3}\ln y_{it-1} + \beta_{hu4}\ln h_{it-1} + \alpha_i + \tau_t + \varepsilon_{it} \quad (21)$$

In Equations (19)-(21) we keep variables such as investment share on GDP and trade openness to capture potential knowledge spillovers. We realise that for Arts and Humanities this may not be relevant but F_{it-1} is the only proxy we can use for international collaboration and the know-how brought to scientific research from abroad. We also keep patents in for Science and Technology and Social Sciences to investigate whether an inverse relationship holds. We do not have adequate time series for R&D personnel and therefore we resort to the corresponding expenditure to proxy this variable, given that the salaries of R&D personnel come from gh_{it-1}. We also lack information about the share of expenditure as well as the average schooling for each of the three thematic areas and we use uniform variables across these fields. It is evident that there are limitations in available data but we use many variables merely as controls to obtain a preliminary view of whether an inverse relationship between economic growth and scientific research exists. Although a Granger-causality test could be

carried out, it is not easily applicable to panel data with heterogeneous effects and thus we refrained from performing it. Hence, the findings cannot be used for any other purpose, nor extended to any other paradigm.

In estimating the models (16) - (18) we consider that they could be suffering from endogeneity. Scientific research, patents and R&D expenditure are most of the times at the same levels within a country. This problem is usually dealt with the use of instrumental variables. Regardless of the usual problem of non-existence of instruments that are correlated with the endogenous regressors and are exogenous to the dependent variables (Durlauf et al, 2005), in the present model the problem of endogeneity is treated with respect to simultaneity and double causality. We use lags for all publication-related explanatory variables which are in turn expressed in logs of five-year averages. Therefore, as these variables are predetermined we avoid ambiguity in causality. All our explanatory variables are predetermined, as they can provide the time for the effect of the variable to become evident and it also helps avoid causality problems.

In addition, the use of Fixed Effects estimation allows for the a_i component to be correlated to the regressors. Therefore, endogeneity stemming from the correlation of simultaneity is also integrated out of the model through the within transformation. Griliches (1979) had stated early on in the frame of exploring the effect of R&D expenditure on subsequent output that cross-sectional estimates lack this richness in the data and neither simultaneity nor the direction of causality could be efficiently tackled. Having a panel dataset and using the fixed effects method in this chapter helps dealing with both of these major econometric challenges.

Also, we account for cyclical effects through the 5-year averages of variables. Thus variations from year to year that owe to cycles either in the economy or in the production of scientific knowledge are integrated out of our model. Potential external shocks must exclude the cyclical type. Time-specific shocks common to all countries which can be a source of endogeneity are captured by the time dummies. The only type of endogeneity not treated rigorously is the one caused due to an external shock which varies both in time and across countries represented by ε_{it}. We claim that it takes much more time for a shock to be realised on scientific publications rather than on economic growth and focus on dealing with more critical forms of endogeneity.

Another potential problem of panel data models is the existence of serial correlation in the errors ε_{it}. In this respect we ran the Wooldridge (2003) test which has shown that the null hypothesis of no first order serial correlation is strongly rejected. This does not pose insurmountable problems for the estimation as we use cluster-robust specific errors which decrease efficiency but provide consistent estimates (Drukker, 2003) regardless of serial correlation. Baltagi (2005, p.222) underlines that the use of fixed effects with this type of standard errors allows for arbitrary autocorrelation. Also, using time dummies captures a significant part of serial correlation. The use of cluster-robust standard errors also accounts sufficiently for heteroskedasticity.

Lastly, the explanatory variables were checked for multicollinearity problems. The results of the correlation table (See Appendix, Table 4-13) give rise to worries in this respect, as they show some high correlation patterns. In particular, the S&T publications are correlated with patents and all types of publications are

correlated between them with the coefficient approaching unity in some cases. We carried out different variations of the model to provide for these strong associations excluding variables that exhibit such. These are presented in the findings. For the general model, running regressions without including publications in one or two fields did not produce significantly different findings and thus we preserved them. In contrast, for the models where patents are the dependent variable we excluded publications in arts and humanities as they were insignificant and affected the accuracy of the coefficients of S&T and SS publications. In the next section we will see all specific issues for each version of the model and discuss them in detail.

2.6. Findings

In the quest for finding the association of scientific research with economic growth we start by running a general model where we include first and second lag of publications and the first lag of all other explanatory variables including patent applications and years of schooling. Fixed and Random Effects Regressions were ran even though we do not analyse the latter (they are included in the Appendix), as the assumption of strict exogeneity is difficult to be accommodated in the methodological rationale of the chapter.

In Table 2-2 it is apparent that patents exhibit a positive effect on growth as the relevant elasticity moves in the region of 0.07-0.09. So a 1% percent increase in patent applications can lead to an increase of around 0.08% in real GDP in the next five years. This result falls under the logic of the theoretical model presented, as it verifies a lag from the point that a technology is introduced until

its results are assimilated and incorporated in a country's production. For S&T publications we observe non-statistically significant coefficients and with a negative sign of its first lag in two cases. Surprisingly, human capital is not important for explaining subsequent economic growth although the sign of the coefficient is in most cases positive. We included either the average years of tertiary education or secondary education as well as the total years of schooling as proxies. The results were more or less the same for all three proxies. We prefer the tertiary schooling, in line with Aghion et al (2009) who identify the paradox of the years of primary schooling years being equated with doctoral study years in the average total schooling measure.

For SS and HU publications we observe once again the pattern applicable to most explanatory variables. This is not counter to intuition since the theoretical nature of these thematic areas is likely to be more applicable for social and cultural purposes rather than the production of goods and services. For social sciences, however, it may be that the elasticity of Business and Economics related publications is offset by the negative or no impact of all other disciplines. This theoretical premise is partly supported by Jin (2009) who finds that the impact of business and economics on economic growth is positive and significant.

Table 2-2: The effect of scientific research output on Real PPP GDP per capita of EU27, 1981-2010

	FE1		FE2		FE3		FE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	-0.093*	0.050	-0.098**	0.048	-0.002	0.053	-0.008	0.051
HU publications (1st lag)	0.010	0.063	0.003	0.064	0.020	0.059	0.015	0.061
SS publications (1st lag)	-0.066	0.066	-0.067	0.067	-0.031	0.064	-0.033	0.065
S&T publications (2nd lag)	0.098	0.096	0.103	0.097	-	-	-	-
HU publications (2nd lag)	-0.066	0.049	-0.074	0.050	-	-	-	-
SS publications (2nd lag)	0.058	0.056	0.063	0.057	-	-	-	-
Patents (author-normalised count)	0.084**	0.041	0.080*	0.042	0.075*	0.040	0.073*	0.040
Average Years of tertiary schooling	0.230	0.161	0.244	0.162	0.192	0.163	0.199	0.165
Trade Openness	0.151	0.108	0.146	0.108	0.100	0.099	0.101	0.099
Government expenditure (% of GDP)	-0.092	0.125	-0.093	0.122	-0.065	0.135	-0.058	0.133
Capital investment (% of GDP)	0.030	0.092	0.045	0.091	0.089	0.088	0.102	0.088
1991-1995	0.013	0.045	0.017	0.045	0.002	0.034	0.004	0.035
1996-2000	0.098	0.066	0.105	0.065	0.091	0.059	0.095	0.059
2001-2005	0.126	0.103	0.132	0.102	0.158	0.100	0.163	0.101
2006-2010	0.165	0.138	0.174	0.137	0.223*	0.133	0.232*	0.134
Constant	8.707***	0.515	9.090***	0.610	8.946***	0.579	8.933***	0.565
Observations	114		114		118		118	
R-squared (within)	0.8651		0.8647		0.851		0.849	
R-squared (between)	0.6108		0.6025		0.697		0.7126	
R-squared (overall)	0.5648		0.5348		0.6053		0.5677	
F test	42.52		46.08		28.44		32.4	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) FE1 & FE3: Fixed Effects of logged 5-year averaged GDP per capita against logs of 5-year moving average per capita variables, FE2 & FE4: Fixed Effects of logged 5-year averaged GDP against lagged values of logs of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

(e) In FE1 and FE2 second lags of publications are also used as explanatory variables.

The first implications of the findings of Table 2-2 is that scientific research does not affect economic growth directly but this may take place through a mediator such as technology or human capital. We discuss this further after considering the same model but with the growth rate of real GDP per capita as the dependent variable. However, the negative coefficient of the first lag of S&T publications may express another fact which is in agreement with one of our key arguments. That is, the long-term investment in scientific research comes at an opportunity

cost of investing in other sectors of the economy with quicker returns in the short term and this choice is evident in reduced GDP in the first years.

However, we must underline that potential methodological reasons of statistical insignificance of the coefficients of the explanatory variables could be in place. The small size of the sample which leads to relatively high standard errors is a potential source of inefficiency that causes the estimates to become statistically insignificant. In the same line, the use of fixed effects, which sacrifices the between dimension of the data to tackle unobserved heterogeneity and simultaneity, could weaken the statistical significance of the estimates. What is important to note though is that despite these two caveats, our data show that technology seems to drive economic growth. This finding corroborates the first part of our theoretical framework. It remains to see if and how scientific research contributes in the improvement of technology to test the second part of the theoretical background.

We now proceed to discuss the findings of the fixed effects regression of the economic growth rate on the explanatory variables used in the first version of our model above. The findings presented in Table 2-3 are similar with the corresponding findings of Table 2-2 but now more explanatory variables exhibit statistical significance.

Firstly, the effect of patents is statistically significant at the 1% level of confidence and the elasticity of response is in the neighbourhood of 0.08. This translates into an increase of 0.08% in the growth rate of real GDP as a response to a 1% increase in patent applications. Moreover, trade openness and government

expenditure become statistically significant and have positive signs. The magnitude of trade openness varies from 0.23 to 0.29 and for government expenditure it moves between 0.097 and 0.17. Again SS and HU are not defining economic growth and therefore we should consider these variables in the sequential context discussed in the next section.

Table 2-3: The effect of scientific research output on economic growth rates of EU27, 1981-2010

	FE1		FE2		FE3		FE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	-0.115*	0.067	-0.121*	0.065	-0.065	0.065	-0.066	0.063
HU publications (1st lag)	0.008	0.038	0.004	0.038	0.014	0.036	0.009	0.036
SS publications (1st lag)	-0.079	0.049	-0.084*	0.049	-0.080	0.054	-0.080	0.053
S&T publications (2nd lag)	0.008	0.085	0.018	0.084	-	-	-	-
HU publications (2nd lag)	-0.011	0.033	-0.013	0.033	-	-	-	-
SS publications (2nd lag)	0.015	0.034	0.019	0.034	-	-	-	-
Patents (author-normalised count)	0.083***	0.023	0.080***	0.022	0.053*	0.030	0.051*	0.030
Average Years of tertiary schooling	0.013	0.126	0.025	0.123	0.059	0.127	0.067	0.126
Trade Openness	0.292***	0.047	0.292***	0.044	0.230***	0.059	0.228***	0.059
Government expenditure (% of GDP)	0.111**	0.050	0.097**	0.048	0.168***	0.057	0.157***	0.058
Capital investment (% of GDP)	-0.112	0.084	-0.111	0.080	-0.001	0.101	-0.001	0.099
1991-1995	-0.069**	0.029	-0.068**	0.030	-0.071***	0.025	-0.069***	0.025
1996-2000	-0.022	0.046	-0.019	0.044	-0.029	0.033	-0.025	0.033
2001-2005	-0.067	0.070	-0.065	0.067	-0.043	0.052	-0.037	0.051
2006-2010	-0.137	0.093	-0.133	0.090	-0.098	0.068	-0.089	0.066
Constant	-1.472***	0.429	-0.029	0.544	-1.591***	0.372	-0.446	0.493
Observations	114		114		118		118	
R-squared (within)	0.4946		0.509		0.3883		0.4008	
R-squared (between)	0.1533		0.2189		0.264		0.3062	
R-squared (overall)	0.1545		0.1612		0.2073		0.1951	
F test	15.07		15.95		9.98		9.76	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) FE1 & FE3: Fixed Effects of growth rates of 5-year averaged GDP per capita against logs of 5-year moving average per capita variables, FE2 & FE4: Fixed Effects of growth rates of 5-year averaged GDP against lagged values of logs of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

(e) In FE1 and FE2 second lags of publications are also used as explanatory variables.

Now we turn at examining the findings of the regressions of the economic growth rate on the growth rates of the independent variables. We estimate equations (12) and (13) including the additional variables we identified before. Because we take growth rates, our observations are reduced considerably to 86 for per capita variables and 90 for the absolute values. The findings of the fixed effect model are presented in Table 2-4.

Table 2-4: The effect of the growth of scientific research output on economic growth rates of EU27, 1981-2010

	FE1		**FE2**		**FE3**		**FE4**	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	-0.059	0.050	-0.077	0.049	-0.064	0.050	-0.074	0.049
HU publications (1st lag)	0.017	0.033	0.015	0.031	-0.033*	0.020	-0.031	0.020
SS publications (1st lag)	0.067**	0.028	0.059**	0.029	0.057	0.034	0.052	0.034
S&T publications (2nd lag)	0.010	0.047	0.003	0.048	-	-	-	-
HU publications (2nd lag)	0.012	0.030	0.015	0.028	-	-	-	-
SS publications (2nd lag)	0.011	0.007	0.009	0.008	-	-	-	-
Patents (author-normalised count)	0.117**	0.051	0.106**	0.054	0.092*	0.050	0.084*	0.049
Average Years of tertiary schooling	0.000	0.151	-0.009	0.153	-0.050	0.135	-0.052	0.137
Trade Openness	0.259***	0.057	0.261***	0.056	0.273***	0.054	0.271***	0.054
Government expenditure (% of GDP)	0.034	0.034	0.032	0.035	0.043	0.029	0.038	0.030
Capital investment (% of GDP)	0.103	0.099	0.109	0.103	0.126	0.084	0.128	0.084
1996-2000	0.121***	0.038	0.120***	0.038	0.109***	0.037	0.109***	0.037
2001-2005	0.027	0.038	0.028	0.039	0.017	0.038	0.018	0.038
2006-2010	0.018	0.043	0.016	0.045	0.016	0.044	0.014	0.045
Constant	-0.018	0.090	0.002	0.091	0.056	0.065	0.065	0.065
Observations	86		86		90		90	
R-squared (within)	0.5731		0.5625		0.5307		0.5306	
R-squared (between)	0.3817		0.3856		0.1846		0.1733	
R-squared (overall)	0.4361		0.4289		0.3171		0.3103	
F test	134.56		157.44		58.89		66.74	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) FE1 & FE3: Fixed Effects of growth rates of 5-year averaged GDP per capita against growth rates of 5-year moving average per capita variables, FE2 & FE4: Fixed Effects of growth rates of 5-year averaged GDP against lagged values of growth rates of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

(e) In FE1 and FE2 second lags of growth rates of publications are also used as explanatory variables.

We can see that patents are robust in explaining growth and have a marginal effect on the subsequent growth rate ranging from 0.084 to 0.117. Now the first lag of the growth rate of per capita publications in social sciences become statistically significant as well with a marginal effect between 0.06-0.07. On other hand, the rates of change in science and technology publications are not statistically significant in explaining subsequent growth rates. An explanation could be that an overlap may exist between S&T publications and patent applications especially when both come from universities and the latter capture the effect of the former. Trade Openness and Government Expenditure are also robust in determining the growth rate of the EU27 countries. S&T and HU publications do not seem to influence the economic growth rates and there we move on in examining the impact of scientific research on technological progress as proxied by patent applications.

In the second phase of our analysis we estimate the model of equation (18) to infer whether scientific research affects patent applications. We follow this route since we believe that the effect of scientific research on growth passes through innovation. Should this be the case then the effect of scientific research on technology is indirectly an effect on growth given endogenous growth theory. Table 2-5 comprises the findings of the estimation of the model.

Table 2-5: The effect of scientific research output on inventive activity of EU27 countries (patent applications), 1981-2010

	FE1		FE2		FE3		FE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	0.331*	0.192	0.299*	0.155	0.286*	0.160	0.303**	0.150
SS publications (1st lag)	0.230*	0.133	0.255**	0.118	0.246**	0.110	0.253**	0.110
GDP per capita in 2005 PPP fixed prices	1.316**	0.591	1.224**	0.520	1.346***	0.500	1.333***	0.492
Average Years of tertiary schooling	-1.358***	0.376	-1.310***	0.353	-1.179***	0.347	-1.204***	0.333
Trade Openness	0.834**	0.335	0.732***	0.263	0.723***	0.248	0.735***	0.254
Expenditure in R&D - business sector	-0.172	0.131	-0.196	0.128	-0.210	0.128	-0.194	0.121
Expenditure in R&D - higher education sector	-0.076	0.148	-	-	0.029	0.043	-	-
1991-1995	-0.017	0.109	-0.023	0.109	-0.035	0.102	-0.035	0.101
1996-2000	0.327*	0.169	0.312*	0.170	0.278*	0.161	0.276*	0.161
2001-2005	0.428*	0.248	0.439*	0.243	0.382	0.232	0.386*	0.230
2006-2010	0.398	0.310	0.401	0.304	0.323	0.289	0.332	0.285
Constant	-10.703*	6.205	-9.456*	5.318	-12.829***	4.513	-12.874***	4.518
Observations	104		105		107		107	
R-squared (within)	0.8678		0.8681		0.8809		0.8804	
R-squared (between)	0.4983		0.5608		0.5908		0.5947	
R-squared (overall)	0.5185		0.5687		0.5989		0.6023	
F test	55.73		61.33		62.58		65.8	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) FE1: Fixed Effects of the log of 5-year averaged patent applications per capita against lagged values of logs of 5-year moving average per capita variables, FE2 : Same as FE1 but with only business sector R&D expenditure FE3: Fixed Effects of the log of 5-year averaged patent applications against lagged values of logs of 5-year moving average variables, FE4: Same as FE3 but with only business sector R&D expenditure

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

We adjust the explanatory variables to match how patent applications are determined by factors not included in our initial model. The primary change is that we replaced government expenditure and capital investment with expenditure in R&D by the academic and business sectors. Intuitively, spending in R&D is expected to induce inventive activity and hence patents and we include its two most likely sources. As we do not have adequate data for R&D personnel we rely on R&D expenditure to control for human resources as well. We kept GDP per capita to test whether increased economic activity in a country induces innovation. We excluded publications in Arts and Humanities as they appeared to

be statistically insignificant in the findings of all estimation processes but also by intuition we do not expect to find association of this discipline with future patents. We keep capital and trade openness to control for potential spillover effects. We also keep schooling to capture innovation that occurs within the business sector as a result of skilled labour or learning by doing. In the final model, we estimate only one lag of scientific research variables since the second lag is globally insignificant in all our attempts to incorporate it as a regressor.

The model performs very well with the vast majority of the variables of interest presenting statistical significance. In particular, S&T and SS publications affect patents with elasticities of 0.3 and 0.25 respectively. Real GDP per capita is crucial in determining patents with an elastic response of around 1,3 showing an inverse effect of the one supported by endogenous growth theory. The theory supports that technology can bring increasing returns to scale in terms of economic output whereas here we see that an increase in real GDP per capita brings about such an effect on patent applications. Trade openness is important perhaps signifying a positive knowledge spillover effect for companies involved in international activities. A paradox which should be discussed is that human capital affects patent applications negatively and it is elastic between -1.3 and -1.1. This finding is in sharp contrast with the rationale that human capital is a positive determinant of growth since it was not important in our first growth model either. We can only assume that, since scientific research is included as a regressor it may capture the effect of human capital given that the former is an output whereas the latter is an input.

Also, the R&D expenditure both in the business and academic sectors do not have an effect on patent applications while Real GDP per capita and scientific research are important determinants. This ambiguity is difficult to be put in a theoretical context and we can only assume that scientific research and the international spillovers are more important factors of producing technological output. Given that in our sample of countries we do not include US, Japan, South Korea and other technologically advanced countries we could assert that spillovers of technological knowledge from EU member states transacting with these countries affect technological progress positively.

We also ran the regressions for the model derived from equations (15) and (16) which had the growth rate of patent applications as the dependent variable and the growth rate of the explanatory variables as regressors. We did not find statistically significant estimates and therefore we do not report these findings. We believe that the loss of observations in the calculation of the growth rates greatly affects the structure of the data due to their limited size and impacts negatively on the findings.

We now switch on the estimation of the inverse models, that is, where the scientific research output in the three broad fields is the dependent variable and economic growth is one of the explanatory variables. We customised the models to match intuition. For example, when the dependent variables is research output in Arts and Humanities we do not include Trade Openness or Patents in the independent variables as they are unlikely to have an effect on such a theoretical field.

From Table 2-6 it is evident that economic growth does not seem to have a significant impact on publications in arts and humanities and social sciences. Only slight evidence is in place for science and technology publications. On the other hand, expenditure in the academic sector are influential on scientific research according to the results. The elasticity is around 0.3, meaning that doubling R&D expenditure of the higher education sector is associated with an increase of 30% in scientific publications in the next five years. This is aligned with the rationale of diminishing returns of capital in the production of scientific research. Economic growth can be related to scientific research inasmuch as growth may bring increased expenditure for the higher education sector. This may be true for Arts and Humanities since excluding R&D expenditure from the model renders economic growth statistically significant for determining the subsequent publishing activity in the field with a nearly unitary elasticity (0.996). This finding for proportionate change in HU publications when real GDP changes reinforces the notion that research in Arts and Humanities is a direct effect of prosperity. The existence of such an effect essentially could classify research in these fields as a self-fulfilling choice of researchers rather than a growth-enhancing activity.

Table 2-6: The effect of growth on scientific research output for EU27 countries, 1981-2010 – Fixed Effects model

	FE1-S&T		FE2-SS		FE3-HU		FE4-S&T		FE5-SS		FE6-HU	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
R&D expenditure in the higher education sector	0.292**	0.136	0.167	0.140	0.298**	0.127	0.132**	0.053	0.078**	0.038	0.166***	0.051
Patents (author-normalised count)	0.194	0.157	0.382***	0.118	-	-	0.254	0.169	0.414***	0.109	-	-
GDP per capita in PPP 2005 prices	0.485	0.404	0.064	0.669	0.225	0.732	0.826*	0.428	0.319	0.629	0.667	0.607
Average Years of tertiary schooling	-0.335	0.561	0.096	0.509	-0.215	0.460	-0.273	0.578	0.148	0.513	-0.198	0.456
Trade Openness	0.006	0.203	-0.073	0.361	-0.225	0.232	0.250	0.167	0.068	0.410	0.019	0.224
Capital investment (% of GDP)	-0.412**	0.173	-0.108	0.430	-	-	-0.326**	0.162	-0.068	0.383	-	-
1991-1995	0.019	0.082	-0.003	0.078	-0.026	0.093	0.026	0.077	0.002	0.074	-0.002	0.088
1996-2000	0.125	0.140	0.139	0.178	-0.029	0.129	0.133	0.125	0.139	0.166	-0.009	0.133
2001-2005	0.035	0.212	0.177	0.255	-0.015	0.215	-0.070	0.170	0.107	0.258	-0.079	0.227
2006-2010	-0.004	0.255	0.813**	0.328	0.586**	0.287	-0.140	0.199	0.718**	0.332	0.499	0.314
Constant	-5.038	4.013	-5.524	6.267	-6.950	7.068	-0.963	3.789	-0.440	5.785	-3.002	5.676
Observations	105		105		105		108		108		108	
R-squared (within)	0.7805		0.8881		0.7577		0.7898		0.8958		0.7779	
R-squared (between)	0.7665		0.6754		0.4719		0.5769		0.7898		0.4985	
R-squared (overall)	0.7997		0.7487		0.5138		0.666		0.8367		0.5549	
F test	20.8		95.29		40.52		23.23		80.23		36.71	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) FE1: Fixed Effects of the log of 5-year averaged per capita S&T publications against logs of 5-year moving average per capita variables, FE2 : Fixed Effects of the log of 5-year averaged per capita SS publications against logs of 5-year moving average per capita variables FE3: Fixed Effects of the log of 5-year averaged per capita HU publications against logs of 5-year moving average per capita variables, FE4: Fixed Effects of the log of 5-year averaged S&T publications against logs of 5-year moving average explanatory variables, FE5: Fixed Effects of the log of 5-year averaged SS publications against logs of 5-year moving average explanatory variables, FE6: Fixed Effects of the log of 5-year averaged HU publications against logs of 5-year moving average explanatory variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

Some evidence for a positive effect of patent applications on social sciences publications seems to be present as well at around 0.4% for each increase of 1% in patent applications. This finding is contrary to Hellman's (2007) contention that patents are unlikely to affect subsequent research, let alone research in social sciences. The association of patents to subsequent publications in Social Sciences can be attributed to the potential development of strands of social sciences actually related to patents such as Innovation and Technology Management, Intellectual Property Rights and other relevant subfields of Economics and Business.

For science and technology, the regressions show a significant association of expenditure with increased publishing activity in these fields. The same pattern does not apply for patents. It would be expected to have a bi-causal relationship between science and technology and patents but this is not the case here. A possible explanation is that, in the majority of countries, technological progress is not of critical size to push scientific activity further. Instead, patents may push other activities such as commercialisation and business strategy which is corroborated by the finding that patents strongly enhance research in Social Sciences. In countries where this effect holds, causality probably runs only from publications to patents substantiating the theoretical assertions of our chapter.

Moreover, it is evident from the regressions that research in the arts and humanities is highly likely to have a purely social rather than any form of economic impact upon a country. Perhaps the economic impact may come in the very long term if the contributions in new knowledge of the humanities upgrade the level of sophistication and cultural identity of a country leading to either enhancement in human capital or

creation of new cultural products such as historical tourism or new museums. For some elements of the social sciences this may be the case as well.

2.7. Discussion and Policy Implications

The findings of this chapter seem to be in partial alignment with general intuition and with the majority of the literature on the importance of technology for economic growth as well as the contribution of scientific knowledge for the advancement of technology (Mansfield, 1991). Scientific knowledge may indeed form the cornerstone upon which innovations are developed but the effect on human capital is not immediately evident. Innovation expressed by patent applications is shown to be a strong determinant of growth, although it does not present increasing returns to scale. The estimated elasticities move in the region of 0.1 for patent applications and are statistically significant but they do not show the magnitude expected by endogenous growth models. Zeira (2011) provides an explanation of this discrepancy supporting that a patent competition is in place which implies similar research activities carried out by different stakeholders. This non-optimal allocation of resources limits the increasing returns effect as described by endogenous theory.

Science and Technology and Social Sciences publications are found in our results to be important determinants of technology at the national level, even though the publications considered in the paper are of international interest and calibre. This stylised fact probably occurs as a result of the knowledge spillover that characterises the production of scientific knowledge. Notwithstanding that the lion's share of this type of knowledge is produced within the academic system of countries, international collaboration still plays a vital role in the involvement of academics in

publications. Thus, the total production of publications for a country with weak R&D may reflect the choice to incorporate new knowledge in its production function and to a much lesser extent its ability to produce such ground-breaking knowledge.

Since our models are estimated at the country-level, our findings suggest that scientific knowledge produced within a country is important for the generation of intra-country technology. Technically speaking, if the theory of vertical innovation as outlined in Aghion and Howitt (1992) stands, then countries with weak R&D capacity are likely to be mere followers as also supported by the North-South paradigm (Krugman, 1979; Coe et al, 1995). In the opposite case where horizontal innovation prevails and scientific knowledge is not characterised by Schumpeterian obsolescence, our findings represent an alternate reality: in the sample of countries used, a high ability to produce knowledge exists, which is efficiently channelled in the production process through innovations within a reasonable time frame. In the countries that this reality holds the effect is much stronger than the ones in which the capacity to produce impactful scientific knowledge is low. In countries with a comparative advantage in inventions, national research policies should aim to provide additional support for the discovery of new ideas and their applications, given that these policies are optimally designed to maximise the quantity and quality of scientific knowledge. On the other hand, countries that do not produce scientific knowledge of direct use in technology could consider to progressively shift policies towards different types of scientific knowledge and seek for collaboration with countries that are scientific research leaders to guide them.

A constructive extension of the present chapter must be considered, whereby the policies of the different countries will be incorporated in the puzzle. We could not include R&D personnel as an explanatory variable although we did partially proxy it with R&D expenditure. However, this must take place in combination or with parallel inclusion of the individual level analysis, as the data currently available for public R&D funding for the countries used in the sample is insufficient to provide with a full picture about the problem. As we have presented empirical evidence of an indirect effect of scientific research on subsequent growth, it is critical to be examined, whether research funding is allocated and utilised efficiently for producing such scientific research of high quality. If it proves so, then policy-makers would have solid ground to support research funding schemes and the growth path of Figure 2:1 would be corroborated to a significant extent. If not so, then relevant policies should focus on optimally reshaping funding schemes.

2.8. Conclusions

The nature of the association between science and economic growth is surely a burdensome puzzle to solve. From the viewpoint of economics, science is important for its likely contribution to technology and human capital which in turn are widely considered to be drivers of economic growth. Equally important are the relevant implications such as choice of the involved economic agents and policies towards socioeconomic prosperity. Therefore, it is imperative at all times but especially in periods of economic recession that the topic climbs the priority list in the agendas of policy-makers at an exponential pace. Is it an easy decision to invest in science given its long-term payback nature when unemployment thrives and GDP keeps

falling? Unquestionably no, but in so doing, policy-makers must offer well-documented evidence that the long-term return of science is worth the opportunity cost entailed. This opportunity cost usually concerns short-term repayment of national debt. Our chapter claims to have contributed in documenting empirically whether it is worth directing policies towards scientific research.

We demonstrated that for governments, research policies will be economically safer to turn to funding science and technology or social sciences rather than the arts and humanities. We understand that this statement is by no means absolute. Our dataset has only 6 time intervals and these limit the breadth of lagged values we can use. Perhaps a potential impact of Arts and Humanities research would take longer to materialise than our dataset covers. Examining the period of 1930-1980, Adams (1990) finds that it takes around 20 to 30 years for scientific knowledge to impact on productivity. We found a ten-year effect for Science & Technology and Social Sciences but for the Arts and Humanities the case described by Adams may be applicable.

Nonetheless, competitive funding coming from schemes such as the EU Framework Programme may have better chances to enhance growth in a rapid pace focusing purely on funding research in applied sciences and engineering. Under this rationale, block grants should be retained for universities in order to play their role in human and social capital building. In any case, future research policy must be extremely cautious in terms of securing that funding is allocated to the most promising researchers from the view of expected quantity and quality of output, as well as its future value added in the production process.

We face a number of limitations in addressing the effect of scientific research on economic growth. One key limitation of the paper is that the quality of scientific research is not taken into account. Total publications per country are used and there is not any weight to account for their quality such as citations of journal impact factors. To account for quality, Jin considered only top journals of economics to measure the effect of publications on growth for Asian economies (Jin, 2009). We did not follow such a process as our data included publications of countries in all academic fields and it would be overly demanding to distinguish the top of each field and perhaps sub-field. However, we argue that, since the source of the journal publications is the ISI Web of Science, we are able to secure a threshold level of quality. Another limitation is the lack of data in scientific research at the country level, which does not allow to go further back and examine whether greater lags of the explanatory variables have an effect on growth.

The chapter tries to investigate the mechanism through which scientific research in different fields affects economic growth and it offers some useful insights to that direction. However, there is room for improving and expanding research in the economics of science, innovation and growth. A first area where further research is needed is the development of a theoretical model for the production of scientific research output. The idiosyncratic features of this process perhaps necessitate the use of a multiple output production function including all outputs of academic scholars including teaching, administration, advocacy to government and business and writing proposals for funding. Such an input in the literature could provide the foundations for big data to be collected and used to test empirically the

determinants of scientific research. Big data for scientific research is also an issue of concern given that the collection of such information is still at infantile stage. A concerted effort should be put in place by academic institutions around the world to collect uniform data for which all researchers will then be granted open access to. The OECD and the EU can claim a pivotal role in coordinating such an undertaking, which will be of high return to policy-makers. It will allow numerous studies to be carried out in the field to ultimately unveil the decisive factors for producing scientific research output of high quality and understand better its impact on economic growth.

2.9. Appendix of Chapter 2

Table 2-7: List of countries (EU27) included in the dataset

Austria	*Germany*	*Netherlands*
Belgium	*Greece*	*Poland*
Bulgaria	*Hungary*	*Portugal*
Cyprus	*Ireland*	*Romania*
Czech Republic	*Italy*	*Slovak Republic*
Denmark	*Latvia*	*Slovenia*
Estonia	*Lithuania*	*Spain*
Finland	*Luxembourg*	*Sweden*
France	*Malta*	*United Kingdom*

Table 2-8: The determinants of real PPP GDP per capita for EU27, 1981-2010 – Random Effects model

	RE1		RE2		RE3		RE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	-0.098	0.093	-0.144	0.091	-0.050	0.067	-0.118*	0.061
HU publications (1st lag)	-0.016	0.061	-0.038	0.059	-0.007	0.057	-0.045	0.058
SS publications (1st lag)	0.037	0.068	0.059	0.063	0.045	0.066	0.082	0.062
S&T publications (2nd lag)	0.033	0.099	0.026	0.103	-	-	-	-
HU publications (2nd lag)	-0.042	0.038	-0.063*	0.037	-	-	-	-
SS publications (2nd lag)	0.036	0.060	0.057	0.061	-	-	-	-
Patents (author-normalised count)	0.184***	0.028	0.178***	0.028	0.166***	0.026	0.169***	0.027
Average Years of tertiary schooling	0.123	0.120	0.159	0.115	0.136	0.120	0.168	0.115
Trade Openness	0.079	0.128	0.141	0.137	0.055	0.105	0.123	0.122
Government expenditure (% of GDP)	-0.174	0.128	-0.162	0.135	-0.132	0.132	-0.122	0.138
Capital investment (% of GDP)	-0.016	0.082	-0.008	0.079	0.054	0.091	0.078	0.096
1991-1995	-0.011	0.042	-0.000	0.045	-0.024	0.032	-0.021	0.035
1996-2000	0.083	0.073	0.089	0.076	0.066	0.059	0.063	0.068
2001-2005	0.080	0.108	0.075	0.115	0.089	0.091	0.078	0.104
2006-2010	0.078	0.134	0.067	0.143	0.101	0.106	0.083	0.124
Constant	9.385***	0.603	9.543***	0.756	9.347***	0.543	9.247***	0.759
Observations	114		114		118		118	
R-squared (within)	0.8276		0.8313		0.8204		0.8159	
R-squared (between)	0.8392		0.838		0.8451		0.8357	
R-squared (overall)	0.8259		0.8114		0.8261		0.8035	
Wald chi2 test	577.2		621.64		461.24		445	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) RE1 & RE3: Random Effects GLS of logged 5-year averaged GDP per capita against logs of 5-year moving average per capita variables, RE2 & RE4: Random Effects GLS of logged 5-year averaged GDP against lagged values of logs of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

(e) In RE1 and RE2 second lags of publications are also used as explanatory variables.

Table 2-9: The determinants of economic growth rates for EU27, 1981-2010 – Random Effects model (logged explanatory variables)

	RE1		RE2		RE3		RE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	0.039	0.056	0.056	0.056	-0.008	0.028	0.012*	0.023
HU publications (1st lag)	0.009	0.024	0.022	0.023	0.003	0.025	0.023	0.020
SS publications (1st lag)	-0.049	0.041	-0.063	0.044	-0.040	0.027	-0.054	0.026
S&T publications (2nd lag)	-0.053	0.054	-0.049	0.055	-	-	-	-
HU publications (2nd lag)	-0.003	0.029	0.009*	0.027	-	-	-	-
SS publications (2nd lag)	0.005	0.035	0.003	0.036	-	-	-	-
Patents (author-normalised count)	0.011***	0.012	0.006***	0.012	0.006***	0.011	0.002***	0.011
Average Years of tertiary schooling	0.075	0.052	0.049	0.052	0.078	0.048	0.057	0.050
Trade Openness	0.080	0.032	0.062	0.042	0.081	0.027	0.057	0.038
Government expenditure (% of GDP)	0.076	0.047	0.073	0.053	0.076	0.045	0.074	0.049
Capital investment (% of GDP)	-0.021	0.079	-0.028	0.084	0.028	0.073	0.019	0.074
1991-1995	-0.056	0.024	-0.061	0.025	-0.064	0.024	-0.063	0.025
1996-2000	0.0001	0.025	-0.003	0.026	-0.010	0.022	-0.005	0.022
2001-2005	0.010	0.032	0.013	0.034	0.001	0.026	0.012	0.028
2006-2010	-0.021	0.041	-0.013	0.044	-0.041	0.029	-0.025	0.032
Constant	-0.523***	0.322	-0.130***	0.355	-0.628***	0.303	-0.257***	0.329
Observations	114		114		118		118	
R-squared (within)	0.3169		0.2597		0.2848		0.2462	
R-squared (between)	0.4904		0.5158		0.4482		0.4747	
R-squared (overall)	0.3357		0.3176		0.3095		0.2984	
Wald chi2 test	451.07		214.6		110.21		95.51	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) RE1 & RE3: Random Effects GLS of the growth rates of 5-year averaged GDP per capita against logs of 5-year moving average per capita variables, RE2 & RE4: Random Effects GLS of the growth rates of 5-year averaged GDP against lagged values of logs of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of the growth rates of all explanatory variables are used in the estimation process.

(e) In RE1 and RE2 second lags of the growth rates of publications are also used as explanatory variables.

Table 2-10: The determinants of economic growth rates for EU27, 1981-2010 – Random Effects model (growth rates of explanatory variables)

	RE1		RE2		RE3		RE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	-0.070	0.048	-0.077*	0.045	-0.033	0.043	-0.041	0.041
HU publications (1st lag)	0.012	0.014	0.012	0.015	-0.005	0.014	-0.004	0.014
SS publications (1st lag)	0.023	0.030	0.019	0.031	0.043	0.027	0.041	0.027
S&T publications (2nd lag)	0.041	0.037	0.040	0.038	-	-	-	-
HU publications (2nd lag)	0.010	0.024	0.008	0.022	-	-	-	-
SS publications (2nd lag)	0.013	0.009	0.012	0.010	-	-	-	-
Patents (author-normalised count)	0.113**	0.050	0.109**	0.050	0.082	0.054	0.078	0.053
Average Years of tertiary schooling	0.011	0.032	0.008	0.034	-0.006	0.037	-0.009	0.037
Trade Openness	0.282***	0.068	0.282***	0.071	0.230***	0.066	0.231***	0.067
Government expenditure (% of GDP)	0.045	0.047	0.047	0.049	0.060	0.040	0.059	0.042
Capital investment (% of GDP)	0.128	0.087	0.141	0.087	0.202***	0.075	0.207***	0.074
1996-2000	0.124***	0.032	0.123***	0.032	0.115***	0.031	0.115***	0.031
2001-2005	0.032	0.029	0.031	0.029	0.039	0.026	0.040	0.027
2006-2010	0.039	0.037	0.038	0.036	0.037	0.033	0.037	0.033
Constant	-0.027	0.042	-0.019	0.044	0.015	0.045	0.021	0.045
Observations	86		86		90		90	
R-squared (within)	0.5335		0.5219		0.4749		0.4731	
R-squared (between)	0.6134		0.6096		0.5145		0.5099	
R-squared (overall)	0.5019		0.4901		0.4270		0.4218	
Wald chi2 test	650.25		539.84		318.30		342.37	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) RE1 & RE3: Random Effects GLS of the growth rate of 5-year averaged GDP per capita against the growth rate of 5-year moving average per capita variables, RE2 & RE4: Random Effects GLS of the growth rate of 5-year averaged GDP against lagged values of the growth rate of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of the growth rates all explanatory variables are used in the estimation process.

(e) In RE1 and RE2 second lagged growth rates of publications are also used as explanatory variables.

Table 2-11: The determinants of patent applications at the European Patent Office for the sample countries, 1981-2010 – Random Effects model

	RE1		RE2		RE3		RE4	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
S&T publications (1st lag)	0.608***	0.197	0.693***	0.207	0.777***	0.206	0.409**	0.197
HU publications (1st lag)	0.031	0.098	0.095	0.121	-0.004	0.098	0.000	0.099
SS publications (1st lag)	-0.096	0.137	-0.117	0.150	-0.184	0.177	-0.039	0.131
S&T publications (2nd lag)	-0.062	0.173	0.042	0.183	-0.030	0.161	-0.150	0.171
HU publications (2nd lag)	-0.028	0.061	0.011	0.062	-0.033	0.069	-0.048	0.056
SS publications (2nd lag)	0.172	0.137	0.168	0.140	0.192	0.148	0.210	0.140
GDP per capita in 2005 PPP fixed prices	1.756***	0.368	1.423***	0.296	1.147**	0.572	2.014***	0.320
Average Years of tertiary schooling	-0.172	0.423	-0.287	0.434	-0.192	0.527	-0.114	0.439
Trade Openness	0.478*	0.250	0.363	0.288	-0.029	0.362	0.908***	0.225
Government expenditure (% of GDP)	0.132	0.308	-0.051	0.310	-0.148	0.373	0.303	0.269
Capital investment (% of GDP)	-0.183	0.325	-0.199	0.337	-0.066	0.318	-0.212	0.328
1986-1990	0.117	0.190	-0.058	0.202	0.174	0.224	0.215	0.168
1991-1995	-0.203	0.227	-0.394	0.251	-0.048	0.301	-0.111	0.203
1996-2000	0.012	0.272	-0.179	0.300	0.293	0.360	0.070	0.243
2001-2005	-0.071	0.335	-0.238	0.379	0.365	0.443	-0.098	0.294
2006-2010	-0.243	0.379	-0.390	0.435	0.357	0.507	-0.338	0.330
Constant	-14.910***	5.167	-15.843***	4.412	-5.056	7.178	-23.069***	3.954
Observations	135		135		135		135	
R-squared (within)	0.8181		0.8287		0.8413		0.8276	
R-squared (between)	0.9054		0.9457		0.6652		0.8642	
R-squared (overall)	0.9031		0.9402		0.6551		0.8814	
Wald chi2 test	1916.74		2428.51		2405.72		1196.5	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) RE1: Random Effects GLS of the log of 5-year averaged patent applications per capita against logs of 5-year moving average per capita variables, RE2 : Random Effects GLS of the log of 5-year averaged patent applications against lagged values of logs of 5-year moving average variables RE3: Random Effects GLS of the log of 5-year averaged patent applications against lagged values of logs of 5-year moving average per capita variables, RE4: Random Effects GLS of the log of 5-year averaged patent applications per capita against logs of 5-year moving average variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

Table 2-12: The determinants of scientific research output for the sample countries, 1981-2010 – Random Effects model

	RE1-S&T		RE2-SS		RE3-HU		RE4-S&T		RE5-SS		RE6-HU	
Explanatory variables	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**	**coeff.**	**st. error**
R&D expenditure in the higher education sector	0.308***	0.073	0.170	0.122	0.270***	0.077	0.234**	0.100	0.141*	0.073	0.327***	0.097
Patents (author-normalised count)	0.173*	0.102	0.247**	0.100	-	-	0.468***	0.132	0.450***	0.071	-	-
GDP per capita in PPP 2005 prices	0.052	0.288	0.204	0.416	0.339	0.264	-0.563	0.381	-0.194	0.355	0.467	0.422
Average Years of tertiary schooling	0.037	0.247	0.858***	0.306	0.464	0.332	0.126	0.348	0.777**	0.319	0.346	0.432
Trade Openness	-0.086	0.102	0.280	0.215	0.096	0.162	-0.414***	0.153	-0.311	0.271	-0.517**	0.218
Capital investment (% of GDP)	-0.226	0.197	0.052	0.390	-	-	-0.042	0.278	0.182	0.327	-	-
1991-1995	0.049	0.058	-0.081	0.057	-0.125*	0.072	0.044	0.065	-0.025	0.047	-0.063	0.072
1996-2000	0.170	0.117	-0.032	0.141	-0.225**	0.113	0.276**	0.132	0.149	0.130	-0.064	0.115
2001-2005	0.102	0.161	-0.119	0.167	-0.368**	0.148	0.164	0.169	0.131	0.168	-0.120	0.167
2006-2010	0.108	0.193	0.461***	0.174	0.147	0.184	0.202	0.198	0.773***	0.185	0.441*	0.240
Constant	-1.240	2.631	-8.683***	3.224	-9.404***	2.440	12.491***	3.123	4.509*	2.740	-0.006	3.794
Observations	105		105		105		108		108		108	
R-squared (within)	0.7712		0.8737		0.7399		0.7066		0.8866		0.7343	
R-squared (between)	0.812		0.811		0.6737		0.9303		0.9018		0.811	
R-squared (overall)	0.8328		0.8448		0.6944		0.9206		0.9052		0.7894	
Wald chi2 test	241.14		696.01		371.1		382.38		994.76		296.57	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) RE1: Fixed Effects of the log of 5-year averaged per capita S&T publications against logs of 5-year moving average per capita variables, RE2 : Fixed Effects of the log of 5-year averaged per capita SS publications against logs of 5-year moving average per capita variables RE3: Fixed Effects of the log of 5-year averaged per capita HU publications against logs of 5-year moving average per capita variables, RE4: Fixed Effects of the log of 5-year averaged S&T publications against logs of 5-year moving average explanatory variables, RE5: Fixed Effects of the log of 5-year averaged SS publications against logs of 5-year moving average explanatory variables, RE6: Fixed Effects of the log of 5-year averaged HU publications against logs of 5-year moving average explanatory variables

(c) Cluster-robust errors used in all models

(d) First lags of all explanatory variables are used in the estimation process.

Table 2-13: Correlation of explanatory variables

Variables	S&T pub.	SS pub.	HU pub.	S&T pub. ptr	SS pub. ptr	HU pub. ptr	Patents	Patents pmr	Average Years of tertiary schooling	Capital investment (% of GDP)	Government expenditure (% of GDP)	Trade Openness	GDP pc (PPP 2005 prices)
SS publications	0.9625	1											
HU publications	0.9502	0.9831	1										
S&T publications ptr	0.188	0.1744	0.1572	1									
SS publications ptr	0.301	0.3737	0.345	0.7304	1								
HU publications ptr	0.3629	0.4289	0.4473	0.6097	0.8521	1							
Patents	0.8536	0.742	0.6928	0.1640	0.2039	0.2116	1						
Patents pmr	0.1684	0.1043	0.0737	0.7474	0.5143	0.3247	0.3509	1					
Average Years of tertiary schooling	0.114	0.1099	0.0723	0.4814	0.5888	0.5523	0.1516	0.3065	1				
Capital investment (% of GDP)	-0.1025	-0.1547	-0.1821	0.0713	0.0259	-0.0066	-0.011	0.1178	0.0027	1			
Government expenditure (% of GDP)	-0.0777	-0.0217	-0.0088	-0.0798	0.0075	0.0885	-0.1596	-0.3108	0.0887	-0.4889	1		
Trade Openness	-0.3196	-0.235	-0.2536	-0.12	0.0921	-0.0007	-0.2968	0.0782	0.0167	0.0966	-0.0999	1	
GDP per capita in PPP 2005 fixed prices	0.2317	0.2046	0.1773	0.5305	0.5145	0.3491	0.277	0.6545	0.3062	0.2695	-0.4604	0.3238	1

Notes:
Observations:175
Notes: S&T: Science and Technology, SS: Social Sciences, HU: Arts and Humanities, pub.: publications, pmr: per million residents, ptr: per thousand residents, PPP: Purchasing Power Parity, GDP: Gross Domestic Product

3 THE EFFECTS OF DIFFERENT FUNDING TYPES ON SCIENTIFIC RESEARCH OUTPUT

In this chapter we study the effect of different types of funding on scientific research output discussing the multiple econometric challenges entailed and applying various methods to tackle them. For this purpose a dataset was constructed and utilised at two different levels: a) a panel data of 172 tenure-track faculty researchers employed at the University of Cyprus from 1999 until 2013 with information regarding their personal characteristics and research funding and output and b) a cross-section dataset of 1909 publications for the same researchers for the period 2008-2013. We separated funding into internal grants, national competitive funding, EU funding and Other funding, with the last covering all other funding sources not included in the first three categories. Using both linear and non-linear estimation techniques, including multilevel modelling, we find that, in the cross-section setting, national competitive funding along with Other funding are the only types that seem to be positively and significantly related to citations and impact factor related measures. In the panel setting, national competitive funding seems to affect positively the quantity of research output as well, with both three-year and six-year lags. The other types of funding seem to matter only in specific scientific fields whereas in some cases the sign of the coefficient is counter to intuition.

3.1 Introduction

The global financial crisis has rendered the necessity for understanding the paths that lead to economic growth more prevalent than in any point of time in the last decades. Endogenous models of economic growth emphasised to a great extent on revealing the catalytic role of technology for achieving increasing growth rates. It seems that growth through technology is a robust economic policy direction as it tends to improve productivity in the long-term (Stephan, 1996). Therefore, underlying determinants of technological progress are to the forefront of global interest and will likely form the object of rigorous study within the next years.

Science has been widely considered to be as a potential determinant of technology. To that end, economics of science has become a continuously growing field that can contribute in comprehending better the mechanisms that lead to scientific knowledge, technological advancements and subsequent economic growth.

The roots of the field go back to Nelson at a time where science was at its peak of importance (Nelson, 1959). In the last twenty years a number of authors engaged in defining the constituents of the field (Dasgupta and David, 1994; Stephan, 1996; Esther-Mirjam, 1999; Diamond, 2008). Diamond articulates the role that this field of economics can play. He stated that "*The importance of the economics of science is substantially due to the importance of science as a driver of technology and technology as a driver of productivity and growth*" (Diamond, 2008). Essentially, economics of science can light the way towards the formulation of sophisticated research policies. The optimal social return to research funding and the improvement of research productivity can be achieved by providing appropriate and sound theoretical and empirical analyses in the various strands of the economics of science field.

The present chapter intends to contribute to the economics of science literature and specifically to the strand that focuses on the determinants of scientific research productivity. Scientific research productivity is defined as all published research output in the form of journal articles- and derivative metrics - produced by researchers in a specific period. Research funding is among the factors most widely included in the list of likely determinants affecting scientific research productivity (Diamond, 2008; Stephan, 1996). In the relevant empirical literature, there is a

widely held belief that funding is an important control variable of scientific research productivity and it is very often used as such in econometric models.

Nevertheless, a gap was identified with respect to how various types of research funding affect productivity differently. A researcher can secure funding from several sources. For example, such funding usually comes from the internal budget of universities. Also, funds can be secured either within the framework of national competitive funding schemes or international collaborative schemes such as the EU Framework Programme (FP). Each of these funding types has different characteristics. For instance, while internal funding tends to be oriented towards serving the research interests of the faculty members, EU funding is highly collaborative and demand-driven. The different effect that these sources of funding can have on scientific research productivity have not been accounted for adequately to the best of our knowledge. We identified a number of papers that dealt with related aspects of different scientific research funding schemes which nonetheless did not address significant stylised facts of the funding-output relationship. In a recent study, Hottenrott and Lawson (2013) used the funding amount as explanatory variable for exploring its effect on research productivity of UK academics from 15 universities. They found a positive and statistically significant association with research productivity for public but not for industrial and EU funding. Similarly, Jacob & Lefgren (2011) examined the impact of the United States National Institutes of Health (NIH) secured funding amount, as well as the event of being awarded a grant on postdoctoral researchers, on subsequent research output and found an additional publication on average for grant holders. Another relevant

study investigated *inter alia* the importance of funding for explaining research productivity at the institutional level arriving at a positive relationship (Teodorescu, 2000). However, these studies have not focused on other aspects of funding aside of the amount of money granted and did not consider the difficulty of isolating the way that each researcher actually utilises research funding. For example in specific scientific fields funding is largely used for infrastructure and laboratory-related expenses whereas in others it is utilised for human resources. As a result, £1 million of funding in High Performance Computing may be equivalent, in terms of the effect on research productivity, with £100.000 in Economics. Also, in collaborative projects a number of researchers share the funding. Even in cases where the researcher is the principal investigator, it is not straightforward to distinguish what money goes to researcher-specific costs (salaries, networking, travelling, equipment, software, etc) and what goes to institution-specific costs (overheads). In addition in many institutions a large share of external funding directed to overheads is accustomed to be reinvested back in research activities since the block grant suffices for the actual indirect costs related to research projects. These shortcomings render the use of funding amount, as a proxy for the importance of funding, in question. The present paper proposes an alternative approach. It places emphasis on the funding source and explores the effect of securing research funding from a specific funding agency or scheme, assuming that there is high degree of homogeneity of characteristics among grants within the same funding agency. In addition, the dataset constructed offers the advantage that it enables categorisation of funding

sources in an appealing way, targeting different policy schemes and different types of research projects (individual, collaborative, applied, demand-driven, *etc.*).

The other key gap traced in the literature is the rather superficial response to potential endogeneity of research funding as an explanatory variable of research output. Both two-sided causality and simultaneity are likely roots of the endogeneity problem. This lack of comprehensive approaches and discussions about endogeneity of research funding has created a chain of other deficiencies in the econometric treatment of research funding-output models with the most striking being the limited efficiency of the widely used fixed effects estimators. We do not downgrade the value of this estimator, quite the opposite. The fixed effects method is used as the main econometric approach in this chapter as well, as it may help to overcome problems such as unobserved heterogeneity and in this case endogeneity due to simultaneity of productivity and funding caused by the potential existence of a time-invariant "research talent" variable. Nevertheless, it still carries drawbacks that need to be further challenged and with the present chapter we are the first to use multilevel modelling in that respect, albeit aware that it is not a panacea. Again, strong assumptions must be in place to establish it as a viable econometric approach. We utilises a direction provided by the regression discontinuity framework design to construct a plausible assumption for homogeneity of researchers. This framework randomises the individual effect of observations situated very close (either above or below) to a pre-specified cut-off with the assumption that these are highly likely to be homogeneous (Imbens & Lemieux, 2008). Such an assumption justifies the use of multilevel modelling and the random effects thereof.

However, selecting only observations around a cut-off poses selectivity bias concerns in the process. In our dataset, the cut-off is inherent as it concerns the minimum criteria for researchers to enter a tenure track. As such we do not cause further selectivity bias.

With further use, multilevel modelling can gradually develop into a valuable tool for economics of science given the different scientific fields, institutions or even countries that can be used as separate levels for empirical studies of research productivity. This prospect is realistic, provided that the source of endogeneity is comprehended and modelled more explicitly on a case-by-case basis (Bell & Jones, 2014).

The chapter is structured as follows: The second section provides a review of the literature of research productivity determinants, stressing research funding as the focal point and discussing the methodological approaches of the reviewed studies. The third part presents the theoretical model behind the methodology which is presented in section four, with references to the relevant literature wherever necessary, along with the analysis of the dataset and the models to be estimated. Section five analyses the findings and section six concludes.

3.2 Literature review

Scientific research productivity is measured by published research output and can be expressed either as a stock or flow. Such output is in the vast majority of times published in scientific journal articles. In specific fields such as the humanities, books, chapters in books or monographs matter more than journal publications. In

this chapter, we use only journal publications as the base of research output indicators and to that end we do not include any fields where journal publications are not the norm. Even though there may be unpublished research material we assume it to be unfinished and expect to be published in subsequent years. For example, in computer science some conferences are so prestigious that are considered as equivalent to journal publications. But the proceedings are eventually published in peer-reviewed journals as a special edition and they are thus taken into account. In mathematics being invited to chair a conference is said to be one of the top research achievements. Although we understand the differences of what is considered good research across fields, for the purposes of our chapter, unpublished research is not measured. The risk of double-counting different versions of the same article would be high had we attempted the opposite. Measuring only published output is a common approach in the empirical literature on the determinants of research productivity (Levin & Stephan, 1991; Auranen & Nieminen, 2010; Gonzalez-Brambila & Veloso, 2007).

There is a vast literature for scientific research productivity and its potential determinants. This literature, however, when the efficiency of research funding in improving research productivity is the focus point, has only alluded to the problem. Jacob and Lefgren (2011) emphasise this fact, claiming that non-optimal allocation and use of this funding is a risk for the government not explicitly taken into account. They also elaborate on how understanding and creating the proper surrounding conditions for funding to be efficient can trigger increased research productivity.

In this literature review, we will firstly embark upon a review of important and relevant papers targeting the determinants of research productivity, as we consider the present chapter and thesis as a contribution to this strand. Subsequently, we will concentrate our attention to papers that consider funding as their primary explanatory variable of interest. We also review the literature for the econometric methods used for such studies.

3.2.1 Determinants of research productivity

Prior studies have examined research productivity and its determinants from various perspectives. Some of which were conducted outside the field of economics but are nonetheless relevant due to the interdisciplinary connection and interest of research as a scientific field. Although, we refer to these studies, we do not elaborate much on their methodologies as they diverge greatly from the methodological approaches used in the economics field.

Carayol and Mileille (2004) examine research productivity by using a sample of laboratories for the period from 1993 to 2000 for the Louis Pasteur University. They use the personal attributes of the researchers and interaction variables thereof to explain research output published either in journal articles or patents. They find that the existence of a blend of different skills and different statuses in terms of employment is an enhancing factor of research output both in journal publications and patents.

Harris and Kaine (1994) used a sample of 134 Australian university economists examining potential determinants such as research environment and research

characteristics from a qualitative perspective, interviewing and asking for the personal input of researchers. Their results show that the right to choose their own research agenda is very significant for researchers, as they are highly motivated to work in an area that stimulates their interest and enthusiasm.

Wood (1990) approached the determinants of research output having as fundamental objective to reveal personal and institutional characteristics that are of particular importance for the process. She identified a wide range of potential determining factors such as funding, type of research, and other personal attributes. More specifically, her findings reveal that researchers may select to place emphasis either on research or on teaching and administration, thus determining to a significant extent their research output. In relation to this argument, she discussed the possibility that productive researchers may become such on the expense of quality teaching. Essentially, the trade-off lies in the time that an academic is willing to devote to research or teaching. If this time is fixed across researchers or if appropriate monitoring exists for the quality of teaching then this choice should not affect research productivity. In our chapter we consider that these provisions are in place. Also, the field of research is, according to Wood, a critical factor shaping research productivity due to the differences in norms and expectations within each field. Gonzalez-Brambila & Veloso (2007) agree with this line of reasoning as their data verify the importance of scientific fields for explaining differences in research productivity. However we assert that only with appropriate normalisation across research fields one can infer such an effect. Publishing five journal articles per year in chemistry may be equivalent with publishing one journal article in economics. For

this reason, in the present chapter we secure valid comparison across fields via three actions: a. estimate separate models for each scientific field, b. normalise where possible the research output to ensure comparability and adopt a pooled approach and c. shift to multilevel modelling and run the regressions considering the scientific field as a distinct level.

Crespi and Geuna (2008) extracted data from the Thomson Scientific Database for 14 OECD countries and examined the returns of funding in research activities at the macro level measured by publications and citations. They estimated how and to which magnitude public R&D expenditure in the higher education sector affected future research output in the countries of interest, accounting at the same time for the length of the lag. They used the unrestricted polynomial distribution lag approach to derive the most representative lag period for the effect of R&D funding to materialise, reaching the conclusion that it takes around 6 years for the R&D to reach the peak effect on future academic research output with an elasticity of 0.145 for publications and 0.158 for citations. Auranen & Nieminen (2010) also follow this rationale by implementing a six year lag between funding and publications whereas Gonzalez-Brambila & Veloso (2007) consider a one-year lag which is rather insufficient to capture the time needed for the publication process to be completed. In the present chapter we estimate the funding effect on research productivity using both 3 and 6 year lags and thus we are within the optimal lag period according to the authors' findings. We do that since in some fields (i.e. Chemistry, Physics) publications are likely realised earlier than 6 years from obtaining the funding. However, our approach differs in other respects with the paper of Crespi and Geuna

and not only for considering the individual level. Due to the macro nature of their study Crespi and Geuna rely solely on the fixed effect of countries and time to control for unobserved heterogeneity, while we study other alternative methods as well which are more applicable at the micro level. Additionally, we use a variety of composite indicators as dependent variables since a straight count of publications or citations are sometimes imperfect measures of research output.

Gonzalez-Brambila and Veloso (2007), approached the determinants of research productivity using a rich dataset of Mexican researchers accounting for both research output and impact. They emphasised age as the key factor and other determinants such as quality of education, scientific field, overall budget, but not specific funding for each scientist. Furthermore, they employed a debatable econometric approach, the validity of which is at least debatable. They estimate a negative binomial fixed effects model and then divide the dependent variable by the first-step estimates of the time-variant variables. Subsequently they ran a model to estimate the effects of time-invariant regressors on research output. They applied this two-step process to obtain estimates for the explanatory variables that do not vary with time since they are dropped from the fixed effect estimation process. Although this method was originally proposed by Turner and Mairesse (2003), neither of these two studies provides background for the validity of this method. It thus seems as a rather arbitrary transformation not supported theoretically in any of the relevant econometric studies focusing on fixed effects negative binomial models (Hausman, et al., 1984). When using the fixed effects transformation, the estimation of time-invariant variables is sacrificed and by using this method one

does not retrieve the lost by the within-transformation estimation results. This argument is supported by Greene (2011) whereby in the frame of discussing the vector decomposition fixed effects method, the rationale of which is similar to the two-step process described above, he criticises the authors stating that the proposed estimator does not consistently and unbiasedly estimate the time-invariant coefficients. He elaborates that these are still unidentified and that their approach entails an assumption which fits more to a random effects rather than a fixed effects model.

He *et al* (2009) used a sample of 65 biomedical scientists from New Zealand in order to find the relation of research output with various forms of collaboration. Despite using composite research output indicators to account for the production of knowledge from the sample of scientists and the use of both publication- and scientist-level datasets, they follow a rather cumbersome econometric estimation method. They use negative binomial to accommodate the count nature of their data, including fixed effects and lagged dependent variables. However, the obvious endogeneity of the lagged dependent variable may result in severe upward bias for the coefficients and consequently their results. We address this problem by using dynamic GMM estimation using mean-transformed dependent variables. Moreover, the authors do not take into account whatsoever the dimension of funding, albeit being featured in most studies of the field as a main control variable. The fixed effect accounts for time-invariant individual characteristics and the time effect captures time-variant effects that are common for all scientists in their sample. Thus funding is not accounted for in their estimation process leading to omitted variable

bias. Another caveat in the estimation process of the paper is that it infers on estimates of the fixed effects negative binomial model for the time-invariant variables. In reality, the coefficients of the FE Binomial Model are not dropped only because the transformation process is applied on the dispersion parameter and not the X_{it}s. This fact causes the estimation process to leave behind some sort of a "transformation residual" for the time-invariant variables, which however is not meaningful and should be ignored.

In the same line, Goudard and Lubrano (2013) focus on the aspect of collaboration but extend the definition renaming it to social capital. The authors endeavour to construct a theoretical model for explaining research productivity drawing largely from the conceptual rationale of the human capital model of Diamond (1984). They use a dataset of publications by economists from the EconLit database for 14 European countries from 1991-2007 and estimate the model through multilevel modelling for individuals and departments, so as to provide for both effects. Their results indicate that international collaboration is more beneficial for researchers and they conclude that the exchange of ideas at this level tends to render them more innovative and productive. For local collaboration the authors infer no significant association to increased productivity.

Age is a factor that has also attracted the attention of researchers in their search for causal factors of research productivity. There is a general notion for a non-linear effect of age on research productivity although early sociological studies had shown the quite opposite effect (Cole, 1979; Stern, 1978).

Diamond (1984, 1986) studied research productivity of scientists in the course of their career using samples from university academics in the fields of mathematics, physics and economics. Using publication counts and citation metrics he found a monotonically diminishing effect of research productivity with age.

Oster and Hamermesh (1998) used a sample of 208 economists from 17 top research institutions and found that publishing activity diminishes severely along with age. They noted however that the density of the achievements of a researcher is what matters to get papers published and not the age.

In agreement with Oster and Hamermesh, Baser and Pema (2004) examine the effects of age on research productivity of economists in nine USA universities. Using composite measures of productivity derived from publications, citations and journal impact factors they find that after 20 years of engagement in economics research activity, the scholars in their sample start to produce less both in quantity and quality. Similarly, Beaudry and Allaoui (2012) find the peak of research productivity of Canadian researchers engaged in nanotechnology after 16 years of academic career.

In the same line, Levin and Stephan (1991) find that age is associated with research output in a quadratic fashion, expressed by an inverted U-shaped curve, with the peak of publishing activity found at the age of 53 years. It is hereupon noted that the effects of age are directly related to the effects of experience examined in the present paper. However, the intuition for the former *vis-à-vis* the intuition for the latter is quite contradictory and perhaps offsetting. As the experience of a researcher increases, this would theoretically lead to the acquisition of additional

knowledge not only of the scientific area, but also of the techniques and know-how of publishing, resulting in more publications. In contrast, previous literature asserts that as researchers grow older (and thus their experience increases) their productivity declines due to limited motivation. Our rationale is that the ageing effect does not exist in the form presented by previous studies, but instead its seemingly strong effect upon research output might be merely a product of the selective behaviour of senior researchers towards fewer papers in more prestigious journals. Stephan (1996) underlines that apart from the assumed correlation of age with productivity, there are other significant factors that are likely to affect research productivity, which are not yet explored. She moreover elaborates on the fact that a number of studies have found very low R-squares for such life-cycle models and support that the ageing effect can explain only a trivial amount of the variance of research productivity among researchers. Wood (1990) also supports that ageing effects could be of ambiguous direction since experience may prevail upon the effect of age.

Nevertheless, Levin and Stephan have made a strong point regarding the ageing effects in research productivity in a seminal paper. They have constructed a life-cycle model in which researchers embark upon research activities driven by investment-oriented motives. This theory is fairly supported by their empirical results which are derived from the use of a sample of physicists. The only departure from this theoretical view concerns particle physicists for whom the authors claim that an additional motive to "solve the puzzle" handed them by Albert Einstein as a "religious quest" exists, thereby eliminating the ageing effect (Levin & Stephan,

1991). Encompassing this feature in the utility function causes research productivity to remain high until retirement. Our notion is that this curiosity-driven research productivity could be present in other scientific fields as well and depends upon the passion of individual researchers or even their willingness to mentor doctoral and post-doctoral fellows which can result in increased research output. For these reasons, in the present chapter, we choose to include experience in the models as it is theoretically more appealing.

Another vital constituent of the research productivity puzzle has been the collaboration factor. The mainstream theory is that collaboration enhances research output not only due to the easily perceptible "more people: more work" effect but also with respect to the quality of research and the duration of increased productivity. This has been documented only in recent years and for specific research environments.

Lee and Bozeman (1995) use self-reported collaborators of 443 academic scientists in the USA and show that collaboration is important for a straight count of publications but not for fractional publications when the number of collaborators is taken into account.

He *et al* (2009) show a strong correlation between the two variables, especially between international collaboration and published output. However, the increased emphasis given to the element of collaboration by policy makers tends to stand on intuitive ground rather than cogent evidence. The authors support that local collaboration should not be neglected as it can provide unique combinations of knowledge exchange as in the case of international collaboration.

Gender is included within the most basic factors said to affect research productivity (Abramo, et al., 2008; Frietsch, et al., 2009). This is supported by different characteristics between the two genders such as devotion to family instead of career, patterns of collaboration, emphasis on quantity or on quality of research output etc. In the vast majority of studies, women are found to publish less than men (Fish & Gibbons, 1989; Long, 1992; Xie & Shauman, 1998; Mairesse & Turner, 2005). Xie & Shauman (1998) corroborate this line of arguments finding that women publish annually 20% less than men whereas Turner and Mairesse (2005) reveal that published papers per year for men are higher by an average of nearly one publication than women. A relevant study, albeit agreeing with the authors in terms of the quantity of publications, underlines that women have more citations on their published work than men (Culotta, 1993).

Summarising the main wave of studies of research productivity determinants was considered as a bridge to the next section which shifts our focus to different types of funding as the drivers of research output.

3.2.2 The effect of funding on research productivity

Several studies have focused on funding and its importance for helping researchers increase their productivity (Teodorescu, 2000; Jacob & Lefgren, 2011; Jacob & Lefgren, 2011). Countries use different funding schemes for research. In the EU, countries tend to choose between Block Grant and National Research Contracts systems in order to fund research activities (European Commission, 2009). Auranen & Nieminen (2010) compare the funding systems of eight countries and find considerable differences among systems but no significant association whatsoever

of levels of funding with the corresponding research productivity measured by publications. The authors suggest that perhaps research policy should abstain from funding and concentrate on finding other attributes which are more useful for increasing research productivity.

In Cyprus all public Universities are funded directly by the government budget through a Block Grant to cover for their basic operational costs and only and, in addition, research funding is also channelled on a competitive basis through the National Funding Scheme of the Research Promotion Foundation (RPF). Such combination of research funding methods seems ideal since, on the one hand, direct funding fuels academic institutions with adequate funds for maintaining infrastructures and research laboratories and on the other hand, the existence of an external funding agency- such as the RPF- provides incentives for researchers to become and remain competitive throughout their whole career (Stephan, 1996).

Gonzalez-Brambilaz and Veloso (2007) have provided for funding by including budget variables that are time variant but are the same for all individuals. The impact of an additional 1 million of funding in the budget of the national funding agency was found to be 0,12%, which does not convince of an important effect on research output, In any case, the fact that funding did not concern each researcher individually does not leave room for secure conclusions on its actual effect on research productivity.

Lee and Bozeman (1995) on the other hand find that researchers who had secured funding were more productive in publications than others. Here enters the simultaneity problem again. Unless this problem is modelled adequately, a result

such as the one of Lee and Bozeman could merely state the fact that funding is simply given to the most productive researchers who continue to be productive. Therefore we try to address this shortcoming in our methodology.

Wood (1990) analysed the funding aspect by scientific field, highlighting the differentiation that exists among fields as to the importance of funding for carrying out research. The author traced that scientific fields that belong to physical sciences usually require substantial and continuous funding for research results to be produced at a high level of quality. In other fields such as Economics, it was concluded that researchers may not need funding, especially if theoretical research is their primary area of focus. Fully in line with this contention, Harris and Kaine (1994) find funding to be of no significance for explaining research productivity of economists in Australia.

Jacob and Lefgren (2011) studied the impact of securing a NIH grant on future publications and citations using data for the period 1980-2000. They find that the holders of this type of grant produce one publication more in the subsequent five-year interval than their counterparts not funded by NIH. The authors claim that their findings support the existence of a funding market whereby researchers that do not receive the NIH grant shift to other funding agencies or form collaborations with other grant holders in order to fund their research. This pattern adds to the importance of our chapter as the impact of multiple types of funding is considered and can thus provide feedback to the assertion of the authors. However, the authors use an interesting econometric approach for estimating these effects suggesting that *"applications just above and just below the funding cutoff will be unlikely to*

differ in any unobservable determinants of the research output but will experience a large difference in the likelihood of receiving funding". They use these priority scores as instruments for estimating the impact of receiving a grant on research output. The scores are unknown before the evaluation and the final ranking of proposals and thus unrelated to the ability of a single researcher. This renders them random variables. Essentially, the authors tacitly imply that the ability for research which is encountered very often in the literature cannot be much different for researchers which received a priority score so close to each other as the regression discontinuity analysis dictates. This methodology, albeit innovative, entails a questionable technique for assessing the impact of a grant on future research productivity, such as selecting only applications that are around the funding cutoff. This may facilitate the endogeneity-solving rationale described above but causes selectivity bias to the dataset and the estimation process. When excluding observations from the sample a selectivity bias is caused as the high and low scores are not taken into account. Even if the authors discussed about the marginal or average researcher then the variance of the excluded observations could have useful information to provide to the estimation process and the coefficients could have been different. Thus the sample stops being random despite having imposed artificial randomisation by the assumption of the cut-off proximity of scores.

The authors use the same rationale in another study which focuses on the impact in the careers of post-doctorate researchers that received a grant from NIH especially designed for PhD holders in their early stage of their careers (Jacob & Lefgren, 2011). Again they use only the applicants that are situated around the cut-

off of funding by applying the regression discontinuity framework. They consider the grant as a treatment, the effect of which is estimated through both OLS and Regression Discontinuity, and find that researchers who had secured the grant observed an increase of one journal publication in the subsequent five-year period following the grant. The authors consider that the ability of the applicants in their sample does not differ much and thus do not account for unobserved heterogeneity.

Beaudry and Allaoui (2012) examine the effect of public and private research funding on subsequent journal publications of academics in the field of Nanotechnology in Canadian universities. The authors find that public funding enhances the number of articles but not the same applies with private funding. This is probably because funding from the private sector is usually directed towards industrial research which results in patents rather than journal publications. However, a key caveat for this study is that the authors use only one type of research output measure without accounting for the quality of the output.

Arora and Gambardella study the proposals submitted to the National Science Foundation in the field of Economics for the period from 1985 to 1990 and their impact on future research output (Arora & Gambardella, 2005). They find that NSF funding is highly and positively influential for the research productivity of junior researchers but quite the opposite for senior researchers. The authors have utilised weighted research output indicators based on publications and journal impact factors. They identified as a significant shortcoming of their approach the non-explicit treatment of unobserved heterogeneity of applicants which can cause upward bias in the estimates of the effect of funding on future research output. We

address unobserved heterogeneity explicitly in our model with the fixed effects approach.

Defazio *et al* (2009) approach funding as a determinant of research productivity through a collaboration perspective. They examine this regime utilising data for 294 researchers from research consortia from the 4th EU Framework Programme whereby collaboration was mandatory in the vast majority of the calls for proposals. They use the log of publications as an explanatory variable and an indicator variable of whether a researcher had access to funding or not and find a positive and statistically significant relationship. However, their approach presents three caveats: firstly using the log of publications as the dependent variable causes a loss of all zero publication observations. Secondly, the indicator variable for funding may be misleading as it does not capture the magnitude of the funding either in money but most preferably in our view the number of funded projects. Lastly, having only publications as the left-hand side variable limits their analysis to merely one type of research output not accounting for quality of research output. It is evident from the review of the literature on determinants of research productivity that there is a gap in both funding variables as well as their econometric treatment. In what follows we present the theoretical context which shapes our methodological approach towards addressing these gaps.

3.3 Theoretical context

The most prominent theoretical model for research productivity was constructed by Levin and Stephan (1991) in a seminal paper. The authors assume that researchers choose how to allocate their time throughout their career between research and other activities such as teaching and administration so as to maximise their utility functions, that is

$$\mathbf{H} = \int_{\mathbf{t=0}}^{\mathbf{T}} \mathbf{e}^{-\rho \mathbf{t}} \mathbf{U}(\mathbf{r_t}, \mathbf{g_t}) \mathbf{dt} \qquad (1)$$

whereby $t = 0$ is the year of PhD acquisition, T is the end of the career point assumed known, U is the utility function which depends on research output r and consumer goods g and ρ is the time preference parameter. Essentially, the model provides a general framework for structuring the optimisation objective of a typical researcher in a career context. We are interested in specific periods and therefore focus on the flow of research output through a production function rather than the career stock as in the above model.

The critical factor shaping the model of Levin and Stephan is the share of time devoted to research. Since we examine a single research institution in this paper, we assume that the share of time is fixed across our sample by deduction of their, by assumption, fixed administration and teaching time from the total time available. Thus, we can now shape the production function of the typical academic researcher keeping in mind the three components of a production function for knowledge as described by Stigler in his Nobel-prize lecture and identified by Stephan (2010): *a.*

Time and cognitive inputs, b. Research Resources, c. Serendipity. We discuss these concepts in relation to Equation (2) below:

$$Y_{i,t} = A_t K_{i,t}^{\alpha} L_{i,t}^{\beta} H_{i,t-k}^{\gamma} S_{i,t}^{\delta} \quad (2)$$

where Y is research output, A is the current level of background knowledge, L is the research group under the supervision the researcher (including himself) probably consisting of post-graduate students and post-doctorate researchers and H is the level of current knowledge of the researcher, that is his/her human capital. For time, we consider it as fixed and we proxy cognitive input with our human capital variable which relies on education and experience. Resources are covered by all the components in the production function, especially capital, labour and social capital. Serendipity is a random factor assumed to occur as a by-product of other activities such as talking to a colleague or observing a random phenomenon and this cannot be captured in the theoretical model. It is embodied in the random error in our econometric model but cannot be estimated since it is non-observable.

This simple production function is consistent with substantial arguments pertaining to the economics of science. The first is that, the higher the level of knowledge A the easier it is to apply combinations and produce further scientific knowledge. This is frequently referred to as the "standing on the shoulders of giants" effect using Newton's well-known say. The second is that collaboration expressed through S helps to produce more and better research output. The third is that infrastructure and capital in general are essential in the majority of scientific fields for producing

research output (Beaudry & Allaoui, 2012). The experience of researchers and their previous research output record, including qualitative indicators, are captured by H.

However, we note that the production function concerns the factors of research production stemming from the core research activities of the institution and that become available to an academic faculty researcher. External funding will be incorporated subsequently. Before doing so, we should see where funding comes from to become an indispensable piece for this production function.

Funding offers the opportunity to researchers to advance their research in a number of ways. By investing in equipment and consumables if in a laboratory-intensive field, acquiring large infrastructure (buildings, offices) and other capital goods such as hardware and software and obtaining access to datasets and other resources. It also facilitates funding for the research group members of the faculty member to retain or extend research assistance. It moreover enables researchers to network, build better skills and acquire knowledge through participation in conferences or relevant training and secondments to international counterparts. Therefore, funding affects all elements of the production function, aside from A on which its effect is likely to be negligible since it concerns the whole field. This is represented by the following expression where funding is denoted by M and enters the production function as an input with k being the lags needed for funding to become effective for research output:

$$Y_{i,t} = A_t K_{i,t}^{\alpha} L_{i,t}^{\beta} H_{i,t}^{\gamma} S_{i,t}^{\delta} M_{i,t-k}^{\theta} \quad (3)$$

Examining the production function in (3) with view to transform the equation to a model suitable for econometric estimation we can see that there are available proxies that can serve towards that end. Let us assume that research output is the number of peer-reviewed journal publications within a predefined time period. In practice, this assumption dictates the response variable to be of count nature. Our dataset concerns a single institution and therefore we assume that the allocation of time among research, teaching and administration are preset by the regulations of the institution, unless an externally funded research project is secured where the institution allows additional research time to the faculty member. We also assume that the basic K is endowed to all researchers equally and differences in K are due to securing external funding. The L factor concerns, aside from the researcher, the members of the same research group or laboratory and likewise S represents local and international collaborators. External collaboration can be accounted for by including corresponding proxies in the form of local and international coauthors. The A factor as well as K and L differ among scientific fields and therefore the production function must also be considered separately for each scientific field. Or if all research output is pooled together, then appropriate weightings should take place to capture these differences.

It is noted that this is a general theoretical model constructed for the purposes of estimating the econometric model in this paper. Since we use a range of research output indicators as well as both cross-section and panel data, we diverge from this exact setting in several cases where we opt to handle econometric challenges and

pivot in convenient directions to achieve this outcome. Essentially, the type of research output we use drives the functional form of equation (3).

3.4 Methodology

The current section outlines the methodological tools used for estimating the effect of funding on research productivity. Apart from the intrinsic features of the funding-output relationship in research, we were also motivated by both the attributes of our datasets and the econometric challenges traced in the literature to select the most suitable methodology. In each approach we try to address as many of the challenges as possible, albeit not feasible as some are mutually excludable in terms of econometric treatment. We discuss extensively how we deal with each challenge and the models are presented in the subsequent section that also deals with findings.

3.4.1 Datasets

3.4.1.1 Data collection

We were interested to see how funding affects the productivity of researchers and predominantly researchers pursuing a career in academia; not occasional researchers such as doctorate or post-doctorate fellows or visiting staff. This means that they are hired as permanent academic staff and follow a specific career ladder starting from lecturer and assistant professor and continue, once tenured, to become associate professor and full professor. Thus we consider our sample to be drawn from a population of all academics being on a tenure track as a similar system with perhaps different title is followed in many developed countries. We have drawn

our sample from the University of Cyprus[3]. It was an excellent source of information due to the public availability of information of personal characteristics and funding information for tenure-track researchers and the fact that the sample fulfils the desired properties as explained below.

The data collection process resulted in two datasets. The first dataset encompassed all publications of the academics of ten departments of the University of Cyprus who have been faculty members in a tenure track for part or for the whole period under study (2008-2013). We used the ISI Web of Science to acquire this information and, where needed, we sought for additional sources of information such as the research reports of the University of Cyprus published every three years. The main purpose of creating this dataset was to explore whether publications in the ISI Web of Science that acknowledged funding sources had a better quality, as measured by indicators such as citations and journal impact factors, than publications with no funding acknowledgement. Our final sample consisted of 1907 observations ranging within the time frame from year 2008 up to 2013 since no data were available for earlier years. We assumed that information provided for funding by the researchers was correct and that researchers always acknowledged their funding sources. The publications were then merged with other information regarding the authors that were members of the faculty of the University of Cyprus and the dataset had both publication-relevant and author-relevant information.

[3] See Appendix, 3.7.1, for detailed background information for the University of Cyprus.

Our second dataset was a panel of 172 researchers for 15 years producing an initial dataset of 2580 researcher-year observations. In order to extract information for researchers' funding and personal characteristics we used research reports of the University of Cyprus for the period from 1999-2010 which were published on a three-year basis (University of Cyprus, 2002, 2005, 2009a, 2012). We did this in order to use two different sources of information and cross-check the robustness of the cross-section model results. Also the fact that until 2007 UCY was the only university in Cyprus generalises our findings to the whole of Cyprus. To harmonise the dataset with the three-year feature of the research reports, along with the need to avoid excessive zeros in the data and to handle potential cyclicality in the productivity of researchers, we transformed the panel dataset into three-year intervals. After taking out the missing observations we ended up with a dataset of 468 observations that fulfilled all the information needed for our model. Since we use lagged values of funding, in the descriptive statistics table below, the observations for all variables, except funding, add up to 640 since they include the 2011-2013 interval, for which funding information is not available (not necessary for our setting of the model since we use lags of funding variables).

A suspicion for the existence of selection bias in the sample dictated a detailed clarification to that respect. The fact that these researchers come strictly from the University of Cyprus (UCY) is not seen as a source of selection bias as the scientists of UCY fulfil the criteria for comparability with counterparts from all research-advanced countries in the sense that a very strict process for hiring tenure-track academics is in place. This is one of the main reasons that no other institution from

Cyprus is included in our sample[4]. The minimum requirements for entering a tenure track involve at least possession of a PhD and the competition amongst candidates has also rendered post-doctoral research equivalent to a prerequisite criterion for the ten departments that we included in our sample. Indeed all faculty members have a PhD degree and post-doctoral experience in various countries including USA, UK, Greece and other European countries. In areas such as literature, architecture, law or theology this is not the case since faculty is hired without a PhD. However, we do not include these departments due to lack of data. In recent years, the other two public universities of Cyprus have also imposed strict criteria for hiring tenure-track academics. Therefore generalisability of our findings is primarily secured for Cyprus and then for universities or countries with similar characteristics.

Also, the fact that the first PhD holders from a Cypriot University do not graduate before 1996, means that nearly all faculty members used in our sample are graduates of Universities from other countries such as UK, USA and Greece. The only likely source of bias concerns the special conditions surrounding their working environment compared to academics working in other countries, such as proximity to the research excellence centres or better benefits from knowledge-spillovers externalities. However, these limitations are also valid for the majority of Universities situated in areas outside UK and USA. Arora, David and Gambardella (1998) discuss selection bias in their study which focuses only on the Biotechnology sector in Italy using the arguments that the distribution of research output amongst their sample

[4] For a detailed report for the Research and Innovation system in Cyprus see Tsipouri & Athanassopoulou, 2014.

researchers follows a similar distribution with the corresponding researchers of US or other research-intensive countries.

We initially separated funding into six categories: internal grants (Internal), national competitive funding (RPF), European Union funding (EU), prestigious funding (NSF), culturally-adjacent funding (Greek National Funding-GGET) and other funding (Other), with the latter covering all other funding sources not included in the first five categories. Monetary measures of this funding were not available for all cases and nonetheless they posed the additional difficulty of distinguishing among the shares of each researcher in a research grant. Therefore, we used counts of funding links for each publication in order to reflect the importance of participating in a funded research project upon the quality of a publication. This practice is also supported by Arora and Garbadella (2005) who find no association between funding magnitude and subsequent research output but find an effect of selection for funding on research output.

3.4.1.2 Descriptive statistics

The dataset consists of several composite research output indicators as well as the explanatory variables, that is, the funding variables and the remaining control variables. In Table 3-1 we can see the descriptive statistics for the dependent variables. The mean citations are around 9 per article, whereas, their weighted by the number of years counterparts are normalised around 2.38. Normalisation by author brings similar results as fractional citations average to 2.31. When normalised

by both year and author they reach 0.63. The average number of pages per article is approximately 13.

Table 3-1: Descriptive statistics for cross-section dependent variables

Variable	Observations	Mean	St. Deviation	Min	Max
5-year JIF	1847	2.84	3.27	0.22	51.88
Citations	1903	8.58	37.50	0	1373
Years- weighted citations	1903	2.38	7.98	0	274.6
Fractional Citations	1903	2.31	6.10	0	147.5
Years-Author- Weighted Citations	1903	0.63	1.42	0	36.88
Pages	1909	12.96	8.43	2	70
JIF-Author Weighted Pages	1847	11.00	21.72	0.22	666.71
JIF-Author Weighted Publications	1847	0.85	0.97	0.05	19.08

The summary statistics table below presents the variables of interest which concern funding secured from different sources. Internal funding accounts for 12% of the publications whereas RPF and EU funding correspond to 36.3% and 21.4% of publications respectively. Other sources of funding cover around 46% of the publications and the other two categories (NSF and GGET) are limited to a total of 9%. Industrial funding was initially of interest but the frequency of its acknowledgement was negligible and thus it was not taken into account.

Table 3-2: Descriptive statistics for cross-section funding variables

Variable	Observations	Mean	St. Deviation	Min	Max
Internal	1907	0.12	0.34	0	2
RPF	1907	0.36	0.69	0	4
EU	1907	0.21	0.60	0	5
NSF	1907	0.07	0.37	0	6
GGET	1907	0.01	0.10	0	1
Other	1907	0.46	1.39	0	20
Other funding	1907	0.54	1.47	0	20

Also, in the majority of our models, we compressed the NSF, GGET and Other Funding into one category as the first two categories were not frequently encountered in the funding acknowledgements and their inclusion in the model was statistically insignificant in all specifications. The summary statistics including the new "Other Funding" variable can be seen in the above table.

We also used other controls that are considered influential determinants for the production of research output. Regarding personal characteristics three types of such variables were considered: a) gender, b) experience and experience squared due to the likely non-linear effect of experience on research productivity, measured from the year of acquiring their PhD until the year of the publication and c) the quality of higher education the researchers received, as expressed by dummy variables for degree and/or PhD from high calibre universities (TOP-20 Times and Guardian Universities for the last 5 available years). Interaction variables between the two are also used, named Education and Education1 respectively. Additionally we used in some model specifications a dummy variable of whether a researcher proceeded directly from degree to PhD without having a Master's degree. The education variables are used to capture possible early-career excellence and their descriptive statistics for the cross-section dataset are described in Table 3-3. Also, in terms of publication-related controls, local and international coauthors are accounted for, along with the number of references as a proxy of the breadth of a specific scientific field (Abt & Garfield, 2002).

Table 3-3: Descriptive statistics for cross-section control variables

Variable	Observations	Mean	St. Deviation	Minimum	Maximum
TOP-20 Degree	1871	0.19	0.39	0	1
TOP-20 PhD	1879	0.35	0.48	0	1
No Master	1871	0.33	0.47	0	1
PhD Years	1875	5.78	1.69	3	13
Education	1871	0.18	0.39	0	1
Education 1	1909	0.36	0.48	0	1

We now shift to discuss the descriptive statistics for the panel dataset. We can see from Table 3-4 that the mean of publications within the three-year periods is 5.28 and the respective average for year-weighted citations amounts to 10.62. Regarding funding we can easily observe that researchers had participated in 1.43 RPF projects on average whereas for EU projects the respective figure is lower than 1 reaching 0.95. NSF and GGET account for averages of merely 0.03 and 0.02 respectively per researcher in a three-year interval, whereas internal funding reached 0.33 and other funding 0.37. As it is obvious, RPF and EU are the most frequent types of funding utilised by the researchers in the sample and internal and other funding follow. NSF and GGET are the types of funding that researchers need collaboration with either high-calibre peers in the case of NSF or culturally-close colleagues in the case of GGET. As these types are less frequent we unify them with other funding in most specifications of the model.

Table 3-4: Descriptive statistics for panel data variables

Variable	Observations	Mean	Std. Dev.	Min	Max
Publications	640	5.28	4.98	0	33
Author-weighted publications	640	1.99	1.77	0	10
First-authored publications	640	1.4	1.88	0	15
Year-weighted citations	640	10.62	22.95	0	300
Year-author-weighted citations	640	3.1	5.07	0	48
Pages	640	71.3	60.71	0	393
Adjusted JIF	598	0.16	0.76	-1	6.58
RPF	468	1.43	2.28	0	15
EU	468	0.95	1.81	0	12
NSF	468	0.03	0.28	0	4
GGET	468	0.02	0.17	0	3
OTHER	468	0.37	0.87	0	6
INTERNAL	468	0.33	0.56	0	3
Other funding	468	0.42	0.98	0	7
Average References	598	32.24	23.41	0	320
International Coauthors	640	7.13	15.49	0	246
Local Coauthors	640	7.87	14.38	0	168
TOP-20 Degree	640	0.12	0.32	0	1
TOP-20 PhD	640	0.23	0.42	0	1
No Master	640	0.23	0.41	0	1
PhD Years	640	5.35	2.68	0	16
Education	640	0.10	0.31	0	1
Education 1	640	0.25	0.43	0	1
Biology	640	0.06	0.25	0	1
Business	640	0.14	0.34	0	1
Chemistry	640	0.09	0.28	0	1
Civil	640	0.07	0.26	0	1
Computer	640	0.14	0.35	0	1
Economics	640	0.12	0.33	0	1
Electrical	640	0.08	0.27	0	1
Mathematics	640	0.16	0.37	0	1
Mechanical	640	0.07	0.26	0	1
Physics	640	0.07	0.26	0	1

The ten departments we use concern the entirety of physical and engineering sciences (Physics, Chemistry, Biology, Mathematics, Computer Science, Civil Engineering, Mechanical Engineering, Electrical and Computer Engineering) along with Economics and Business Administration from the social sciences. We chose to

include these departments due to the availability of data but also of the fact that journal publications are the norm of published research output. We can see that Mathematics accounts for 16% of the sample whereas Computer Science and Business represent 14% of the sample each. The smallest department is Biology with only 6% of the sample whereas Civil Engineering, Mechanical Engineering and Physics are slightly higher with 7% of the sample each.

3.4.1.3 Research output Indicators

As it is asserted, different research output indicators may give different productivity results for the same researcher (Henrekson & Waldenstrom, 2011). This argument renders the use of diverse indicators mandatory for drawing reliable and robust inference. In this light, as dependent variables, we use several research output indicators (ROI), most of them composite. A caveat of our approach is that we cannot include books and chapters in books as they are difficult to obtain and because any attempt for their quantification in composite indicators is purely subjective (Johnes & Johnes, 1995). In what follows, it is explained how each variable is calculated and what it represents. We divide the analysis into cross-sectional and panel data research output indicators.

The indicators are concerned with the quality of the journal article at the cross section level and both the quantity and quality for the panel data setting of our model. Therefore, we use citation- or journal impact factor-related metrics for quality and publications and pages for the quantity of output. Pages are actually used as a measure of both quantity and quality given some underlying assumptions

discussed later. We also use combinations of both quantity and quality of research output in two cases.

citations: Denoted by C_i, it represents citations that an article received as measured in April 2014. This unweighted index is meaningful only if different regressions are run separately for each year in the dataset and thematic field dummies are included as a control for the size of the thematic area. In the fixed effects models where time-invariant variables such as thematic field dummies are dropped, we use the number of references as a control for the size of the field.

frcitations: Citations that an article received, as measured in April 2014, divided by the number of authors of the article. This fact gives meaning to this unweighted index only if different regressions are run separately by year in the dataset since citations of different years cannot be pooled together unless weighted by year. It is symbolised with $c_i = C_i/a_i$ implying a per capita type of notation.

wcitations: Weighted Citations are the total citations for a publication weighted by the number of years passed since the year of the publication or in mathematical notation, $w_i = C_i/(2014 - t_i)$. For example a publication in year 2008 which received 10 citations will have a wcitations measure of 10/(2014-2008)=10/6=1.67. This weighting which decreases with every year passed is similar with Sidiropoulos et al (2006) with the difference that we divide citations by the number of years passed whereas the authors give a weight of 4 for each citation received in the first year and then divide with the same mode we do (i.e. year-2 = 4/2, year-3= 4/3, year-4 = 4/4, etc).

wfcitations: Weighted Fractional Citations are Weighted Citations divided by the number of authors so that the net research output per researcher is measured. The equation is similar to the wcitations indicator only now C_i is replaced by c_i resulting in $\rho_i = c_i/(2014 - t_i)$. A publication in 2008 which received 10 citations and had 3 coauthors will have a wfcitations measure of (10/3) ÷ (2014-2008)=10/18=0.56.

jifdeviation: The 5-year (2008-2012) Journal Impact Factor (JIF) deviation of a publication is the deviation of the JIF of the journal -that includes the publication- from the average JIF of the scientific field divided by that same average. This gives an insight of the significance of the publication's journal as compared to the other journals of that field and dividing it by the average allows for comparison among thematic areas as it is transformed into a relative variable. The equation is $\Pi_i = (\pi_i - \bar{\pi})/\bar{\pi}$, where π_i is the JIF of the journal within which the article is published and $\bar{\pi}$ is the mean JIF of the scientific field as derived from the ISI Web of Science.

article pages: It measures the pages of each publication and it is denoted by g_i. This does may not say much about quality but it is the only measure that can claim to account for quantitative aspects of research output at the publication level.

avjifap: Average JIF-Author-Pages measure multiplies the JIF deviation by the pages of the publication and divides by the authors subtracts the same calculation but this time using the average JIF of the scientific field., that is $Y_i = (\pi_i - \bar{\pi})g_i/a_i$. A publication with 10 pages and 5 coauthors in a journal that has a JIF of 1.5, in a

scientific field that has an average JIF of 1, will have the following avjifap: (10/5)*(1.5-1)=2*0.5=1

avjifauth: Average JIF-Author measure is expressed by $y_i = (\pi_i - \bar{\pi})/a_i$. Essentially, it divides the JIF deviation from the scientific field mean by the authors of an article. A publication with 5 coauthors in a journal that has a JIF of 1.5, in a scientific field that has an average JIF of 1, will have the following avjifap: (1.5-1)/5)=0.5/5=0.1

The respective panel data research output indicators measuring quality, are the sum of the cross-section indicators described above. For example the **avjifauth** indicator for researcher r for a specific three-year period T is $Y_{rT} = \sum_{i=1}^{n} \sum_{t=1}^{3} Y_{it}$. All these indicators are included in Table 3-19 in the Appendix.

For the quantitative research output related to the panel dataset we have the following indicators:

Publications: It is the straight publications count of a researcher for a three-year period regardless of coauthorship. The publications are the ones included in ISI Web of Science, thereby adding a minimum threshold of quality to the indicator since the database has the vast majority of top journals in the fields under study. It is denoted by $P_{rT} = \sum_{i=1}^{n} P_i$, where i stands for publications.

First-Authored Publications: It is the straight count of first-authored publications of a researcher for a three year period. This indicator does not take into account the number of coauthors. It emphasises the possibility that the first author is related to the originality of the idea as well as increased research effort

compared to coauthors. We assume this applies scientific fields acknowledging though that this may not always be the case. Similarly to publications it is expressed by $\Phi_{rT} = \sum_{i=1}^{n} \Phi_i$ and Φ_i corresponds to first-authored publications.

Fractional Publications: It is the straight publications count of a researcher for a three-year period providing for coauthorship. The coauthorship is taken into account at the publication level and then the results are aggregated. The indicator is denoted by $f_{rT} = \sum_{i=1}^{n} f_i$.

Table 3-19 in the Appendix outlines all research output indicators along with their notation and their corresponding calculation formulae as explained above.

3.4.2 The models

In this section we present the models to be estimated. We separate the models that estimate the funding effects in cross-section and panel data. We write the models as beijg in linear form but in certain cases they are non-linear. For this reason in a subsequent section we explain succinctly how the model becomes for each estimation method.

Cross section model (Publication level):

$$ROI_i = \beta_1 RPF_i + \beta_2 INTERNAL_i + \beta_3 EU_i + \beta_4 OTHERFUND_i + \beta_5 INT_i + \beta_6 LOC_i + \beta_7 REF_i + \beta_8 PAGES_i + \beta_9 JIF_i + \beta_{10} DEP_i + \beta_{11} FEM_i + \beta_{12} PHD_i + \beta_{13} DEG_i + \beta_{14} MASTER_i + \beta_{15} YEAR + \varepsilon_i \quad (4)$$

where the explanatory variables are described as follows:

ROI: A Research Output Indicator (ROI) measuring quality of research output (See Table 3-19, Appendix)

RPF: The number of acknowledgements for RPF funded projects in an article

INTERNAL: The number of acknowledgements for internally funded projects in an article

EU: The number of acknowledgements for EU funded projects in an article

OTHER: The number of acknowledgements for funded projects from miscellaneous sources in an article

INT: Number of international co-authors in the article

LOC: Number of local co-authors in the article

EXP: Experience of a research counted in years from the year oh PhD award

EXPSQ: EXP squared to capture non-linear effects of experience

REF: The references of the article that capture the size of the scientific subfield of the author

PAGES: The number of pages of an article

JIF: The Journal Impact Factor of the journal in which the article is published

DEP: An indicator variable for the department in which the researcher is a faculty member

FEM: The gender of the researcher (female=1)

PHD: A dummy variable of whether the researcher obtained their PhD from a TOP-20 University

MASTER: A dummy variable of whether the researcher proceeded directly from a degree to a PhD without having a Master's degree

DEG: A dummy variable of whether the researcher obtained their first degree from a TOP-20 University

Panel data model (Researcher level):

$$ROI_{it} = \beta_1 RPF_{it-k} + \beta_2 INTERNAL_{it-k} + \beta_3 EU_{it-k} + \beta_4 OTHERFUND_{it-k} + \beta_5 INT_{it-1} + \beta_6 LOC_{it-1} + \beta_7 EXP_{it} + \beta_8 EXPSQ_{it} + \beta_9 REF_{it-1} + \beta_{10} DEP_i + \beta_{11} FEM_i + \beta_{12} PHD_i + \beta_{13} DEG_i + \beta_{14} MASTER_i + \alpha_i + \tau_t + \varepsilon_{it} \quad (5)$$

where the explanatory variables are as in the cross-section model but now they are transformed to match the panel level which includes researcher-specific variables for a number of time periods. More specifically:

- for the four funding variables, the first (and second) lag of the sum of funded projects is used
- for international and local coauthors as well as references the lagged average is used
- the researcher characteristics variables remain the same although they are not estimated when the fixed effect method is used.
- α_i is the individual-specific effect which is either fixed or random depending on the estimation method
- τ_t is a time period-specific effect

Depending on the estimation method the models are slightly differentiated. Such examples are the Dynamic GMM method where a lagged dependent variable is included, or the multilevel random effects model where the department effect becomes random and the model is estimated in two levels. In what follows, all estimation methods are explained.

3.4.2.1 Estimation of cross-section models

We base the setting of our cross-sectional models on non-linear estimation approaches, except for research output indicators that are in the form of deviation from the mean and are estimated by OLS. Most dependent variables are in the form of count data and thus either a Poisson or a Negative Binomial model were appropriate in order to obtain sensible results. The data are overdispersed, meaning that the requirement of the Poisson model for equidispersion (the mean to equal the variance) is not met. Thus we use Negative Binomial with cluster-robust errors to account for heteroskedasticity (Wooldridge, 2002, p.57). In cases where Negative Binomial is not an option due to non-convergence, we use Poisson with White's heteroskedasticity-robust errors (White, 1980). Despite the requirement for equidispersion, the advantage of Poisson is that consistency is maintained even when the dependent variable is not Poisson-distributed (Wooldridge, 2002, p. 646) and the use of White's robust errors secures sensible inference on hypothesis testing and validity of the pertinent Wald tests.

The problem of unobserved heterogeneity was also under concern and we included individual dummies for researchers to tackle any issues that may arise. We moreover

include year dummies in order to capture time-specific effects. As zero-counts are determined by the same process as positive counts, the negative binomial is appropriate for our model without the need to use the hurdle or zero-inflated forms. The only problem is the incidental parameters issue, whereby in the context of maximum likelihood estimation, as individuals in the sample grow to infinity according to the asymptotic theory, the individual dummies grow to infinity as well rendering the estimator inconsistent (Lancaster, 2000). Trivedi defends the individual dummies approach stating that the incidental parameters problem is perhaps overemphasised (Trivedi, 2010). In any case, any inference from the estimation of this model should be drawn bearing in mind this idiosyncrasy and perhaps rely more on the panel estimation which integrates out the individual effects, thereby not causing the incidental parameters concern (Cameron & Trivedi, 1998).

The model is as in (4):

$$\mathrm{E}(\mathrm{y_i}|\mathrm{X_i}, \alpha_\mathrm{i}, \mathrm{t}) = \exp(\mu + \xi \sum_{\mathrm{t}=1}^{5} \lambda_\mathrm{t} + \gamma \sum_{\mathrm{i}=1}^{171} \alpha_\mathrm{i} + \beta \mathrm{X_i} + \mathrm{u_i}) \qquad (6)$$

where y_i is the dependent variable, X_i represents the explanatory variables, μ is the intercept, a_i represents the researcher dummy variables, λ_t provides for time-specific effects and u_i are the statistical errors of the model.

3.4.2.2 Multilevel modelling for cross-section

We also apply a multilevel model with three levels: the scientific field, the faculty member and the publication denoted by $i, j\ and\ k$ respectively. The occurrence concerns the metric used for the quality of publications, i.e. citations. This requires adding a random intercept for both the individual and the scientific field and thus the model becomes:

$$E\left(y_{ijk}\middle|X_{ijk}, \xi_{jk}, \theta_k\right) = \exp(\beta_0 + \beta_1 X_{ijk} + \beta_2 X_{jk} + \theta_k + \xi_{jk} + u_{ijk}) \qquad (7)$$

where y_{ijk} is the dependent variable, X_{ijk} represents the explanatory variables at the first level (publications), X_{jk} represents the explanatory variables at the second level (researchers), θ_k, and ξ_{jk} provide for scientific field-specific and researcher-specific random effects respectively and u_{ijk} are the statistical errors of the model.

The model provides for unobserved heterogeneity both at the scientific field and the individual level. These effects are considered as random and are defined based on their variance-covariance matrix.

3.4.2.3 Estimation for panel data

We chose the Poisson model and its variations (Negative Binomial) for panel data and treated the individual effects as fixed, as firstly proposed by Hausman *et al*. (1984) and applied by Gonzalez and Veloso (2007). The use of fixed effects seems to be the norm in the relevant economics literature (Gonzalez-Brambila & Veloso, 2007; He, et al., 2009; Kelchtermans & Veugelers, 2005), as the ability or talent of a researcher to produce and publish research is by intuition considered unique. The

individual effects should thus be able to be correlated with the explanatory variables so as to maintain such a theoretical imposition. This will be further discussed and relaxed in subsequent sections. In Negative Binomial fixed effects, as in the respective Poisson, the estimator conditions on the within-individual sum of the dependent variable observations requiring the existence of at least two periods of data and one non-zero period, giving $\sum_{t=1}^{T} y_{it} > 0$ (Cameron & Trivedi, 2009). This is translated into loss of observations concerning individuals that do not meet this prerequisite condition.

The model applied is presented below. The model is estimated using Conditional Maximum Likelihood (Hausman, et al., 1984).

$$E(y_{it}|X_{it}, Z_i, a_i) = \exp(\mu + \gamma Z_i + \beta X_{it} + \alpha_i + u_{it}) \quad (8)$$

y_{it} is the dependent variable, X_{it} represents the explanatory variables that vary within individuals and time, Z_i represents the time-invariant explanatory variables, α_i is the fixed effects of individuals and u_{it} are the statistical errors of the model.

Moreover, the following assumptions apply:

a) The explanatory variables that vary with time may be correlated with the individual effects or $E(X_{it}\alpha_{it}) \neq 0$

b) The time-invariant explanatory variables are not correlated with the individual effects or $E(Z_{it}\alpha_i) = 0$

c) Explanatory variables are not correlated with the errors or $E(Z_{it}u_{it}) = E(X_{it}u_{it}) = 0$

d) The expected value of the individual effects and the errors is zero or $E(u_{it})= E(\alpha_i) = 0$

e) The explanatory variables are not characterised by multicollinearity (see Table 3-20 & 3-21, Appendix)

As the FE estimator is based on mean differences it has the disadvantage that it is based only on within variation and does not capture the between dimension of the data as this is not identified in the FE estimation process. It is evident from Table 3-17 that the within variation is lower than the between variation for all dependent variables that we use and thus we expect loss of efficiency resulting in high standard errors. We also report random effects estimations that cover both within and between dimensions, for purely informational purposes, as we cover this possibility through multilevel modelling in subsequent sections.

The paradox with the fixed effects negative binomial model is that the estimates include coefficients for the time-invariant variables. This takes place due to the fact that the conditional likelihood used imposes the fixed effect transformation on the dispersion parameter and not the explanatory variables. Nevertheless, we neither report not attempt to infer on these estimates as He *et al* (2009) erroneously have done, since the coefficients are some sort of a by-product of the estimation process due to the inclusion of the Gamma function that accounts for overdispersion and do not represent interpretable results (Hausman, et al., 1984).

3.4.2.4 Dynamic panel data model

We also use the dynamic GMM to estimate a model in which the lagged research output indicators also serve as control variables. We do this bearing in mind that the fixed effect also accounts for contemporaneous correlation of the dependent variable (Cameron & Trivedi, 2015) and we seek for examining the existence of true-state dependence, in case potential serial correlation is not contingent solely on the fixed effect. It is important to underline that transformed dependent variables enter the equation as our data are positive and non-linear and do not match the model requirements. We demean data according to the scientific field and this also helps us not to include the corresponding dummy variable in the model as it would be integrated out in transformation. Based on the above, our model takes the form:

$$y_{it} = \beta_0 + \varphi y_{it-1} + \beta_1 X_{i,t-k} + \alpha_i + n_t + u_{it} \quad (9)$$

where y_{it} is the dependent variable, y_{it-1} is the lagged dependent variable, X_{it-k} represents the explanatory variables that vary within individuals and time, some of which are lagged or twice lagged with $k = 0,1,2$, n_t represents time dummies, α_i is the fixed effect of individuals and u_{it} are the statistical errors of the model.

3.4.2.5Multilevel modelling for panel data

In accounting for unobserved heterogeneity among scientific fields and researchers and taking into account the hierarchical character of the data, we run a multilevel model using these two levels to form the necessary hierarchy. Essentially, researchers are nested into scientific fields. The effect of the scientific field may vary, as well as the individual effect concerning researchers. We fit a Poisson model

and use publications or author-weighted publications as dependent variables. We thus use the following set-up for the model:

$$E\left(y_{ijt}\middle|X_{ijt},\xi_{jk},\theta_k\right)=\exp\left(\beta_0+\beta_1X_{ijt}+\theta_j+\xi_{ij}+u_{ijt}\right) \quad (10)$$

where y_{ijt} is the dependent variable, X_{ijt} represents the explanatory variables at the first level (individuals), θ_j, and ξ_{ij} provide for scientific field-specific and researcher-specific random effects respectively and u_{ijt} are the statistical errors of the model.

The model uses the assumption mentioned in earlier sections regarding homogeneity of the researchers in terms of their ability to produce research output. All other related factors can be heterogeneous but are random and do not relate to the explanatory variables. The fixed part of the model hinges on researchers' observed attributes.

3.4.3 Discussion on econometric challenges for the research funding-research output relationship

In modelling the effect of funding on research productivity we faced a number of problems that needed to be addressed. We discuss these challenges here in a separate section:

a. Simultaneity between research funding and research productivity

b. Heterogeneity of research output among different scientific fields

c. Dynamic nature of research productivity

Along the process of applying the methodology, more challenges of lesser magnitude arose, which were discussed and provided for, where necessary.

3.4.3.1 Simultaneity between research funding and research productivity

There is a propensity in the literature to consider research talent as a simultaneous cause of funding and output. Talent is widely dealt with using fixed effects and therefore fixed effect models have flourished since they also control for other forms of unobserved heterogeneity. To this end, we follow alternative models and estimation processes as described in the previous section. Essentially, our models address the potential simultaneity caused by the existence of a common latent variable causing both funding and research output success by including it in the fixed effect. Thus, since the fixed effect is integrated out of the model through demeaning in the static model and first differences transformation in the dynamic case, it is allowed to be correlated with the regressors without interferring in the consistency of the estimation process, capturing at the same time potential correlation of research talent with research funding and research output. The fixed effect in panel data is also suitable for incorporating the existence of unobserved heterogeneity in the model, without the incidental parameters problem, as well as the computational burden entailed in estimating each fixed effect separately as in the case of cross section with dummy variables for each individual. This method is widely used in the literature and has significant advantages. We run the Hausman test to that respect in order to have a formal answer as to which estimator should be preferred (Hausman, 1978). The Hausman test provides a statistic to test the null hypothesis of an efficient and consistent estimator, represented by the random

effects estimator, and the alternative hypothesis of a consistent but not efficient estimator which is the fixed effects estimator. Thus rejecting the null hypothesis would suggest that the estimates from random and fixed effects differ systematically and the fixed effects should be preferred due to its consistency. The tests for our model show that in almost every case the fixed effects estimator must be preferred to random effects (See Table 3-18, Appendix).

The Hausman test provides useful guidance for choosing between the trade-off of consistency of the fixed effect against increased efficiency of the random effect but it does not offset the limitations that the former method conveys. Firstly, it cannot estimate the time-invariant variables as their within-variance is zero. Furthermore, it does not take into account the between variance of the data, rendering the relevant estimators much less efficient (Hausman & Taylor, 1981).

In our dataset there is indeed high between variance which cannot be effortlessly neglected (See Table 3-17, Appendix). In order to take between variance into account we supplemented the analysis with the random effects approach. It involves the estimation of random effects Negative Binomial or Poisson models with the inclusion of time-invariant variables with aim to exploit fully the information provided by both the within and between-variance of the data.

It is noted that for random effects to have validity, an alternative assumption of observing a sample of fairly homogeneous individuals (as implied by an assumed common threshold level of sophistication) is necessary as this would render the effect close to being random (Arora & Gambardella, 2005). This means that differences in research productivity among them depend on control variables and a

random effect which is independent of the explanatory variables. This assumption is more plausible for research output indicators extracted from publications and journal impact factors. In the case of citations an asymmetrically high number may indicate a ground-breaking contribution to knowledge.

Also, the fact that researchers from different scientific fields are included in the dataset raises the issue that the expected level of research output may differ among these fields (even though significantly captured by fixed effects which impose in an indirect manner the inclusion of individual specific dummies). This problem is mitigated through demeaning the observations by the means of each department, bringing them at a weighted level, fairly comparable. Both methods tackle the zero observations problem as the former incorporates them in the Poisson or Negative Binomial estimation processes and the latter demeans them out of the model.

However, the coefficients cannot be easily interpreted in a meaningful way. This does not apply only for demeaned data but for all fixed effects models in general, in the sense that the marginal effect (semi-elasticity) includes the fixed effect. The only alternatives to get meaningful marginal effects would be to estimate the fixed effect for each individual and obtain marginal effects for any individual of interest or calculate the average fixed effect for the whole population. The other alternative is to interpret and discuss semi-elasticities since the coefficients can be perceived as such in the fixed effect Poisson and Negative Binomial models.

The other way to account for both between-variance and the difference among departments is to use multilevel modelling. Still, its rationale violates the theoretical grounds of the relationship between research funding and output as described in

the fixed effects discussion above. Bearing in mind the potential shortcomings, this alternative approach is pursued in a subsequent section in an effort, partially, to disentangle from the traditional approach of fixed effects.

Moreover, the fixed effect approach does not consider the possibility that research productivity follows a dynamic process and, instead, provides for autocorrelation through the fixed effect for each individual rather than through a true state-dependence rationale. The Negative Binomial model provides for autocorrelation through the dispersion parameter. The Arellano-Bond estimator facilitates treatment of the possibility of autocorrelation in the dependent variable via a dynamic model and thus a section is focused on exploring and applying this method.

3.4.3.2 Unobserved heterogeneity among individuals and scientific fields

In order to facilitate comparison among heterogeneous fields we ameliorated the methodology by including a multilevel modelling analysis. To that end, we estimated a multilevel model considering the clustered nature of our data, having scientific fields and individuals as separate levels for analysis. The model allows for heteroskedasticity-robust errors using White's sandwich estimator (White, 1980), but potential endogeneity of the regressors is not accounted for. Bell and Jones (2014) support the use of multilevel modelling proposing a solution for the endogeneity problem: to find the causal source and model it explicitly rather than integrate it out of the model using deviations from the means-as in fixed effects.

We speculate again that the most likely source of endogeneity is the simultaneity between research funding and research output. This calls for treatment of a latent

variable that causes both the former and latter variables of interest. We will see below what assumptions are entailed to have a plausible story for the use of multilevel modelling.

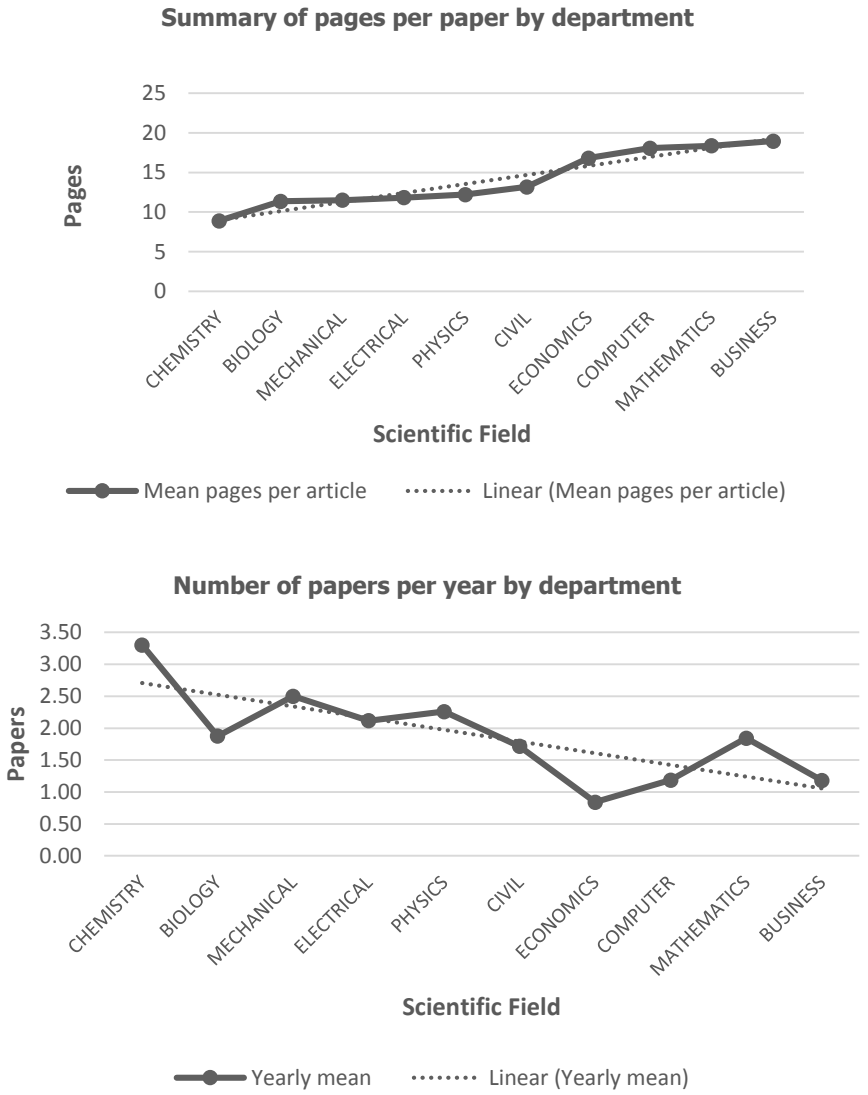
The multilevel modelling approach allows for distinct analysis for each scientific field through the inclusion of a random intercept for each level. In cases where a need arises for modelling the level variables more explicitly, random slopes and random coefficients can be utilised. The outcome is that the between dimension of data is also used in the estimation process and thus the estimator becomes more efficient. Also, it allows for providing for factors, such as scientific field, that may cause the results to vary in an otherwise unexplained manner. For instance, the average number of publications in Physics is higher than that of Business. Contrariwise, in Business, the average number of pages per journal article is higher. The same applies for the average journal impact factor or the citations. The following table presents the differences in publications of researchers by department.

Table 3-5: Summary of Publications per Researcher by Department

Department	3-year mean	Yearly mean	Standard Deviation	Frequency
BIOLOGY	5.63	1.88	4.16	35
BUSINESS	3.55	1.18	2.79	87
CHEMISTRY	9.91	3.30	8.31	56
CIVIL	5.15	1.72	5.45	47
COMPUTER	3.56	1.19	3.06	90
ECONOMICS	2.52	0.84	2.17	77
ELECTRICAL	6.35	2.12	4.35	51
MATHEMATICS	5.53	1.84	4.39	105
MECHANICAL	7.50	2.50	5.67	46
PHYSICS	6.78	2.26	4.92	46
Total	**5.28**	**1.76**	**4.98**	**640**

The following diagram also exhibits the inverse relationship between the number of publications and average pages per article, which shows once more that there are different publishing patterns among fields.

Figure 3:1: Juxtaposition of publications and pages output as per scientific field



It is challenging to define the determinants of differences in publications, let alone when there are differences before we even consider anything else but the scientific field as a determining factor. A more structured model is needed to account for these characteristics and multilevel modelling can serve as such.

Multilevel models estimation produces both fixed and random components. The fixed components are equivalent to the traditional coefficients that result from

regular estimation. The random coefficients are not directly estimated but they are described using the variance-covariance information available for the related variables. The random components resulting from estimation can be in the form of intercepts, slopes or both, if one needs more analytical information for the variable of interest. We are not interested in finding differences among departments or individuals as we are aware that there are such. The aim is to provide for such differences so as to have unbiased estimates for the focal variables, that is, the various funding schemes from which the researchers have secured grants.

However, multilevel modelling carries a number of rather strong assumptions that need to be further discussed. The first assumption is that the effects of the clustered levels is random. In our case, this means that differences in publishing research amongst scientific fields can be department-specific or individual-specific but are randomly distributed among departments and individuals. This is a strong assumption and comes in conflict with the theoretical background of the model. Even in the case where the assumption that talent for research is randomly distributed among individuals is valid, it still causes each individual's performance in publishing research or securing funding in a deterministic manner. The only way for this assumption to have validity is through the existence of a threshold level. That is, to consider that the level of sophistication required to carry out scientific research is high and that all researchers are equipped with such after reaching a threshold level. Any differences from that level and up are assumed non-dependent on individual effects and can thus be explained by controls included in the model (funding, collaboration, experience, resources, etc) and other random factors which

are not related to the regressors, so that the random effect stands. A supporting argument could be that the generation of ideas for research, which is the cornerstone of research output, is a product of a random process. It may be facilitated by means of the control variables mentioned above or as a by-product of other related random activities such as a researcher discussing with a colleague. Lucas (2008) and Alvarez *et al* (2013) support this rationale for the generation and diffusion of ideas in the business sector.

In other words, it is assumed that a researcher, after the completion of a minimum of academic training (i.e. PhD), can write publications and research funding proposals. The quantity and quality of this output is dependent much more on the background factors. In this context, talent is responsible for reaching this minimum threshold but not for the variance in the performance of researchers in producing publications or securing research funding. In rendering the assumption more plausible for our chapter, it can also be asserted that research talent is responsible for outstanding contributions to science, worthy of Nobel-equivalent prizes, which is not the type of research output we consider in the present paper.

Another shortcoming of multilevel modelling is the assumption of normality. Research output measures are in the form of counts or- in any case- positive numbers and are not normally distributed. Taking logs of variables somewhat moderates this requirement but results however in the loss of all zero observations. This shortcoming prevents us from modelling the behaviour of researchers not publishing at all in a specific time interval. We also model publications using the Poisson setting for the representation of count data, which conveys the

equidispersion assumption, not evident in our data. We use bootstrapped robust errors to overcome this problem and we get results that are acceptable for inference. Even though heteroskedasticity cannot be modelled explicitly through this method, the estimators are consistent albeit less efficient.

The above analysis underlines the caveats that multilevel models carry with respect to their restrictive assumptions. It should be highlighted that the different scientific fields are alternatively accounted for through the transformation of research output variables found in previous analysis. This method conveys the advantage of bringing all dependent variables to a comparable level, irrespective of scientific field. It moreover transforms the data to be near normality exploiting the properties of linear estimation methods. The problem is that the results from the estimation process are hard to interpret as they are in deviation form and the fixed effects setting complicates the process yet further. They are however largely in line with the underlying theory and help incorporate the zero observations in the analysis. As no methodological approach is a panacea, we chose to use this method as well to tackle the shortcomings of the model.

3.4.3.3 Dynamic nature of research productivity

The case where researchers who produce well in one time period are likely to produce well in subsequent periods is described by the true state-dependence regime. This causes the dependent variable to be autocorrelated and dictates the inclusion of a lagged dependent variable in the model. However, either demeaning or log-transformation are necessary as there are no available dynamic panel data

models that deal with count data, apart from Windmeijer (2008) and Cameron and Trivedi (2010), who nevertheless propose no alternative for dealing with the endogeneity of the lagged dependent variable. We choose demeaning as we get to keep all zero observations –albeit demeaned. On the other hand, Arellano and Bond (1991) propose an estimator which provides for endogeneity of the lagged dependent variable. The estimator uses second and higher order lags of the dependent variable as instruments for the lagged dependent variable and also allows the same approach for other potentially endogenous explanatory variables. It is also suitable for predetermined variables as these can be instrumented via all their available lags and this fits for the funding variables in our model. We use this estimator and two of its variations to estimate the dynamic research productivity model.

After reviewing the econometric challenges and explained our approach in handling them, we now proceed to review the findings.

3.5 Findings

Firstly, we use the cross-section dataset of the publications and estimate the effect of funding on the quality of the articles. The quality is measured through citations, journal impact factor, and pages of the articles and composite indicators thereof. Then we proceed with the panel data setting and describe the results of the relevant estimation processes, discussing the existence and ways of tackling shortcomings.

3.5.1 Cross-section analysis

We commence our analysis with count data regressions run for each department separately. In later sections we pool all data together and either transform them to become comparable or use multilevel modelling to account for differences among departments. We use Poisson or Negative Binomial for positive outcomes even for cases that they are not integers as it is the optimal option compared to the log-transformation alternative (Santos Silva and Tenreyro, 2006; Wooldridge, 2002, pp. 645-646).

Table 3-6: Negative Binomial Regressions for the effect of funding on Year-Weighted Citations per department

Variables/ Department	Biology	Business	Chemistry	Computer	Civil	Economics	Electrical	Maths	Mech. Eng.	Physics
					Coefficients/Standard errors					
RPF	0.252	1.519***	0.238***	-0.200	0.146	-	0.047	0.215	-0.142	0.021
	(0.211)	(0.506)	(0.070)	(0.393)	(0.112)	-	(0.191)	(0.328)	(0.141)	(0.085)
EU	0.071	14.680***	-0.083	-0.155	0.091	1.953***	0.022	-1.593***	0.206*	0.112
	(0.207)	(1.270)	(0.100)	(0.189)	(0.094)	(0.453)	(0.208)	(0.466)	(0.111)	(0.157)
Internal	0.110	0.126	0.019	-0.518	-0.493	-	1.115	0.703***	-0.296*	0.028
	(0.226)	(0.221)	(0.229)	(0.352)	(0.354)	-	(0.872)	(0.142)	(0.154)	(0.273)
Other funding	0.155***	-16.971***	0.033	0.392**	0.075	-0.109	0.010	0.165*	0.081**	-0.007
	(0.038)	(1.087)	(0.063)	(0.190)	(0.064)	(0.243)	(0.066)	(0.092)	(0.036)	(0.059)
Female	-3.312***	-0.404**	-29.675***	-13.669***	-0.114	-0.888***	0.975**	4.031***	-29.347***	24.813***
	(1.202)	(0.181)	(4.004)	(7.485)	(0.293)	(0.308)	(0.430)	(1.178)	(6.050)	(5.195)
Education1	-7.122***	0.066	0.311	19.977***	3.939***	-0.171	0.350*	0.181**	-0.444	2.498***
	(1.502)	(0.351)	(0.214)	(12.016)	(0.562)	(0.267)	(0.180)	(0.090)	(0.406)	(0.667)
Experience	-1.912***	0.003	-1.559***	-0.938***	-1.221***	0.021*	-1.650***	-1.094***	-1.797***	-1.527***
	(0.396)	(0.016)	(0.208)	(0.500)	(0.288)	(0.013)	(0.400)	(0.287)	(0.369)	(0.331)
Logged references	0.307***	0.612***	0.536***	-0.006	1.139***	0.633**	0.399**	0.132	0.689***	0.488***
	(0.074)	(0.158)	(0.177)	(0.325)	(0.185)	(0.266)	(0.165)	(0.177)	(0.141)	(0.080)
Localcoauth	0.016	-0.239	-0.026	-0.092**	-0.041	-0.393	0.130	0.080*	0.029	-0.042
	(0.023)	(0.254)	(0.058)	(0.037)	(0.038)	(0.246)	(0.095)	(0.046)	(0.036)	(0.047)
Intlcoauth	-0.000	0.045	0.028	0.010	0.039	0.378***	0.117	0.165**	0.092***	0.107***
	(0.021)	(0.109)	(0.038)	(0.053)	(0.046)	(0.126)	(0.074)	(0.076)	(0.027)	(0.012)
lnalpha	-0.935***	-3.125**	-1.259***	-3.357***	-1.400***	-2.324***	-0.344*	-2.225***	-0.826***	-1.959***
	(0.171)	(1.510)	(0.317)	(0.922)	(0.280)	(0.859)	(0.193)	(0.682)	(0.305)	(0.428)
Wald X^2	242.40	.	295.39	998.51	196.50	677.18	115.71	1,124.30	242.71	802.71
Log-likelihood	-310.87	-147.30	-531.16	-252.52	-168.06	-92.96	-446.81	-346.43	-397.78	-297.41
Observations (N)	156	112	306	145	139	90	247	280	239	163

Note: *** p<0.01, ** p<0.05, * p<0.1, Bootstrapped standard errors for all estimates, Individual dummy variables estimated but not reported. Gaps represent variables that could not be included due to non-convergence of the maximum likelihood estimation process or insufficient variation in the data.

The Table above shows the negative binomial regression results for each department. We observe a variety of outcomes with respect to the explanatory variables of interest. RPF funding seems to be statistically significant, affecting citations of Business and Chemistry faculty papers positively. In Economics the variation is insufficient for RPF and internal funding and thus we could not obtain estimates for these variables. With the exception of Computer Science and Mechanical Engineering, for the other disciplines the association is positive albeit not statistically significant.

EU funding is positive and statistically significant only for enhancing the citations of Business and Economics papers and significant at the 10% level for Mechanical Engineering. For the remaining fields, the funding coming from the EU is not important to explain variation in citations. For mathematics the sign of the association is negative and this may be due to that, as Mathematics is principally a theoretical field, the involvement in an EU collaborative project rather compromises the research interests of the researchers. The nature of such projects is close to applied research and only remotely related to the core research interests of mathematicians, thereby leaving little chance to produce a highly cited theoretical paper. This theoretical assertion is further supported if one observes the internal funding influence on the citations of papers. Only in the field of Mathematics is there evidence for a statistically significant and positive relationship between internal funding and subsequent citations. This corroborates the rationale that, in theoretical fields, researchers need only essential funding to be able to produce good quality research. The involvement of researchers from these fields in funded collaborative research projects is probably due to the requirement from their universities for submitting proposals for funding and participate in such consortia. Other funding is more concrete since it has a positive influence on

four fields: Biology, Computer Science, Mechanical Engineering and Mathematics to a lesser extent of significance. In Civil Engineering, Electrical Engineering and Physics no statistically significant impact is visible from the types of funding included in the model. Here we have to repeat the limitation of using the composite indicator of year-weighted citations in combination with the negative binomial model, as marginal effects are not meaningful. We cannot infer on the difference in actual citations if one receives a grant from the sources we have identified. Instead, the statistical significance and the direction of the sign are the outcomes of interest given this limitation, although we refer to semi-elasticities conditional on the fixed effect.

Following from the previous analysis for year-weighted citations, we extend the indicator to accommodate a normalisation based on the number of authors of a paper. Since we have one single researcher of interest in each publication, this composite indicator makes intuitive sense as it isolates the share of citations of that researcher, assuming that all authors contribute equally to a publication. The results for the RPF, EU and internal funding are identical to those of the previous analysis so we will not elaborate further.

Table 3-7: Negative Binomial Regressions for the effect of funding on Year-Author-Weighted Citations per department

Variables/ Department	Biology	Business	Chemistry	Computer	Civil	Economics	Electrical	Maths	Mech. Eng.	Physics
					Coefficients/Standard errors					
RPF	0.206	0.991***	0.237**	-0.435	0.129	-	-0.120	0.308	-0.148	0.037
	(0.167)	(0.199)	(0.096)	(0.336)	(0.131)	-	(0.197)	(0.293)	(0.099)	(0.072)
EU	0.214	-0.691	-0.105	-0.073	-0.024	1.628***	0.005	-1.672***	0.117	0.144
	(0.148)	(0.487)	(0.229)	(0.174)	(0.172)	(0.460)	(0.164)	(0.563)	(0.153)	(0.100)
Internal	0.373*	0.403	0.090	-0.217	-0.859**	-	0.997	0.645***	-0.768***	-0.105
	(0.218)	(0.435)	(0.122)	(0.402)	(0.346)	-	(0.652)	(0.207)	(0.262)	(0.276)
Other funding	0.022	-	-0.124*	0.254	0.039	-0.093	-0.037	0.070	0.096**	-0.099
	(0.047)	-	(0.067)	(0.176)	(0.081)	(0.312)	(0.061)	(0.089)	(0.048)	(0.072)
Female	-3.042***	0.869	-27.843***	-13.145*	-1.248***	-0.783	0.319	3.175*	-32.612***	0.747
	(1.108)	(6.857)	(5.352)	(7.434)	(0.463)	(0.652)	(0.837)	(1.698)	(6.397)	(0.984)
Education1	-6.420***	2.495	0.220	19.807*	4.955***	-0.795**	0.096	0.235	0.007	0.015
	(1.495)	(12.083)	(0.323)	(11.712)	(1.145)	(0.338)	(0.345)	(0.397)	(0.308)	(0.292)
Experience	-1.787***	-0.099	-1.465***	-0.950*	-1.481***	0.034	-1.838***	-0.879**	-2.004***	-0.042
	(0.369)	(0.525)	(0.259)	(0.489)	(0.333)	(0.021)	(0.355)	(0.404)	(0.394)	(0.058)
Logged references	0.630***	0.486***	0.810***	-0.592**	1.684***	0.916**	0.425***	0.085	1.063***	0.851***
	(0.162)	(0.183)	(0.181)	(0.275)	(0.227)	(0.376)	(0.158)	(0.156)	(0.230)	(0.100)
lnalpha	-16.205***	-16.459***	-16.244***	-16.406***	-14.595	-1.929**	-1.403***	-31.849	-1.744***	-15.412***
	(0.486)	(0.160)	(0.148)	(0.213)	(12.976)	(0.793)	(0.399)	-	(0.516)	(0.866)
Wald X^2	194.07	.	340.39	2,275.26	208.24	850.36	109.83	818.7	232.19	249.2
Log-likelihood	-140.79	-73.84	-258.34	-132.31	-76.93	-67.78	-254.33	-202.97	-194.30	-151.80
Observations (N)	156	112	306	145	139	90	247	280	239	163

Notes: *** p<0.01, ** p<0.05, * p<0.1, Cluster-robust standard errors for all estimates in parentheses, Gaps represent variables that could not be included due to non-convergence of the maximum likelihood estimation process.

For other funding the results are different since it is now significant only for citations in Mechanical Engineering. One possible explanation may be that other funding requires extensive collaboration and the normalisation per author has reduced the weighted citations asymmetrically. Also, this collaboration is highly likely to be international, as national funding is accounted for through RPF and internal funding. This can be tested by looking at Tables 3-20 and 3-21 (Appendix), which shows correlation coefficients of all explanatory variables used in the model. Indeed, the correlation coefficient of 0.52 between other funding and international collaboration supports the existence of such a pattern.

In what follows, we used article pages as the quality indicator of research output. The length of research output is widely considered as an indication of productivity. We have to underline however that this is not entirely objective, since as opposed to citation-related indicators, causality may run both ways in this case. For example, an upper limit for the number of pages may be a prerequisite of a specific journal, so an author may be forced to compress their original research output. Or one could state that an impactful contribution to knowledge may be succinct enough to fit in a few pages. But usually the main argument is that more pages are likely to increase the probability to receive citations, as the citing author has more material available to find common grounds with the research described in a publication. In any case, due to these conflicting arguments that can be debated, all inference and analysis are carried out within a modest context.

The first noteworthy result is that in Physics and Chemistry there seems to be an association between RPF funding and the number of pages of an article. It would not be an exaggeration to state that this is revealing, since in these two fields it is accustomed to submit quite concise papers. Thus a paper with more pages than usual may be a result of prerequisite deliverables submitted to the RPF as part of the researcher obligations for receiving the grant. These are by design lengthier than what would have been otherwise submitted, would the researchers rely on own funding to carry out their research. The same story may apply for Business where the effect of RPF funding on article pages is negative. It is possible that a type of effect other than the one described for Physics and Chemistry is responsible for this association. This may reside in fields in which publications are lengthier than others, as is the case with Business which is the top with an average of nearly 20 pages per article (Figure 3:1). The reverse effect of funding on article pages may emanate from bureaucratic burden connected with meeting the requirements of a funding agency, in this case RPF, sacrifising time and effort otherwise devoted to produce research output. Overall, we could state that a self-selection mechanism may be in place which is not observed. Whether researchers submit a concise or lengthy journal article is, in the end, their choice and this effect is latent.

Table 3-8: Negative Binomial Regressions for the effect of funding on journal article pages per scientific field

Variables/ Department	Biology	Business	Chemistry	Computer	Civil	Economics	Electrical	Maths	Mech. Eng.	Physics
					Coefficients/Standard errors					
RPF	0.156**	-0.336**	-0.030	-0.107	-0.001	0.750	-0.140**	0.024	0.065	0.078**
	(0.037)	(0.129)	(0.058)	(0.107)	(0.049)	(0.549)	(0.054)	(0.086)	(0.042)	(0.031)
EU	-0.109	0.628**	0.063	-0.003	0.116**	0.031	0.057	0.564**	-0.093**	-0.048
	(0.068)	(0.133)	(0.093)	(0.053)	(0.033)	(0.088)	(0.045)	(0.175)	(0.044)	(0.049)
Internal	0.064	-0.533**	-0.011	0.048	-0.077	-	0.122	0.232***	0.051	-0.181
	(0.075)	(0.086)	(0.059)	(0.111)	(0.079)	-	(0.146)	(0.118)	(0.080)	(0.127)
Other funding	0.008	-0.148	0.005	0.185**	-0.049**	-0.327***	0.047**	0.056	-0.030**	-0.028
	(0.014)	(0.155)	(0.030)	(0.074)	(0.023)	(0.171)	(0.019)	(0.066)	(0.009)	(0.026)
Female	0.331	-4.915**	-0.393	3.210	-0.337**	-1.651	0.059	-0.621	1.851	3.472***
	(0.330)	(1.222)	(1.271)	(2.841)	(0.106)	(3.662)	(0.112)	(0.473)	(1.265)	(1.853)
Education1	0.708***	-8.364**	0.067***	-4.842	-0.226	-0.525**	0.190**	0.154**	-0.074	2.049**
	(0.423)	(2.121)	(0.037)	(4.486)	(0.235)	(0.114)	(0.089)	(0.054)	(0.098)	(0.206)
Experience	0.184***	0.341**	-0.007	0.187	0.280**	0.091	0.068	0.119	0.144***	-0.266**
	(0.105)	(0.091)	(0.064)	(0.185)	(0.109)	(0.215)	(0.086)	(0.115)	(0.082)	(0.116)
Logged references	-0.009	-0.228**	-0.004	0.007	-0.029	0.122	-0.053	-0.100**	-0.017	0.044**
	(0.008)	(0.076)	(0.013)	(0.037)	(0.037)	(0.109)	(0.035)	(0.039)	(0.019)	(0.017)
Localcoauth	0.009	-0.150**	0.031**	0.028	0.007	0.194**	0.012***	-0.027	0.003	0.049**
	(0.013)	(0.060)	(0.013)	(0.019)	(0.009)	(0.090)	(0.007)	(0.043)	(0.014)	(0.009)
Intlcoauth	-2.962**	-2.960**	-3.475**	-2.359**	-3.053**	-2.532**	-2.774**	-2.125**	-2.670**	-1.941**
	(0.413)	(0.373)	(0.664)	(0.220)	(0.192)	(0.491)	(0.330)	(0.141)	(0.345)	(0.410)
lnalpha	0.156**	-0.336**	-0.030	-0.107	-0.0001	0.750	-0.140**	0.024	0.065	0.078**
	(0.037)	(0.129)	(0.058)	(0.107)	(0.049)	(0.549)	(0.054)	(0.086)	(0.042)	(0.031)
Observations (N)	164	113	306	145	140	90	247	280	240	163
Log-likelihood	-445.76	-366.67	-775.05	-413.93	-460.56	-286.90	-699.65	-929.08	-647.22	-487.13

*Notes: *** p<0.01, ** p<0.05, * p<0.1, Cluster-robust standard errors for all estimates in parentheses, Gaps represent variables that could not be included due to non-convergence of the maximum likelihood estimation process. No measure of goodness of fit is reported since the value of Wald X^2 test cannot be obtained due to a high number of explanatory variables compared to the clusters.*

We also run regressions with journal impact factor (JIF) of an article as the left hand side variable, as well as composite indicators based on JIF. Nevertheless, we do not rely much of our inference on these estimates for a number of reasons. First, the JIF is a quality index for a journal not for a specific article. Although publishing in a high JIF journal is a good predictor for future citations of an article, it cannot be evaluated strictly as such at the time of publication. Second, the nature of causality is of potential concern for some of the variables of interest. For example, there are types of EU funding such as European Research Council grants which are highly prestigious and can contribute in having a paper accepted for publication. Thus the effect of the actual utilisation of funding cannot be straightforwardly distinguished from the funding-prestige effect on publishing in top JIF journals. Therefore, we will not detail on the findings but we keep the tables in the appendix for informational purposes and also elaborate further for JIF related indicators in the panel dataset.

Instead, we will attempt to return to a setting with the citations of articles as dependent variable but in a way that can provide meaning in terms of marginal effects. We thus estimate the model separately for each year and we include dummy variables for each scientific field to provide for differences amongst them. The findings hardly demonstrate any statistical significance for the funding-related explanatory variables. Scientific fields are, as expected, pivotal determinants of citations. The results suggest that other funding and RPF seem to affect the quality outreach of an article to peers only sporadically. International co-authorship exhibits high significance and positive correlation with the citations produced for all years except 2010. This is plausible in the sense that collaboration with international

coauthors can expand the outreach of an article to a wider range of peers through personal networking and increase the probability for additional citations compared to articles with local or no co-authorship.

Table 3-9: Negative Binomial Regressions for the effect of funding on Citations (per publication year)

Research output indicators / Variables	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
	Coefficients/Standard errors					
RPF	0.155	0.116**	0.094	0.059	-0.067	-0.146
	(0.162)	(0.055)	(0.103)	(0.126)	(0.124)	(0.244)
EU	0.018	-0.114*	0.027	-0.026	-0.097	0.104
	(0.133)	(0.062)	(0.128)	(0.179)	(0.186)	(0.204)
Internal	0.076	0.029	0.214	-0.017	-0.115	0.075
	(0.128)	(0.167)	(0.333)	(0.177)	(0.222)	(0.417)
Other funding	0.022	0.048	0.132**	0.018	-0.029	0.149*
	(0.093)	(0.046)	(0.065)	(0.038)	(0.060)	(0.082)
Female	0.141	0.156	-2.697***	-10.793***	-0.576***	-10.012***
	(0.198)	(0.152)	(0.170)	(0.757)	(0.211)	(0.935)
Education	-0.220	-0.053	-1.447***	0.260*	0.110	0.152
	(0.246)	(0.115)	(0.183)	(0.148)	(0.361)	(0.606)
Experience	0.117***	0.006	0.117***	1.565***	-0.079**	-1.175***
	(0.017)	(0.011)	(0.037)	(0.114)	(0.038)	(0.104)
Localcoauth	-0.047	0.070***	0.026	0.026	-0.075	-0.108*
	(0.046)	(0.022)	(0.041)	(0.056)	(0.069)	(0.062)
Intlcoauth	0.050***	0.099***	-0.003	0.096*	0.089**	0.123*
	(0.015)	(0.017)	(0.016)	(0.052)	(0.041)	(0.065)
Logged-references	0.502***	0.477***	0.417***	0.567***	0.465***	0.460**
	(0.178)	(0.125)	(0.148)	(0.200)	(0.168)	(0.233)
lnalpha	-1.080***	-0.420***	-1.335***	-1.279***	-1.431***	-0.613*
	(0.195)	(0.120)	(0.223)	(0.202)	(0.256)	(0.331)
Observations (N)	262	326	321	285	288	342
Log-likelihood	-784.04	-1109.65	-829.75	-674.31	-501.34	-297.17
Wald X^2 test	n/a	321.60	n/a	n/a	n/a	n/a

Notes: *** p<0.01, ** p<0.05, * p<0.1, Cluster-robust standard errors in parentheses, We used negative binomial to estimate the models of wcitations and wfcitations and OLS for the other weighted variables. Individual-dummies are included as explanatory variables but are not reported. No measure of goodness of fit is reported for most years since the value of Wald X^2 test cannot be obtained due to a high number of explanatory variables compared to the clusters.

We pool all data together irrespective of scientific field to run regressions with all available observations and use references to capture the size of each scientific field. We include dummies for each individual to provide for unobserved heterogeneity, even though the concern for the incidental parameter problem, as discussed before, remains. We also used cluster-robust errors for all versions of the model estimation. We used negative binomial for wcitations and wfcitations which are in count form and OLS for the other weighted variables.

The fundamental result originating from the pooled regressions is that other funding is statistically significant for the core research output indicators, whereas for the other types of funding this does not appear to be the case. This fact is surprising since mainstream funding was expected to play a significant role in determining research productivity. The argument of Jacob and Legfren (2011) whereby there exists a market for research funding, which enables researchers to apply in alternative funding schemes should they fail in one or more attempts in core funding schemes may be the answer to this paradox. As the results indicate, researchers go beyond the five core categories of funding we have identified and those who do secure funding from other sources seem to utilise it more productively than holders of core grants.

Defining a mechanism by which this market for funding process may work in Cyprus could shed light as to why this happens. If a researcher writes a proposal for funding from the RPF it usually requires a full-time commitment of time and resources. In case funding comes from the EU, the effort may vary from very low to very high and it is proportional to the involvement of the researcher in the project. In the case

of coordination of an EU funded project the effort is very high where in case of simple participation the effort may be limited to providing basic information to the coordinator of the proposal. For other funding, we assume that the time and resources needed are minimum. This type of funding usually occurs as a result of international collaboration since no other research funding sources exist in Cyprus. Therefore strategic cooperation with international counterparts may bring funding for a researcher and this may take place either in parallel to applying for RPF or EU, or as a substitute choice for not getting funding from these two core funding schemes. In case that other funding comes from these sources it is plausible that it can produce more and better research output than the mainstream grants since Cyprus is a weak country in terms of research capacity as opposed to its most frequent international collaborators in research (UK, Germany, Greece, USA). Therefore the option for researchers may be to engage in strategic collaborations with strong counterparts and harvest the fruits of jointly produced research output.

Table 3-10: Regressions for the effect of funding on research output indicators

Research output indicators	wcitations	wfcitations	JIFdeviation	avjifauth	avjifap	devpages
Variables	**Coefficients/Standard errors**					
RPF	0.074	0.060	0.046	0.004	-0.914	0.027
	(0.051)	(0.061)	(0.061)	(0.035)	(1.023)	(0.023)
EU	0.041	0.015	-0.038	-0.011	-1.099	-0.011
	(0.058)	(0.081)	(0.072)	(0.043)	(0.764)	(0.024)
Internal	0.107	0.085	0.234	0.069	0.221	0.042
	(0.109)	(0.103)	(0.169)	(0.052)	(0.609)	(0.048)
Other funding	0.062***	.	0.146***	0.058***	0.644**	-0.008
	(0.020)	.	(0.055)	(0.019)	(0.322)	(0.017)
Female	-9.153***	-9.354***	0.224	-0.094	-3.271	0.283
	(0.689)	(0.724)	(0.736)	(0.448)	(8.511)	(0.240)
Education	0.203	0.204*	-0.199	-0.123*	-2.006*	0.032
	(0.145)	(0.113)	(0.146)	(0.071)	(1.045)	(0.035)
Experience	-1.494***	-1.537***	-0.015	-0.002	-0.230	0.121***
	(0.108)	(0.114)	(0.118)	(0.070)	(1.349)	(0.038)
Localcoauth	0.033	.	-0.004	.	.	-0.010
	(0.027)	.	(0.017)	.	.	(0.007)
Intlcoauth	0.074***	.	0.041	.	.	0.026*
	(0.017)	.	(0.030)	.	.	(0.015)
Logged-references	0.535***	0.713***	.	.	.	.
	(0.087)	(0.132)	.	.	.	.
lnalpha	-0.884***	-2.048***	.	.	.	.
	(0.132)	(0.409)	.	.	.	.
Observations (N)	1877	1877	1829	1829	1829	1888
Wald X^2 / R-squared	n/a	n/a	0.349	0.327	0.173	0.311

Notes: *** p<0.01, ** p<0.05, * p<0.1, Cluster-robust standard errors in parentheses, We used negative binomial to estimate the models of wcitations and wfcitations and OLS for the other weighted variables. Individual and time dummies included but not reported. No measure of goodness of fit is reported for wcitations and wfcitations estimates since the value of Wald X^2 test cannot be obtained due to a high number of explanatory variables compared to the clusters.

In what follows, we treat the different scientific fields using multilevel modelling. We do so to handle the differences in publication and citation patterns among different disciplines more formally as explained in the model description. The model

is estimated with use of Bayesian estimation using the Markov chain Monte Carlo (MCMC) method (Browne 2015). It is necessary to make a note here regarding Bayesian statistics. This is the sole place of the present thesis this statistical inference rationale is applied and we use it as a vehicle to accommodate the multilevel complexity of the model and the count nature of the data. Elaborating on Bayesian statistics goes far beyond the scope of the thesis. For a detailed review of the rationale and use of Bayesian statistics in multilevel modelling through MCMC see Browne (2015).

Table 3-11: Poisson response multilevel model for quality of research output with department and individual random intercepts

Variables	**Year-weighted citations**		**Year-weighted fractional citations**		**Citations per page**	
	coef.	se.	coef.	se.	coef.	se.
RPF	0.04***	0.022	0.09**	0.044	0.14***	0.038
EU	0.001	0.025	-0.05	0.052	0.001	0.041
NSF	0.05	0.039	-0.11	0.093	0.06*	0.05
GGET	-0.01	0.19	0.17	0.429	-0.09	0.277
Other	0.06***	0.008	0.1***	0.016	0.06***	0.012
Internal	0.09**	0.045	0.04	0.089	0.15*	0.085
references	0.001***	0.0002	0.01***	0.0005	0.001***	0.0004
pages	0.001***	0.002	-0.02***	0.004	.	0.056
First-authored	0.07*	0.04	0.04	0.062	-0.01	0.003
jif5	0.07***	0.002	0.05***	0.004	0.09***	0.007
Intlcoauth	0.05***	0.003	-0.07***	0.009	0.05***	0.008
Localcoauth	0.05***	0.006	-0.24***	0.024	0.07***	0.099
Degree	-0.34***	0.058	-0.27**	0.098	-0.2***	0.087
Phd	0.26***	0.045	0.13**	0.083	0.09	0.051
master	0.19***	0.029	-0.17***	0.066	0.13***	0.003
experience	-0.01***	0.002	-0.02***	0.004	-0.04***	0.065
Female	0.29***	0.043	-0.06	0.086	0.06	0.064
Observations	1811		1811		1811	
Bayesian DIC	8209.03		3659.04		3912.98	

Notes: *** p<0.01, ** p<0.05, * p<0.1, The estimation process was carried out using the Markov chain Monte Carlo (MCMC) method. Random effects for department and individuals were estimated but not reported. Time dummy variables were estimated but not reported. Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit of the model.

We notice that RPF funding is statistically significant and affects positively all citations-related research output indicators. The same does not apply for other funding sources such as the EU. Therefore we cannot charge the inefficiency of the fixed effects estimator for the non-significance of EU funding in explaining research output. The random effects estimator is highly efficient and the finding remains robust. On the other hand, internal funding is important for improving research output according to the results but not when citations are normalised by author. Other funding is important in all cases and corroborates to an extent our discussion for more efficient utilisation of funding coming from non-conventional funding sources due to high calibre of international collaborators.

Department and individual effects are statistically significant but we must emphasise on the fact that these are described according to their estimated variance-covariance matrix and not in the regular manner as all other regressors. Therefore, possible inference from these results should be drawn with caution. In any case as discussed before, these effects *per se* are controlled for, so that they do not distort the estimation process; they are nonetheless outside the variables of interest of this paper and will not be given further attention.

3.5.2 Panel data analysis

We utilise the panel dataset to estimate the effect of securing funding from various sources on the posterior research output. In this setting of the model we incorporate the quantity dimension of research output and we use lags in order to reflect a realistic interval between the period of funding, the work carried out and the publication. It takes substantial time from the day research funding is secured, until

a project is completed and unpublished research output is produced by the time it is published in a peer-reviewed journal. Peer-review and revisions need considerable time and thus we use both three-year and six-year lags to account for this delay. In the case we use two lags, two periods are lost whereas in the one-lag case one period and 172 observations are left out of the estimation process. We use the fixed effects to provide for heterogeneity as well as endogeneity coming from simultaneous correlation of the talent of researchers to research output and research funding.

3.5.2.1 Fixed effects panel data regressions

Since use of the fixed effect implies that time-invariant variables are dropped from the model, including scientific field, we have adjusted the dependent variables to achieve comparability among fields by demeaning them with the scientific field mean. As seen from the table below, RPF funding is an important determinant of all indicators except JIF. Other funding seems to be marginally significant at the 10% level for adjusted publications and citations.

Table 3-12: Fixed Effects Regressions for the effect of funding on research output indicators with one lag

Research output indicators	Adjusted Publications	Fractional Publications	Year Weighted Citations	Year Weighted Fractional Citations	Adjusted JIF	Publication Pages
Variables	**Coefficients/Standard errors**					
RPF-first lag	0.069***	0.097***	0.097***	-0.007	0.060***	0.069***
	(0.025)	(0.024)	(0.018)	(0.017)	(0.018)	(0.025)
EU-first lag	0.049	0.003	0.034	0.013	0.029	0.049
	(0.041)	(0.033)	(0.036)	(0.021)	(0.026)	(0.041)
Internal-first lag	0.064	0.059	0.106	-0.031	0.091	0.064
	(0.076)	(0.095)	(0.074)	(0.065)	(0.061)	(0.076)
Other funding-first lag	0.073*	0.227*	0.097	-0.016	0.019	0.073*
	(0.040)	(0.133)	(0.066)	(0.028)	(0.028)	(0.040)
Experience	0.057	0.066	-0.029	-0.039	0.032	0.057
	(0.038)	(0.076)	(0.049)	(0.027)	(0.035)	(0.038)
Experience squared	-0.003**	-0.002	-0.0001	0.002**	-0.001	-0.003**
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Localcoauth-first lag	0.005	-0.004	-0.003	0.002	0.001	0.005
	(0.005)	(0.003)	(0.003)	(0.002)	(0.002)	(0.005)
Intlcoauth-first lag	0.001	0.003	0.002	-0.004**	0.002	0.001
	(0.003)	(0.005)	(0.004)	(0.002)	(0.002)	(0.003)
Avreferences-first lag	0.002	-0.002	-0.003	-0.002	0.001	0.002
	(0.002)	(0.004)	(0.004)	(0.002)	(0.001)	(0.002)
Wald Chi2/F Test	2.63	25.09	46.41	44.06	1.82	30.30
Observations (N)	437	411	409	409	418	411

notes: *** p<0.01, ** p<0.05, * p<0.1, Cluster-robust standard errors in parentheses

In terms of the magnitude of the effect of funding on subsequent research output we interpret the coefficients as semi-elasticities. That is, the *ceteris paribus* proportional increase in research output caused by a one unit increase in funding projects under the condition of the existence of an individual fixed effect. We apply this explanation since the marginal effect is expressed by $\beta_v E(y_{it}|X_{it}, Z_i, a_i)$ simplified in $\beta_v E(y_{it}|X_{it}, a_i)$ since the time-invariant variables Z_i are dropped out in the estimation process (Cameron & Trivedi, 2015). Thus the marginal effect cannot be meaningful as it includes the fixed effect which is unknown. It is therefore

convenient to use the semi-elasticity property of the coefficient so as to discuss the magnitude of the effect of different funding projects on output.

It seems that on average an additional RPF-funded project can increase field-normalised publications in the three years following funding by 7% and around this area is the corresponding marginal effect of other funding, albeit with less statistical significance. When publications are author-normalised the effect of RPF increases by around 3% but then the effect of internal funding becomes statistically significant and reaches 9%. RPF funding is also important for the quality of the published articles as its impact on citations and author-normalised citations is approximately 10% which is fairly consistent with the effect of 9% estimated in the multilevel model in the cross-section section of this paper. Whether these findings reveal a significant impact of funding is open to judgement since a positive effect is in place but the extent to which its magnitude is satisfactory is contingent to the expected outcome of a funding scheme.

The table below includes the second lag as well, leading to a loss of observations ranging from 154 to 181. Now the importance of RPF in facilitating increases in research output stands for publications and publication pages for a 6 year lag at 5% level and with a marginal effect of around 3-4% and to author-year-weighted citations for a 3 year lag at the 10% level with a marginal effect of 3,2%. The second lag of internal funding has become statistically significant at the 5% level with respect to publications and publication pages and the marginal effect with respect to publications has risen to 25%. This may imply that the grants that the University provides to researchers are of more long-term character as to their effect

in productivity. It is noteworthy that in both settings of the model, EU funding does not seem to contribute towards improving research output and also that no type of funding is associated with an improvement of average JIF.

Table 3-13: Fixed Effects Regressions for the effect of funding on research output indicators with two lags

Research output indicators	Adjusted Publications	Fractional publications	Year Weighted Citations	Year Weighted Fractional Citations	Adjusted JIF	Publ. Pages
Variables	**Coefficients/Standard errors**					
RPF-first lag	0.007	0.011	0.033	0.073**	0.024	0.039
	(0.024)	(0.021)	(0.050)	(0.030)	(0.023)	(0.029)
EU-first lag	0.016	-0.001	0.071	0.010	0.005	0.033
	(0.031)	(0.034)	(0.073)	(0.056)	(0.035)	(0.037)
Internal-first lag	0.085	0.040	0.078	-0.021	0.258***	0.113
	(0.085)	(0.086)	(0.148)	(0.116)	(0.074)	(0.089)
Other funding-first lag	-0.065	-0.104*	0.277	-0.153	-0.189**	-0.037
	(0.050)	(0.061)	(0.274)	(0.119)	(0.088)	(0.063)
RPF-second lag	0.034*	0.034	0.007	0.005	0.036*	0.040**
	(0.019)	(0.021)	(0.037)	(0.024)	(0.022)	(0.018)
EU-second lag	-0.019	-0.027	0.090	-0.045	-0.010	0.006
	(0.031)	(0.038)	(0.096)	(0.072)	(0.040)	(0.030)
Internal-second lag	0.123*	0.191**	-0.029	-0.028	0.105	0.111*
	(0.064)	(0.083)	(0.122)	(0.119)	(0.080)	(0.067)
Other funding-second lag	-0.009	-0.023	-0.134	-0.138	-0.115*	0.040
	(0.057)	(0.066)	(0.123)	(0.091)	(0.066)	(0.066)
Experience	-0.048	-0.072	-0.065	-0.267*	0.002	-0.105*
	(0.059)	(0.062)	(0.168)	(0.145)	(0.075)	(0.058)
Experience squared	0.0001	0.0001	0.001	0.006	-0.001	0.002
	(0.002)	(0.002)	(0.004)	(0.004)	(0.002)	(0.002)
Localcoauth-first lag	-0.0001	-0.002	0.003	-0.002	-0.0001	-0.001
	(0.003)	(0.003)	(0.005)	(0.004)	(0.003)	(0.003)
Intlcoauth-first lag	-0.002	0.001	-0.008	-0.004	-0.005	-0.001
	(0.004)	(0.003)	(0.009)	(0.006)	(0.007)	(0.004)
Avreferences-first lag	-0.0001	-0.002	-0.001	-0.003	-0.001	-0.001
	(0.001)	(0.002)	(0.002)	(0.004)	(0.001)	(0.001)
Wald Chi2/F Test	1.30	31.64	63.41	49.44	2.85	19.11
Observations (N)	283	234	234	234	267	234

notes: *** p<0.01, ** p<0.05, * p<0.1, Cluster-robust standard errors in parentheses

We also ran the above two models using first-authored publications as the dependent variable. It seems that it is purely insignificant and all the explanatory variables are rendered insignificant as well. Therefore, we do not elaborate further for this type of indicator. Instead, we use fractional publications which does not leave out all non-first-authored publications and weighs for the net contribution of

each author. For the one-lag model the findings are in alignment with straight count of publications but they now show significance for internal funding at the 5% level of confidence. It is a result that matches intuition as internal funding targets a specific researcher unlike other funding schemes which aim at more collective or demand-driven research output through collaboration and the requirements of the funding agency. For the two-lag model the same types of funding are significant for net publications but now this stands only at the second lag level. This may be a result of the loss of 177 observations which are probably critical for defining the significance at the first lag level.

We also apply the above model with a random effects approach and include the estimation results in Table 3-22 & 3-23 in the Appendix. This takes place simply for informational purposes as the assumption of the random effects approach that the individual effect is not correlated with the regressors neglects potential endogeneity and may cause severe inconsistency problems to the model. For this reason, in the next section we implement the multilevel modelling approach aiming to handle the heterogeneity problem more suitably and discuss the assumptions needed to render this random effects method more reliable.

3.5.2.2 Dynamic panel data regressions

Although the fixed effects are capable of providing for autocorrelation in the data, if the serial correlation is persistent and does not depend on the fixed effect then the lagged dependent variable should be included as a regressor in the model to capture this dynamic nature of the data. It is also well-known that the lagged

dependent variable is endogenous in the model of the dependent variable and it has to be properly instrumented for the model estimators to keep their consistency. Arellano & Bond (1991) constructed an estimator which provides for the endogeneity of the lagged dependent variable by using previous lags of the dependent variable as instruments. Using Generalised Method of Moments (Hansen, 1982) to estimate the model, the fixed effect is removed, first-differencing the variables with their first lag and the lagged differences enter the model as instruments. The estimation technique was subsequently enriched by Arellano & Bover (1995) and then by Blundell and Bond (1998) to create the well-known system estimator. Windmeijer supplemented the estimator by introducing a correction for small sample bias since the estimated standard errors which are based on asymptotic theory are likely to be underestimated in such samples (Windmeijer, 2005). All versions of the estimator are applied for the purposes of the paper. We augmented the dataset with two additional periods of research output variables in order for the estimator to have adequate time dimensions and be as functional as possible. We did not have such information for the full sample of researchers but for 94 out of 172 researcher-year observations since the rest were either in another university or they were not active researchers at that point. Thus we used these observations along with the orthogonality option of Blundell and Bond (1998) which is suitable for data with missing observations. Essentially, this estimation technique imposes orthogonality by weighting the explanatory variables so that they become orthogonal to the errors (Blundell & Bond, 1998). We used the first lag of funding as the explanatory variable of interest. Using since the second lag led to a loss of

observations which makes impossible the calculation of the AR2 test. We therefore include these findings in the Appendix for strictly informational purposes with only minor discussion.

We use both the system and the difference estimators to estimate the model. The latter includes only differenced regressors in the estimation process whereas the former uses also the initial level equation in deriving the optimal solution and first differences serve as instruments for levels. As Roodman (2009) explains, the differences estimator uses levels to instrument differences while the system estimator uses differences to instrument levels. We consider necessary to use both estimators as the differences estimator is not as efficient as the system estimator, given that lagged differences have shown in many cases to be weak instruments of the dependent variable. On the other hand, the system estimator may exhibit some concession in consistency if the orthogonality condition of the regressors with the fixed effects does not stand for all regressors (Arellano, 2009). Another issue which concerns our data is that both these estimators do not work with count data. Therefore we demean variables by scientific field and transform them in a way to accommodate the use of Arellano-Bond, Arellano-Bover and Blundell-Bond estimators, although this exercise causes a compromise in the intepretation properties of the β coefficients.

Table 3-14: Dynamic Panel Data Regressions for the effect of funding on research output indicators with one lag – GMM Arellano-Bond System Estimator

Research output indicators	Demeaned Publications	Demeaned JIF	Demeaned pages	Demeaned Fractional Pubs
Variables	**Coefficients/Standard errors**			
RPF-first lag	0.444**	0.003	6.023***	0.127***
	(0.174)	(0.010)	(1.478)	(0.039)
EU-first lag	-0.038	0.039	2.195	-0.028
	(0.175)	(0.024)	(1.959)	(0.058)
Internal-first lag	0.879	0.080	8.631	0.199
	(0.555)	(0.057)	(6.645)	(0.180)
Other funding-first lag	0.201	0.021	-0.231	-0.053
	(0.299)	(0.043)	(3.821)	(0.093)
Experience	0.078	-0.028	0.846	0.067*
	(0.090)	(0.018)	(1.200)	(0.040)
Experience squared	-0.004	0.001*	-0.034	-0.002*
	(0.003)	(0.000)	(0.032)	(0.001)
Localcoauth-first lag	0.073*	0.001	0.706***	-
	(0.040)	(0.002)	(0.261)	-
Intlcoauth-first lag	-0.007	0.002	-0.069	-
	(0.013)	(0.002)	(0.072)	-
Avreferences-first lag	-0.002	0.001	0.065	-0.001
	(0.009)	(0.001)	(0.073)	(0.003)
Observations (N)	437	418	437	437
Instruments	61	54	61	59
AR1 test	0.000	0.004	0.000	0.000
AR2 test	0.621	0.876	0.753	0.295
Hansen test	0.459	0.000	0.000	0.000
Sargan test	0.000	0.153	0.497	0.125

Notes: *** p<0.01, ** p<0.05, * p<0.1, Windmeijer corrected standard errors in parentheses, Time-dummies used but not reported

The findings of the system estimator regressions as presented in the above table indicate that there is a significant positive effect of lagged RPF funding on quantity but not quality of journal publications. For publications count, the findings imply that researchers having RPF funding are expected to produce 0.44 publications above the mean of their peers at the university. RPF funding is also important for the total volume of journal publications pages produced in a three-year period as well as author-normalised journal publications count. However, all other types of

funding present a striking statistical insignificance and in some cases a counterintuitive sign in the respective coefficients. This may be due to a number of factors, three of which are discussed briefly. Firstly, we have applied Windmeijer's correction for small sample bias which, aiming at prudence, increases standard errors of the coefficients thus rendering them statistically insignificant. Secondly, the demeaned JIF indicator may form an imperfect representation of journal quality. The third and more probable reason may be that the funding-output relationship may not be explained by a dynamic process but rather the fixed effect suffices to handle autocorrelation. The model seems to be well-specified since the tests perform fairly well. The first order autocorrelation is not rejected whereas the second is strongly rejected. A point of concern is that the Hansen test strongly rejects the possibility for the instruments to be collectively exogenous for all output indicators. Therefore, inference can be drawn with caution but we still rely much more on the static panel estimates for robust inference.

Table 3-15: Dynamic Panel Data Regressions for the effect of funding on research output indicators with one lag – GMM Arellano-Bond Difference Estimator

Research output indicators	**Demeaned Publications**	**Demeaned JIF**	**Demeaned pages**	**Demeaned Fractional Pubs**
Variables	**Coefficients/Standard errors**			
RPF-first lag	0.164	1.661*	1.278	-0.052
	(0.339)	(0.936)	(2.749)	(0.140)
EU-first lag	0.038	-1.259	1.401	0.010
	(0.290)	(1.420)	(3.331)	(0.105)
Internal-first lag	0.193	2.043	-6.445	-0.159
	(0.794)	(2.105)	(8.048)	(0.315)
Other funding-first lag	0.259	0.575	4.807	-0.017
	(0.282)	(0.976)	(3.090)	(0.093)
Experience	0.165	-0.132	2.302	0.100
	(0.212)	(0.632)	(3.081)	(0.079)
Experience squared	-0.010*	-0.005	-0.094	-0.005***
	(0.005)	(0.015)	(0.082)	(0.002)
Localcoauth-first lag	0.089	0.170	1.099**	-
	(0.081)	(0.178)	(0.468)	-
Intlcoauth-first lag	-0.011	-0.044	0.169	-
	(0.015)	(0.033)	(0.170)	-
Avreferences-first lag	0.007	-0.006	0.168*	0.0001
	(0.010)	(0.028)	(0.088)	(0.003)
Observations (N)	267	255	267	267
Instruments	43	37	43	41
AR1 test	0.030	0.003	0.048	0.033
AR2 test	0.388	0.776	0.404	0.113
Hansen test	0.482	0.743	0.827	0.479
Sargan test	0.244	0.257	0.796	0.184

Notes: *** p<0.01, ** p<0.05, * p<0.1, Windmeijer-corrected standard errors in parentheses, Period-dummies used but not reported

3.5.2.3 Multilevel modelling for panel data

In this section we briefly discuss the findings from the estimation of the panel data multilevel model since the results are generally similar with our previous models[5].

Table 3-16: Multilevel model with random effects for publications and fractional publications

Variables	**Publications**		**Publications - slope**		**Fractional Publications**	
	coef.	se.	coef.	se.	coef.	se.
Local Coauthors	0.01**	0.002	0.01***	0.002	0.01***	0.003
International Coauthors	0.0003	0.003	0.0001	0.003	-0.001	0.003
Internal	0.1**	0.051	0.09*	0.051	0.12**	0.051
RPF	0.06***	0.016	0.06***	0.016	0.04***	0.013
EU	0.05*	0.026	0.05*	0.026	0.04	0.024
Other funding	0.06*	0.033	0.07**	0.03	0.004	0.03
Experience	0.008	0.006	0.001	0.007	0.003	0.007
Top-20 PhD	0.13	0.12	0.145	0.113	0.17*	0.104
Top-20 Degree	0.11	0.149	0.12	0.156	0.14	0.137
Female	-0.16	0.13	-0.15	0.129	-0.17	0.112
Constant	1.23***	0.091	1.21***	0.104	0.46***	0.101
Random Effects						
Department	0.33***	0.042	0.33***	0.012	0.31***	0.041
Department-slope	-	-	0.003	0.067	-	-
Researcher	0.47***	0.034	0.47***	0.037	0.32***	0.037
Observations	463		436		463	
Wald Chi2 (13)	72.05		70.78		95.32	
Log-likelihood	-1142.62		-1082.13		-739.81	
LR test	430.48		417.55		104.66	

note: *** p<0.01, ** p<0.05, * p<0.1, Period dummy variables estimated but not reported, Heteroskedasticity-robust standard errors reported.

As we can see from Table 3-16 the results are robust to previous specifications of the model and indicate statistical significance of the RPF funding at the 1% level in all cases. Internal funding is significant at the 5% level in the intercept specifications whereas in the slope specification it becomes significant at the 10% level. EU and

[5] We ran the model with both Stata and MLWin and the results are generally robust with small differences in the magnitude of the coefficient effects. In Table 3-16 only the results from Stata estimation are presented as we had to exclude the year dummies in the MLWin case so as to smoothly estimate the model.

other funding appear to be significant at the 10% level for determining publications and in one case at 5% level of significance. When the dependent variable is fractional publications, EU and other funding seem to have little to null explanatory power as they are statistically insignificant.

3.6 Conclusions

The purpose of this chapter was to explain the effect of different types of funding on academic research productivity. In addition, we envisioned that sensible answers could be provided with respect to the most usual applied econometric concerns in examining the association of funding and output. To that direction, we constructed two datasets; a cross-section dataset that had journal publications as the unit of analysis and a panel dataset based on individuals and years which covered further time periods. Using these datasets we explored via different econometric approaches how research grants influence the quantity and quality of subsequent journal publications. We applied fixed effects negative binomial for count panel data, as well as multilevel modelling for both cross-section and panel data and dynamic panel data regressions for the panel dataset. We used these different approaches to tackle different challenges posed by the nature of the funding-output problem and its econometric complications, since no single approach can offer a universal solution to all problems. The employment of these different models has also served as a robustness test for our findings.

In the cross-sectional analysis, we found that the statistical significance of funding for increasing quality of journal publications varies across departments. For some departments RPF funding is critical, whereas for others, internal grants are decisive

for enhancing either citation- or JIF-related composite indicators. When all data are pooled together we find that only other funding is an important constituent of quality. This means that the effect of other funding is stronger in general terms compared to the core funding schemes.

The panel data results show that when using the fixed effects approach, the predominant estimation method in the literature, we find significance in most indicators for national competitive funding as well as other funding. For internal grants we do not find significant association as it seems that most researchers enjoy this grant, thereby resulting in zero to little differentiation among their research productivity in the sample. EU funding is in the vast majority of cases insignificant for determining research output indicators. As EU funding is demand-driven – with the exception of ERC grants – this insignificance in explaining research output may be a result of the nature of the projects funded, which diverge from the core of the researchers' interests and perhaps lead to minimum output in the form of publications.

When accounting for the multilevel nature of the data to take different scientific fields into account more formally, we undertake the hypothesis of homogeneity among researchers and the possibility for a random effect thereof, keeping in mind that this is a rather strong assumption. This leads to increased efficiency of the estimator as it exploits both within and between variance and the results are closer to intuition as most types of funding have a positive and statistically significant association with research output.

We find little convincing evidence for the existence of a true state dependence pattern when using the Arellano-Bond estimator. All specifications exhibit statistically insignificant results with some coefficients being counter to intuition as well. The exception is national competitive funding-RPF, which appears to be positive and important when using the system estimator with one and two lags. Therefore it is safe to conclude that potential autocorrelation may be captured by the fixed effect in the static model and that the three-year periods we use remove cyclicality effects which are usually responsible for true state dependence.

The chapter has carried out detailed analysis of the funding-output connection. A variety of methodological tools were utilised and the most important challenges were addressed. There is evidence for the existence of a market for research funding from which the researchers select where to apply. This emanates from researchers that do not receive the grant from mainstream funding agencies and may shift to other less conventional funding schemes or target collaborations that facilitate easier access to alternative funding sources.

Nevertheless, the paper conveys limitations. The first is that we could not distinguish among different types of funding included in the "other funding" variable. Such a separation could shed light as to whether some specific type of funding therein is more important than others. However, we support strongly that the core types of funding chosen are indeed the most popular among scientists and more specifically for the researchers in our sample. A survey that took place at the University of Cyprus in 2009, with respect to how faculty valued the importance of external funding, corroborated our selection of funding types. It revealed that 75% of the

faculty consider funding as important for their research. From the sample 55% said that the RPF funding is very important whereas another 20% stated that is fairly important up to important. 57% replied similarly for European funding and an additional 16% expressed weak to moderate importance for that type of funding (University of Cyprus, 2009).

Another limitation of the paper is that the complexity in the data and the econometric methodology allow only for trivial extraction of marginal effects which are of particular importance for the field of economics and the models of interest. It would be useful to infer on the magnitude of the impact of funding upon subsequent research productivity. This could indeed create fertile ground for funding policy-making in science with measurable results in terms of productivity based on expected benchmarks. However, it must be noted that even in the case where we had simpler data that allowed for marginal effects, inference would be drawn with caution as the funding attributes may differ even among projects funded within the same funding scheme.

3.7 Appendix of Chapter 3

Table 3-17: Within and between variance of panel dependent variables

	Standard Deviation			Variance		
Variable	overall	between	within	overall	between	within
JIF	19.37	16.93	9.82	375.08	286.6	96.44
First-authored publications	1.88	1.63	1.18	3.54	2.67	1.39
Pages	60.71	45.55	37.97	3685.43	2074.7	1441.79
Author-weighted publications	1.77	1.45	1.06	3.12	2.1	1.13
Publications	4.98	4.07	2.79	24.76	16.58	7.8
Adjusted JIF	0.76	0.79	0.46	0.58	0.63	0.21
Demeaned Author Weighted Publications	1.67	1.37	1.06	2.79	1.88	1.13
Demeaned Pages	59.03	43.98	37.97	3484.15	1934.56	1441.79
Year-weighted Citations	22.95	20.04	14.37	526.74	401.6	206.42
Author-year-weighted citations	5.07	4.5	2.93	25.66	20.27	8.56

Table 3-18: Hausman test for fixed effects and random effects in the panel data model

Dependent Variables	**chi2**	**p>chi2**	**Method preferred**
Publications	177.76	0.00	Fixed Effects
First-authored publications	7.99	0.5347	Random Effects
Author-weighted publications	27.65	0.0011	Fixed Effects
Pages	73.36	0.00	Fixed Effects
Adjusted JIF	35.03	0.0001	Fixed Effects
Year-weighted Citations	120.36	0.00	Fixed Effects
Author-year-weighted citations	132.25	0.00	Fixed Effects

Table 3-19: Calculation of Research Output Indicators used as dependent variables

Dependent Variable	Cross-section level	Panel level
5-year JIF deviation	$\Pi_i = (\pi_i - \bar{\pi})/\bar{\pi}$	$\Pi_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} \Pi_{it}$
Citations	C_i	$C_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} C_{it}$
Year-weighted citations	$w_i = C_i/(2014 - t_i)$	$w_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} w_{it}$
Fractional Citations	$c_i = C_i/a_i$	$c_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} c_{it}$
Year-Author- Weighted Citations	$\rho_i = c_i/(2014 - t_i)$	$\rho_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} \rho_{it}$
Publications	P_i	$P_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} P_{it}$
Pages	g_i	$g_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} g_{it}$
JIF-Author Weighted Pages	$Y_i = (\pi_i - \bar{\pi})g_i/a_i$	$Y_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} Y_{it}$
JIF-Author Weighted Publications	$y_i = (\pi_i - \bar{\pi})/a_i$	$y_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} y_{it}$
Author weighted Publications	$f_i = P_i/a_i$	$f_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} f_{it}$
First -authored publications	φ_i	$\Phi_{rT} = \sum_{i=1}^{n}\sum_{t=1}^{3} \varphi_{it}$

Table 3-20: Correlation coefficients for all cross-section variables

Variables	jif5	first	rpf	Eu	nsf	gget	other	internal	references	citations	pages	coauth	intlcoauth	localcoauth	jifap	ap	authw
jif5	1																
first	-0.04	1															
rpf	0.1	-0.05	1														
eu	0.03	-0.1	0.06	1													
nsf	0.01	-0.01	-0.03	0.12	1												
gget	0.02	-0.04	0	0.1	0	1											
other	0.27	-0.01	0.03	0.25	0.07	0.02	1										
internal	0.04	-0.08	0.1	0.03	0.03	0	0	1									
references	0.25	-0.04	0.05	0.04	-0.02	0.01	0.06	0.05	1								
citations	0.2	-0.01	-0.02	-0.01	0	0.01	0.1	-0.02	0.52	1							
pages	-0.09	0.13	-0.15	0.05	0.11	-0.03	-0.01	-0.01	0.34	0.14	1						
coauth	0.22	-0.21	0.12	0.21	0.03	0.06	0.47	-0.03	0.17	0.27	-0.08	1					
intlcoauth	0.23	-0.07	-0.01	0.17	0.07	-0.02	0.52	-0.06	0.16	0.32	0.04	0.79	1				
localcoauth	0.02	-0.25	0.2	0.1	-0.06	0.12	0.03	0.03	0.05	-0.01	-0.2	0.51	-0.12	1			
jifap	0.44	0.1	-0.05	-0.04	0.01	-0.02	0.01	-0.01	0.46	0.09	0.38	-0.17	-0.07	-0.18	1		
ap	-0.14	0.3	-0.19	-0.07	0.04	-0.04	-0.12	0	0.11	-0.03	0.73	-0.41	-0.21	-0.37	0.44	1	
authw	-0.18	0.38	-0.15	-0.16	-0.05	-0.06	-0.22	0	-0.11	-0.07	0.14	-0.65	-0.39	-0.5	0.24	0.65	1
jifauth	0.73	0.12	0.01	-0.06	-0.02	-0.01	0.03	0.03	0.25	0.11	0.01	-0.23	-0.11	-0.22	0.68	0.18	0.31
frcitations	0.25	0.06	-0.04	-0.04	-0.01	0	0.07	-0.02	0.31	0.5	0.07	-0.06	0.02	-0.13	0.31	0.12	0.15
wcitations	0.28	-0.02	0	0.01	-0.01	0	0.15	-0.01	0.52	0.96	0.12	0.29	0.34	-0.01	0.09	-0.06	-0.11
wfcitations	0.29	0.05	-0.01	-0.04	-0.02	-0.01	0.1	0	0.31	0.46	0.05	-0.06	0.02	-0.13	0.3	0.1	0.13
citationspp	0.44	-0.01	0	0	0.02	0.01	0.22	-0.01	0.14	0.54	-0.15	0.21	0.21	0.04	0.04	-0.16	-0.12
degree	0.07	0.08	0.14	-0.04	0.04	-0.04	0.02	-0.03	0.03	-0.01	0.02	-0.01	0.03	-0.06	0.09	0.01	0.02
phd	0.04	-0.02	0.08	0.01	0	-0.02	-0.01	0.07	0.05	0.03	0.04	-0.01	0.01	-0.04	0.06	-0.01	-0.02
master	0.1	-0.1	0.06	-0.07	-0.03	0	0.05	0.01	0.08	0.04	-0.08	0.1	0.04	0.1	0	-0.09	-0.1
experience	-0.06	-0.1	0.11	-0.01	-0.1	0.02	-0.09	0.11	0.04	-0.06	0.1	-0.01	-0.06	0.08	0.06	0.07	0.01
phdyears	0.01	0.01	-0.05	0.05	0.03	-0.02	0	-0.07	0.03	0.02	0.04	0.02	0	0.03	-0.01	0.03	0
female	0.1	0.1	0.11	0.02	-0.03	0.02	0.01	0.02	0.05	0.01	0	0.07	0.04	0.05	0.03	-0.03	-0.07
y2008	-0.03	0.01	-0.16	-0.05	-0.02	0.01	-0.08	-0.1	-0.05	0.05	0.01	-0.06	-0.01	-0.08	0	0.03	0.07
y2009	0.04	0.04	-0.02	-0.01	-0.01	0.05	-0.01	-0.01	0.02	0.12	-0.02	-0.01	0.02	-0.05	0.04	0.01	0.02
y2010	-0.05	0.02	-0.01	-0.01	0.01	-0.04	0	-0.01	-0.04	0	-0.03	-0.02	-0.03	0.01	-0.02	0.02	0.05
y2011	0.01	0	0.07	-0.03	0.06	-0.01	0.04	0.05	0.03	-0.01	0.03	0.01	0.02	-0.01	-0.01	0.01	-0.02
y2012	0.03	-0.03	0.05	0	-0.02	-0.01	0.03	0.04	-0.02	-0.06	-0.05	0.04	0	0.08	-0.02	-0.07	-0.07
y2013	0	-0.04	0.06	0.1	-0.02	-0.01	0.03	0.02	0.06	-0.1	0.06	0.03	0.01	0.05	0.01	0	-0.05

Table 3-21: Correlation coefficients for all cross-section variables (continued)

Variables	pages	jifauth	frcitations	wcitations	wfcitations	citationspp	degree	phd	master	experience	phdyears	female	y2008	y2009	y2010	y2011	y2012	y2013
pages	1																	
jifauth	0.01	1																
frcitations	0.07	0.38	1															
wcitations	0.12	0.14	0.5	1														
wfcitations	0.05	0.39	0.93	0.55	1													
citationspp	-0.15	0.23	0.58	0.55	0.54	1												
degree	0.02	0.09	0.01	-0.01	0.01	-0.02	1											
phd	0.04	0.05	0.01	0.02	0.01	-0.02	0.63	1										
master	-0.08	0.01	-0.01	0.04	-0.01	0.04	0.08	-0.02	1									
experience	0.1	-0.03	-0.09	-0.06	-0.07	-0.16	0.12	0.22	-0.08	1								
phdyears	0.04	0.01	0	0.01	-0.01	-0.01	-0.04	0.07	-0.29	-0.07	1							
female	0	0.05	0	0.03	0.01	0.02	0	-0.14	-0.16	-0.17	-0.03	1						
y2008	0.01	0.04	0.13	-0.01	0.02	0.11	0.03	0.03	0.02	-0.11	-0.03	-0.02	1					
y2009	-0.02	0.05	0.14	0.07	0.06	0.16	0	0.04	-0.05	-0.06	0.03	-0.02	-0.19	1				
y2010	-0.03	-0.03	0.04	-0.01	0.02	0.02	-0.02	-0.01	0	-0.03	0.01	-0.02	-0.19	-0.21	1			
y2011	0.03	-0.02	-0.02	0.01	0.01	-0.01	0.05	0.04	0.02	0.05	0.03	0.01	-0.18	-0.2	-0.2	1		
y2012	-0.05	-0.01	-0.11	0.04	0.05	-0.1	-0.04	-0.05	0	0.02	-0.02	0.03	-0.18	-0.2	-0.2	-0.19	1	
y2013	0.06	-0.02	-0.17	-0.1	-0.15	-0.17	-0.01	-0.05	0	0.13	-0.01	0.02	-0.2	-0.22	-0.22	-0.21	-0.21	1

Table 3-22: Random Effects Regressions for the effect of funding on research output indicators with one lag

Variables	Adjusted Publications	Weighted Citations	Weighted Fractional Citations	Adjusted JIF	Publication Pages
			Coefficients		
rpf-first lag	0.024	0.093***	0.088***	0.004	0.030*
	(0.020)	(0.021)	(0.021)	(0.012)	(0.016)
eu-first lag	0.062*	-0.008	-0.021	0.001	0.025
	(0.038)	(0.031)	(0.035)	(0.015)	(0.020)
internal-first lag	0.100	0.054	0.107	-0.019	0.124**
	(0.070)	(0.084)	(0.084)	(0.059)	(0.059)
otherfund-first lag	0.088**	0.100**	0.096**	0.003	0.010
	(0.038)	(0.043)	(0.044)	(0.027)	(0.034)
EXPERIENCE	0.039*	0.030	0.007	-0.054**	0.057**
	(0.021)	(0.032)	(0.036)	(0.025)	(0.022)
experience2	-0.001*	-0.002	-0.001	0.001**	-0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
localcoauth-first lag	0.024***	0.007**	0.006*	0.003	0.012***
	(0.005)	(0.003)	(0.003)	(0.002)	(0.003)
intlcoauth-first lag	0.0001	0.009***	0.003	0.0001	0.003
	(0.002)	(0.003)	(0.004)	(0.002)	(0.002)
avreferences-first lag	-0.001	-0.002	-0.001	0.001	-0.001
	(0.002)	(0.002)	(0.003)	(0.001)	(0.002)
FEMALE	-0.062	-0.012	-0.115	-0.090	-0.023
	(0.197)	(0.208)	(0.241)	(0.152)	(0.122)
PHD	0.081	0.368**	0.401*	-0.075	0.178*
	(0.134)	(0.178)	(0.207)	(0.132)	(0.104)
DEGREE	0.162	0.176	0.108	0.031	0.097
	(0.182)	(0.216)	(0.249)	(0.146)	(0.122)
ln_r	-	0.594***	1.373***	-	2.010***
	-	(0.152)	(0.173)	-	(0.261)
ln_s	-	1.662***	0.791***	-	5.479***
	-	(0.248)	(0.205)	-	(0.327)
Wald Chi2/F Test	96.95	72.40	53.19	18.12	96.61
Observations (N)	436	436	436	417	436

note: *** p<0.01, ** p<0.05, * p<0.1

Table 3-23: Random Effects Regressions for the effect of funding on research output indicators with two lags

Variables	Adjusted Publications	Weighted Citations	Weighted Fractional Citations	Adjusted JIF	Publication Pages
			Coefficients		
rpf-first lag	0.012	0.089***	0.097***	0.002	0.031
	(0.022)	(0.029)	(0.028)	(0.012)	(0.023)
eu-first lag	0.058	0.009	-0.003	0.011	-0.001
	(0.045)	(0.042)	(0.048)	(0.020)	(0.032)
internal-first lag	0.087	0.077	0.136	0.007	0.104
	(0.088)	(0.108)	(0.105)	(0.070)	(0.076)
otherfund-first lag	0.026	0.151*	0.085	0.053	-0.027
	(0.078)	(0.088)	(0.088)	(0.063)	(0.059)
rpf-second lag	0.015	0.021	0.013	0.006	0.007
	(0.030)	(0.035)	(0.034)	(0.013)	(0.030)
eu-second lag	-0.017	-0.049	-0.083	-0.008	0.010
	(0.041)	(0.051)	(0.056)	(0.019)	(0.039)
internal-second lag	0.205**	0.139	0.142	0.112	0.191**
	(0.098)	(0.113)	(0.112)	(0.083)	(0.085)
otherfund-second lag	0.026	-0.047	-0.030	-0.018	0.042
	(0.049)	(0.067)	(0.067)	(0.035)	(0.042)
Experience	0.008	0.048	0.024	-0.054**	0.078**
	(0.028)	(0.059)	(0.063)	(0.027)	(0.038)
experience2	-0.001	-0.002	-0.002	0.001*	-0.002**
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
localcoauth-first lag	0.021***	0.011**	0.005	0.002	0.012***
	(0.006)	(0.004)	(0.005)	(0.003)	(0.003)
intlcoauth-first lag	0.001	0.004	0.006	0.008***	0.004
	(0.004)	(0.006)	(0.006)	(0.002)	(0.004)
avreferences-first lag	-0.001	-0.001	-0.001	0.003	-0.002
	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
FEMALE	-0.028	-0.022	-0.098	-0.206*	0.051
	(0.269)	(0.247)	(0.282)	(0.122)	(0.148)
PHD	0.209	0.476**	0.603**	-0.158	0.298**
	(0.163)	(0.212)	(0.244)	(0.112)	(0.130)
DEGREE	0.184	0.391	0.232	0.184	0.156
	(0.215)	(0.252)	(0.281)	(0.126)	(0.141)
/ln_r	-	0.557***	1.299***	-	2.053***
	-	(0.203)	(0.202)	-	(0.406)
/ln_s	-	1.762***	0.774***	-	5.649***
	-	(0.405)	(0.283)	-	(0.524)
Wald Chi2/F Test	73.97	76.67	60.39	63.98	104.52
Observations (N)	283	283	283	267	283

note: *** p<0.01, ** p<0.05, * p<0.1

Table 3-24: Negative Binomial Regressions for the effect of funding on JIF-Author-Pages per department

	Biology	Business	Chemistry	Computer	Civil	Economics	Electrical	Mathematics	Mechanical	Physics
						Coefficient				
RPF	0.338*	-0.155	0.079	-0.150	0.022	0.860	-0.083	-0.154	0.099	-0.006
EU	-0.154	0.157	-0.116	-0.088	0.181***	0.226	-0.011	0.196	-0.166***	-0.37***
INTERNAL	0.292**	-0.048	0.083	0.179*	-0.396**	.	0.380*	0.290	-0.308*	-0.139
Otherfunding	0.025	1.000***	-0.130***	0.123	-0.119**	-0.391*	0.050	0.086	0.014	0.036
FEMALE	1.779*	-6.449	-0.418	6.398*	-1.17***	2.964	-1.51***	-2.030***	6.544**	7.972
Education1	1.277	-10.229	0.128***	-10.369*	0.411	-0.050	-0.338*	-0.208**	0.101	3.303***
EXPERIENCE	0.436	0.352	-0.092	0.396	0.327**	-0.204	0.015	0.419**	0.406**	-0.541
/lnalpha	-0.83***	-1.48***	-1.331***	-1.632***	-1.37***	-1.284***	-1.25***	-1.039***	-0.880***	-0.407
Observations (N)	148	101	306	141	133	86	242	271	238	163

note: * p<0.01, ** p<0.05, *** p<0.1

Table 3-25: Negative Binomial Regressions for the effect of funding on JIF-Author per department

	Biology	Business	Chemistry	Computer	Civil	Economics	Electrical	Mathematics	Mechanical	Physics
						Coefficient				
RPF	0.220	0.413**	0.085	-0.086	0.038	1.150*	0.080	-0.208	-0.024	-0.082
EU	0.084	-0.56*	-0.260*	-0.116*	0.117	0.173	-0.036	-0.709	0.001	-0.425**
INTERNAL	0.214	0.450*	0.118**	0.198*	-0.297	.	0.285	0.219	-0.215***	0.058
Other funding	-0.008	1.032*	-0.150*	-0.130**	-0.108***	-0.336**	-0.018	0.183	0.040*	0.082
FEMALE	1.042	-4.047	0.354	3.577	-0.912*	4.149	-1.54*	-1.521*	4.029**	9.108
Education1	0.208	-6.186	0.077**	-5.947	0.420	0.169	-0.48*	-0.426**	0.129	1.928**
EXPERIENCE	0.118	0.212	-0.064	0.220	0.114	-0.253	0.030	0.310**	0.233***	-0.565
/lnalpha	-3.430*	-73.034	-20.783	-37.649	-21.513	-35.389	-21.950	-20.371	-34.551	-1.988**
Observations (N)	148	101	306	141	133	86	242	271	238	163

note: *** p<0.01, ** p<0.05, * p<0.1

Table 3-26: Negative Binomial Regressions for the effect of funding on Journal Impact Factor per department

Field	Biology	Business	Chemistry	Computer	Civil	Economics	Electrical	Maths	Mechanical	Physics
Variables					**Coefficients**					
RPF	0.363**	-0.084	0.078*	-0.146	0.13***	-0.476	0.067	-0.103	0.054	-0.046
	(0.149)	(0.155)	(0.046)	(0.136)	(0.021)	(0.690)	(0.080)	(0.096)	(0.072)	(0.052)
EU	0.150	-0.144	0.021	-0.024	-0.019	0.102	-0.045	-0.275	0.045	-0.28***
	(0.097)	(0.145)	(0.027)	(0.047)	(0.034)	(0.101)	(0.037)	(0.838)	(0.065)	(0.089)
INTERNAL	-0.014	0.183*	0.143*	0.059	0.006	.	0.074	0.274	0.108	-0.004
	(0.184)	(0.104)	(0.077)	(0.131)	(0.105)	.	(0.106)	(0.225)	(0.118)	(0.238)
otherfunding	0.081***	0.588***	0.030	-0.019	0.006	0.091	0.027	0.355***	0.033***	0.144**
	(0.026)	(0.135)	(0.025)	(0.069)	(0.009)	(0.154)	(0.024)	(0.122)	(0.010)	(0.070)
FEMALE	0.713	-4.753	-1.143	1.409	0.072	0.534	-0.63***	-0.954**	-0.845	0.911
	(0.601)	(3.162)	(0.776)	(1.886)	(0.059)	(4.026)	(0.146)	(0.453)	(2.146)	(4.010)
Education1	-0.557	-7.602	0.045	-3.348	0.882***	0.921***	-0.115	-0.37***	-0.030	-0.216
	(0.730)	(5.670)	(0.032)	(3.062)	(0.220)	(0.247)	(0.163)	(0.126)	(0.144)	(0.404)
EXPERIENCE	-0.030	0.288	-0.135***	0.118	-0.058	-0.049	0.093	0.208**	-0.079	-0.026
	(0.181)	(0.244)	(0.040)	(0.127)	(0.088)	(0.239)	(0.114)	(0.106)	(0.137)	(0.248)
LOCALCOAUTH	-0.023**	0.010	-0.009	0.002	0.017	-0.107	-0.069	0.055**	0.002	-0.032
	(0.010)	(0.066)	(0.015)	(0.035)	(0.014)	(0.171)	(0.047)	(0.026)	(0.024)	(0.021)
INTLCOAUTH	0.012	0.032	0.020	-0.024	0.038***	0.049	0.011	0.018	0.073***	-0.005
	(0.028)	(0.049)	(0.021)	(0.048)	(0.005)	(0.121)	(0.015)	(0.042)	(0.013)	(0.011)
/lnalpha	-2.049***	-17.43***	-16.81***	-51.667	-27.48	-23.594	-28.642	-15.9***	-2.74***	-1.93***
Observations (N)	148	101	306	141	133	86	242	271	238	163
	(0.193)	(0.235)	(0.223)	.	.	.	.	(0.455)	(0.890)	(0.418)

note: *** p<0.01, ** p<0.05, * p<0.1

Table 3-27: Dynamic GMM Regressions for the effect of funding on research output indicators with two lags (System estimator)

Variables	Demeaned Publications	Demeaned JIF	Demeaned pages	Demeaned Fractional Pubs
	Coefficients			
rpf-first lag	0.472**	-0.002	5.110***	0.110*
eu-first lag	-0.006	0.030	2.707	-0.003
internal-first lag	0.432	0.037	9.934	0.261
otherfund-first lag	-0.509	0.144	-5.208	-0.315**
rpf-second lag	0.060	-0.004	1.384	0.076
eu-second lag	-0.092	0.044*	1.791	-0.037
internal-second lag	-0.404**	-0.030	-5.037	-0.079
otherfund-second lag	0.902*	-0.004	11.803	0.456
Experience	0.052	-0.053*	0.304	0.007
Experience2	-0.003	0.001*	-0.019	-0.001
Local coauthors-first lag	0.082***	-0.001	0.936***	-
Int. coauthors-first lag	-0.002	0.008***	0.161	-
Avreferences –first lag	0.011	0.000	0.084	0.000
Observations	283	267	283	283
Instruments	60	55	60	58
AR1 test	0.013	0.075	0.004	0.007
AR2 test	-	-	-	-
Hansen test	0.785	0.507	0.615	0.473
Sargan test	0.000	0.000	0.000	0.000

Notes: *** p<0.01, ** p<0.05, * p<0.1, Windmeijer corrected standard errors obtained but not reported, Period-dummies used but not reported

We also run both estimators using the second lag of the predetermined funding variables. We do not expect the estimator to be analogously efficient since the observations are now radically reduced especially in the differences estimator. As we see from Table 3-27 where the system estimator is utilised, the first lag of RPF is robust to this new specification of the model and the second lag of the funding variables are in their majority statistically insignificant or have a sign inversely related to what is expected. The specification tests also exhibit that the model has caveats, as the AR2 test cannot be performed in any version of the model.

Table 3-28: Dynamic Fixed Effects Regressions for the effect of funding on research output indicators with two lags – differences estimator

Variables	Demeaned Publications	Demeaned JIF	Demeaned pages	Demeaned Fractional Pubs
	Coefficients			
rpf-first lag	0.113	-0.099	1.514	0.010
eu-first lag	0.072	-0.037	-0.753	0.019
internal-first lag	0.367	-0.193	1.433	0.230
otherfund-first lag	-0.267	-0.035	1.994	-0.251
rpf-second lag	0.219	-0.014	2.866	0.086
eu-second lag	-0.099	0.059	-0.875	-0.051
internal-second lag	0.105	-0.141**	1.258	-0.112
otherfund-second lag	0.901	0.046	7.163	0.474**
Experience	-0.142	-0.109	-5.975	-0.018
Experience2	-0.004	0.002	0.071	-0.004
Local coauthors-first lag	0.096	0.010	1.149*	.
Int. coauthors-first lag	0.019	-0.001	0.168	.
Avreferences –first lag	0.004	0.0001	0.096	-0.001
Observations	145	140	145	145
Instruments	35	31	35	33
AR1 test	0.854	0.071	0.287	0.290
AR2 test	-	.	.	.
Hansen test	0.595	0.582	0.506	0.305
Sargan test	0.568	0.783	0.327	0.325

Notes: *** p<0.01, ** p<0.05, * p<0.1, Windmeijer corrected standard errors obtained but not reported, Period-dummies used but not reported

In the difference estimator of which the results can be observed in Table 3-28 above, the caution should be even further extended. Now not only AR2 test is not carried out, but the AR1 test exhibits autocorrelation in the errors. All second lags of the funding variables are insignificant and the only result that can be mentioned is that Internal Funding is statistically significant for positively enhancing author-weighted publications. Nevertheless, any inference should be exercised with caution and it is wise to abstain from drawing conclusions based on the latter estimates of the model.

3.7.1 Background of the University of Cyprus

The University of Cyprus was established in 1989 and admitted its first students in 1992. It was founded in response to the growing intellectual needs of the Cypriot people, and is well placed to fulfil the numerous aspirations of the country. Despite its brief history, the University of Cyprus has earned the respect of the international academic community and the appreciation of Cypriot society.

When the University of Cyprus first opened its doors to students, the incoming class consisted of 486 undergraduate students. The Departments that existed at the time were the Physical Sciences (Mathematics, Physics, Chemistry, Computer Science) and Social Sciences (Economics, Business Administration). In 2003 the Biology department along with the Polytechnic School were founded and the latter consisted of 3 departments: 1. Civil Engineering and Architecture, 2. Mechanical Engineering and 3. Electrical and Computer Engineering. During the academic year 2013-2014 there were 7048 students (undergraduate and postgraduate). Now the University has 22 departments.

Research at the University of Cyprus is wide-ranging, and includes both the individual projects of its academic staff, as well as collaborative efforts that involve local and international research centres, institutes, and universities. To that end, the University provides its researchers with internal funding opportunities. These concern research projects and are approved by the Research Committee, following evaluation by peer review (at least two reviewers). In 2009, 28 research programmes received internal funding. Of these 28 research projects, 9 were applied research projects reaching funding of €237,750 in total.

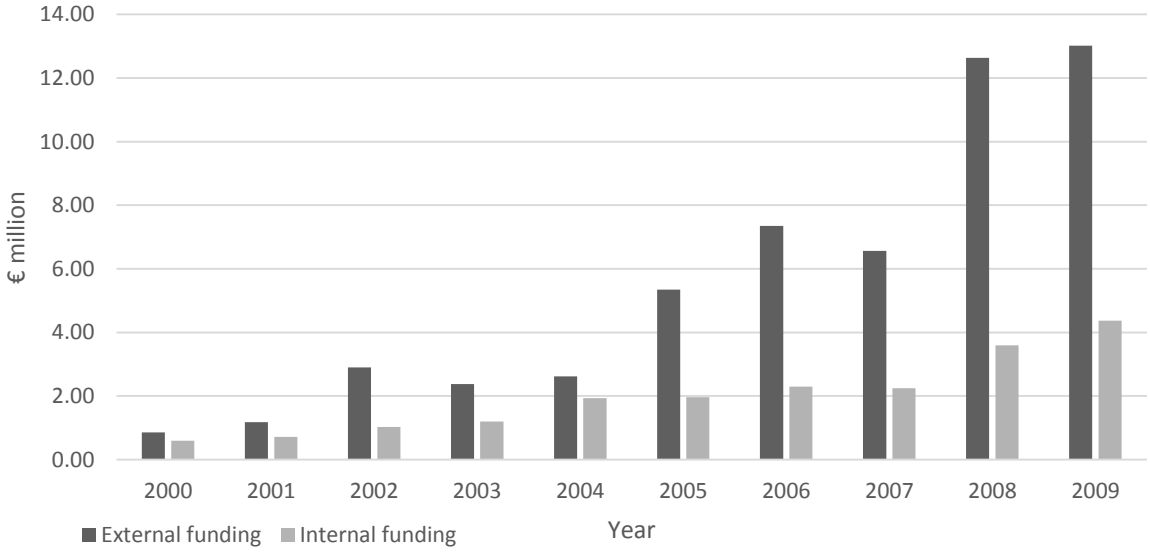
Overall, the internal research projects are characterised by collective effort, and involve a number of researchers from the University, international collaborators and postgraduate associates, and they are conducted on the basis of a specific proposal, timetable and budget. The total internal funding for research projects, in 2009, was €600,000.

In addition, since 2000, the A. G. Leventis Foundation has supported the research activity of the University of Cyprus through funding a number of research programmes in basic research. The A. G. Leventis Foundation provides the University with €170,000 annually. The A. G. Leventis Foundation has funded 15 research programmes to date and its research programmes are highly sought by members of the academic staff of the University of Cyprus. It should be noted that internal research projects funded by the Leventis Foundation, are evaluated by a peer review of international academics as well. The proposals selected for funding are those which score the highest evaluation marks.

Also, the University of Cyprus has been very active in participating in the national framework programme for research and technological development of the Research Promotion Foundation as well as the European Union Framework Programme for Research and funding schemes from other international funding agencies. The following graph compares the performance of the University of Cyprus in securing research funding. It is striking that the funding from external sources is considerably higher than internal research funding and it has increased rapidly in absolute terms since 2000. The University provides incentives to its faculty members to participate in externally funded projects and reciprocates success with the reduction of teaching

or administration hours. Generally a policy of equal distribution of workload is in place.

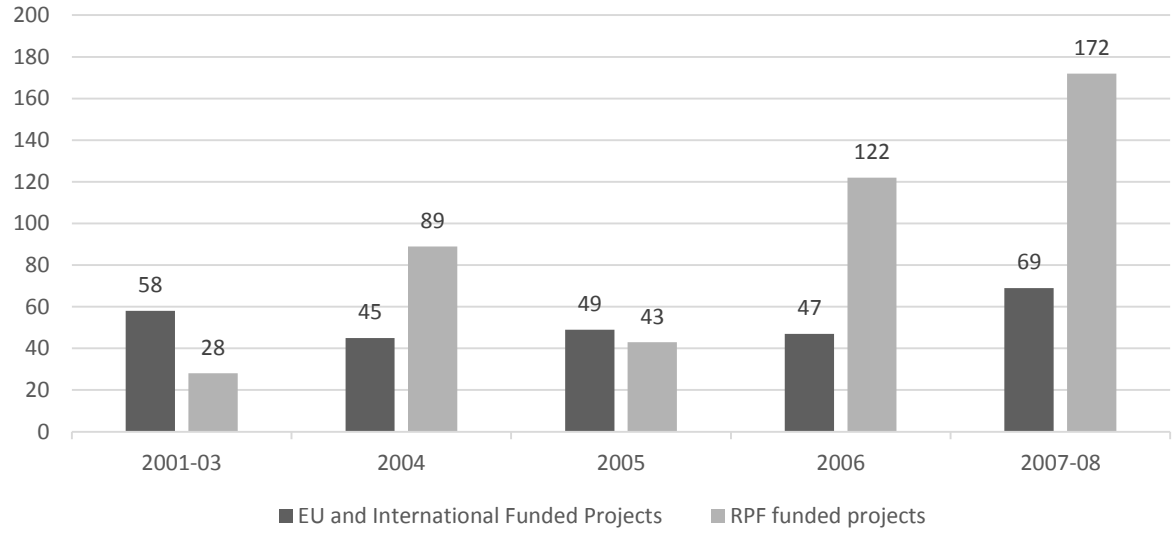
Figure 3:2: External and Internal Research Funding at the University of Cyprus, 2000-2009 (in € million)



Source: University of Cyprus Research, 2010

In the following graph the number of funded projects per year can be observed for the period 2001-2008. The clustering of specific years in groups of two (2007-08) or three (2001-03) has to do with the available calls for proposals by the RPF. For example in 2007 there were only two available calls for proposals whereas in 2008 more than 20 were released. Again the performance shows a significant annual increase for the RPF funded projects secured. Although the graph does not include information for years 2009 and 2011 (in 2010 no calls for proposals were available), it is well known that the University of Cyprus performed similarly or even better than 2008.

Figure 3:3: Number of externally funded projects of the University of Cyprus per year, 2001-2008



Source: University of Cyprus Research, 2010

4 COMPETITIVE RESEARCH FUNDING ALLOCATION: WHO GETS THE MONEY?

Abstract

We examine competitive research funding allocation by analysing if success of individual researchers in securing funding is determined by their research output indicators. We utilise data from the Research Promotion Foundation of Cyprus from 2003 to 2011 to explore the case of the faculty members of the University of Cyprus. Employing various econometric estimation methods, the results show a direct and positive association of past research performance to the funding decision for cumulative output mainly in citation-related indicators. On the contrary, lagged 3-year average and career average research output of researchers do not appear to be significant determinants of success in securing funding. These findings imply that reputation is likely to be more important than research productivity for the outcome of the funding allocation decision. Policy implications derived from the magnitude of the estimates include the need for a more efficient evaluation system for research proposals. Ideally, this evaluation system should place more emphasis on past performance rather than other criteria given the role this determinant can play as a research quality signal for the policy-makers.

4.1 Background

Research funding has become a core economic policy issue, especially with the onset of the latest financial crisis. Amidst this crisis, a number of governments tend to sacrifice the long-term development perspective of their countries for the short-term arrangement of debts and current obligations, so that markets do not downgrade their financial credibility. In contrast, other countries have supported Research and Development (R&D) to enhance the creation of new products and markets and achieve high growth rates in the long term. The latter policy option is in line with studies from the endogenous growth theoretical context which have asserted that research is the one of the most development-enhancing sectors in the economy (Romer, 1990; Aghion and Howitt; 1992; Nelson & Romer, 1996; Howitt, 1998). If research is selected as a long-term growth-enhancing policy though, it must be shielded by designing research funding schemes that can render the

allocation of grants optimal. In the opposite case, it is a double loss due to the opportunity cost of not paying debts instead. Thus, it becomes apparent that where research funding goes matters greatly especially during periods of economic recession.

As a consequence, who gets the money and what the desired result of a research funding policy is are issues that need to be examined in more depth. Does a government target the benefits of research results through allocating research grants to highly competent and reputable researchers or uses funding to integrate more researchers in the process and increase the critical mass of research output? Logically, the answer must be somewhere between these two alternatives, albeit Arora *et al* (1998) support that inequality in funding towards more productive researchers can increase research output thereby preferring the first option. Which of the two is important is usually a matter of the development of the research capacity of a country. Countries that are weak in research capacity are likely to favour the integration option more than research excellence. The opposite should apply for countries with high research capacity. Therefore, the ideal research funding allocation mechanism would be designed taking into account the intrinsic attributes of this process and the specific needs of the country initiating the policy. It is therefore useful to obtain an understanding of possible reasons that drive the decisions for allocation of research funding. In order to approximate such a finding, in this chapter we aim to mitigate the gap of the existing literature concerning the association between past research productivity and research funding allocation.

A number of studies have investigated potential determinants of success in gaining funding from competitive funding schemes (Arora, et al., 1998; Feinberg & Price, 2004). The scientific evaluation process is the most decisive factor for the allocation of competitive research funding. How the score is decided is the object of a study that attracts paramount interest (Esther-Mirjam, 1999). Our chapter addresses this gap by considering this process at the individual level.

In the past a very limited number of studies have focused on the allocation research funding and even fewer have explored the effect of past research performance in the final decision. Several studies have focused on other aspects of research funding, such as its *ex-post* economic impact, its relation with various forms of research output and its usefulness among different disciplines (*e.g.* Gonzalez-Brambila & Veloso, 2007; Auranen & Nieminen, 2010; Beaudry & Allaoui, 2012). A gap was traced in studies researching the determinants of who gets the funding. Whether the selection of funded parties is based on the scientific proficiency of the applicants, the novelty of the proposed research or other factors, such as collaboration patterns and foreseen socioeconomic impact, is unknown at the moment. A number of criteria that address these characteristics do exist in evaluation processes but are unlikely to reflect the importance and magnitude of these determinants. The absence of such studies from the literature can be largely explained by the lack of data.

The present paper attempts to exploit the existence of such publicly available data at the individual level for scientists of the University of Cyprus (UCY) with information about their funding success in the Framework Programme of the

Research Promotion Foundation of Cyprus (RPF). The main aim is to explore the determinants of funding success of academic researchers. We emphasise on the importance of research productivity of academic researchers as a determinant. Apart from the pure scientific importance of this topic, it is our normative thesis that a rational and prudent allocation of research funds must be secured so as to ensure the best results-cost ratio possible.

Therefore, the objective of this chapter is to examine the importance of past research productivity in rendering researchers more successful in securing funding. We concentrate on past research productivity, given that it is the only solid criterion that can be interpreted as a signal of human capital in research and for future research quality. Evidence derived from the findings of this chapter will ideally provide useful insights to research policy-makers.

The chapter is also expected to contribute in studying an unexplored phenomenon and might constitute the cornerstone for a new research agenda for the economists that deal with economics of science (Stephan, 1996; Diamond, 1996; Dasgupta and David, 1994). There are certainly similar data for other countries which have not yet been exploited due to the time-consuming nature of enquiring and obtaining such information from the units of interest (research funding agencies, universities, individual researchers). Thus, producing a clear and sound methodology of analysing this kind of data might play a catalytic role for other researchers to follow the paradigm and generate comparable results for other countries in the near future.

To this end, the paper is structured as follows: The next section describes the literature for research funding allocation and provides basic background information for the research funding system of Cyprus. The third section is twofold. Firstly, it focuses on the methodological approach describing the dataset and analysing the econometric models and then presents the findings for each model specification along with discussion of relevant implications. The last section concludes and provides suggestions for further research.

4.2 Literature Review

The literature in the field of economics regarding the optimal allocation of research funding is not extensive given the importance of this topic, especially within the frame of endogenous economic growth. The roots of the recognition for the importance of technological change- and thus science- for the improvement of economic growth rates goes back in the 50s where Solow (1956) concluded that the only factor which could boost the efficiency of capital and labour is technological change. There were a series of strong assumptions made in the Solow model. Solow, among many other strong assumptions, presumed that technological change is produced exogenously to the economic system but such a contention could by no means be accurate nowadays. Governments and businesses around the world devote vast amounts on research and development and therefore this process has become purely endogenous to the growth equation. This fact attaches great importance to the economics of science and, more interestingly for the purposes of the present chapter, to the mechanisms that channel funding from the government

to the academic research community. A number of science economists have endeavoured to explain the specifics of this process.

4.2.1 Previous studies

Dasgupta and David (1994) and then Stephan (1996) and Diamond (1996) offered thorough and constructive reviews of the economics of science field with some reference to research funding but no specific analysis as to the optimality of its allocation based on past research productivity. They moreover provided arguments supportive of the importance of economics of science and the role that the field should play in the formulation of economic policies for scientific research. This contention was reinforced later by Esther-Mirjam (1999) who surveyed the various studies from different disciplines that engage in science policy.

Apart from these theoretical theses, the number of studies in the literature approaching empirically the research funding allocation topic are strikingly limited. Most studies focus on the institution level (firms, universities, laboratories) but very few provide any kind of analysis at the individual level (Feinberg and Price, 2004; Arora & Gambardella, 2005; Abramo et al, 2009; Van den Besselaar & Leydesdorff, 2009). The present paper aims to address this gap using the case of the Research Promotion Foundation of Cyprus.

A number of studies emphasised on the participation and success of firms in research funding schemes. Aschhoff (2010) analysed the research funding allocation mechanism in Germany at the firm level and described the characteristics of the winning firms. The author found that having received funding in the past is an

important determinant of receiving funding again. Other critical factors concerned the size of the firm and the knowledge capacity the firm possessed. This paper showed that previous knowledge is essential for public funding allocation where the proxy used was the number of patents since at the firm level intellectual property that can commercially exploited is more important than scientific publications. Correspondingly, in our approach we utilise data regarding scientific publications and citation-related indicators as proxies of previous scientific research output.

In the same line, Blanes and Busom (2004) examined the participation of firms in research funding schemes in Spain and claimed that quality of scientific human capital and expected returns were important determinants of whether a firm would participate in a research funding proposal. Additionally, Santamaria *et al* (2010) studied the funding allocation process for a Spanish funding initiative and found that university-industry collaborations formed important decisive factors for choosing a proposal for funding.

Tanayama (2007) focused on the analysis of research proposals for obtaining funding in Finland's Tekke by Finnish firms. Awareness of the stylised facts of the funding programme was found to be critical for the funding decision. However, no provision for previous research activity was in place and thus it can be argued that the process lacks completeness with respect to the consideration of potential determinants of gaining funding. Rather, only corporate characteristics related to R&D were included in the model such as the balance sheet figure for R&D expenses. The authors admit that this type of indicator is not a reliable proxy for R&D investment and research activity.

Geuna (1998) performed an investigation of potential determinants for the participation of universities in the EU research projects and found that the key factor that explained this tendency was the previous research output of the institutions. This can be a result of two factors: either the evaluators assessed the proposals of highly productive institutions favourably or the fact that these institutions were productive in research may also be the outcome of previous successes in securing research grants. Geuna used both the probability of entering a research consortium and the number of times a university has done so and found the same results. Along with research output, the size of the institution and the thematic area of the project played an important role in the participation pattern of universities. It can be assumed that a set-up cost is in place whereas institutions having a critical mass of researchers and infrastructures have a competitive advantage over other younger institutions with less resources. In our study we consider a single institution and therefore this subject will not form an area of particular interest, although it deserves attention in future studies in the field.

Hsu *et al* (2009) go into depth in the procedural nature of the funding schemes, dealing with the selection of government-sponsored R&D projects at the state-of the-art of the scientific fields of interest. They draw upon relevant information obtained from a national research institute in Taiwan and argue that the selection is rendered difficult by the coexistence of the conflicting participating parties, the availability of experts for new technology review, and the ambiguity of new technology. They infer that differences of weights toward each of the evaluation criteria exist among various groups of peer panels. Peers from the government and

academia value social benefits more than other criteria, whereas researchers are more concerned about intellectual properties and the evaluators from the industry emphasise the importance of viability. Their results reinforce further the importance of the present paper. The subjectivity of peer reviews is likely to be evident in our results as well, inasmuch as the projects funded by the RPF aim to serve more or less the same purposes as the ones considered in Hsu et al (2009). The concern is whether the most productive and efficient researchers are given the opportunity to carry out the funded projects or an alternative selection pattern is in place, as implied by Hsu et al (2009).

Only a handful of studies have tried to explain the funding allocation process to individual scientists through different perspectives. Feinberg and Price (2004) investigate the role of social capital in the selection process for funding from the National Science Foundation Economics programme. The paper provides a thorough approach to the specificities of the NSF programme. Essentially, it explores the importance and extent of the investment in types of social capital, such as participation in professional networks (i.e. NBER) and previous research productivity in obtaining grants from the NSF. The authors use a Probit model and albeit discussing the existence of endogeneity and unobserved heterogeneity in the econometric model, the authors do not practically address these problems. Thus, their results may be a product of the existence of these problems and do not form a completely reliable base for inference.

Relatively, Arora et al (1998), used a sample of 700 research proposals submitted in the Italian National Research Council funding programmes in the thematic area of Biotechnology to study the effect of research funding on research output of research groups. They investigate *inter alia* the impact of past publications on the assigned grant budget of successful proposals. They found a positive and significant coefficient using, however, only past publications as a proxy for previous research output, as opposed to our chapter where different composite measures are used allowing qualitative adjustments. In addition, the authors limit their study in the field of Biotechnology while in the present paper a wide range of scientific fields is incorporated.

Arora and Gambardella (2005) studied the proposals submitted to the National Science Foundation in the field of Economics for the period from 1985 to 1990. They identified the attributes of the successful and unsuccessful researchers and found that publication indices are important factors for success. Nevertheless, they argue that they are not the only ones since "non-productivity" related factors, such as collaboration patterns and location, seem to be equally vital for the funding decision.

Lee and Om (1996) highlight that with reference to the criteria considered in the selection process of an R&D project from multiple proposals, the factors that are considered important at public R&D institutes are significantly different from those at private ones. The authors use a questionnaire survey approach in order to verify this assumption and find that in selecting a development project, the key factors considered important at public R&D institutes differ substantially from those at private ones. More specifically the market characteristics factor –including

components such as demand and rivalry- is considered more important at private R&D institutes, while the diffusion effect factor is considered more important at public institutes. Nevertheless, the focus of the authors is limited to distinguishing between the attributes of public and private institutions applying for funding. Neither personal nor productivity characteristics have undergone any form of special treatment something we address in this chapter.

In a different approach, the study carried out by Van den Besselaar and Leydesdorff (2009) assesses the practice of peer-review based project selection in the Netherlands Research Council funding scheme. The basic questions the authors pose are close to our objectives as they are concerned whether funding goes to the best researchers and if these researchers can be identified by the evaluators. In addition, the authors examine the degree to which other factors influence the probability of receiving funding, such as the role of co-applicants, the effects of gender, and the effect of the discipline of the application. The ultimate purpose of their study is to facilitate the improvement of the research system functioning. Their results are nonetheless both revealing and alarming: the correlation analysis showed that the past performance, represented by publications and citations of the applicant for the three-year period before the evaluation, is only weakly related to success and only low correlation exists between the indicators of past research performance and the amount of money received. This verifies the concern for non-optimality of research funding allocation to a considerable extent-albeit different conditions apply for the Netherlands in comparison to other countries- and adds further importance to the scope of our chapter. It should however be noted that

reservations exist as to the econometric approach followed by Van den Besselaar and Leydesdorff (Analysis of Variance – ANOVA) as it does not take into account important problems of the model such as endogeneity and unobserved heterogeneity.

There is a dearth of papers on the effect of past research productivity on funding success in the existing literature. These studies have shown that there is correlation of past research productivity with the funding decision outcome, albeit in most cases weak. They have found that other factors seem to be equally or more important. Since these studies have emphasised specific thematic fields, the research focus of the present chapter is rendered even more important. Also a thorough econometric approach is missing from the few studies that addressed this issue and we aim to address this shortcoming. Subsequently, we will proceed to discuss the background of research policy in Cyprus along with the system for the evaluation of research proposals.

4.2.2 Background of the Research Funding system in Cyprus

Cyprus ranked last in 2010 among EU member states in the R&D intensity performance irrespective of the vast increase observed in R&D spending in absolute terms. From 0,18% in 1992, Cyprus has reached 0,45% in 2007; far from the 3% target set by the Lisbon strategy objectives. Yet, the average growth rate of GDP of around 4% in the first decade of 2000 has not allowed the increase of research expenditure to translate into satisfactory performance in R&D intensity (research expenditure as a % of GDP), the only widely acceptable macroeconomic R&D indicator. This was limited within the range of 0.38 to 0.50 with most of the times

being the last among all other EU member states. Nevertheless, it is widely admitted that steps forward have taken place during these years and the upward course of both relative and absolute figures was the desired outcome for a country being in an infantile state in the R&D sector.

Additionally, in 2009, the decision of the government to apply cut-offs in the budget for research to compensate for the revenue reduction due to the economic crisis had spread a dose of panic amongst the research community. This had a direct effect upon the Research Promotion Foundation (RPF) programmes as well: 35% reduction in all open programmes and suspension of programmes in which proposals were not submitted at the time.

Research was essentially introduced in Cyprus after 1992 with the establishment of the first University, the University of Cyprus. Before that landmark year, minor research was carried out in a few governmental research oriented authorities such as the Agricultural Research Institute and the State Laboratory and one or two private tertiary education institutions. Research funding varied from non-existing to trivial at the time: in 1992, R&D intensity reached 0.18% of GDP whereas before that year no available data exist, even though it is widely known that the relevant ratio is unlikely to be far from zero. From 1992 until 1996 the government subsidised the University of Cyprus via the state budget in a Block-Grant fashion. No competitive funding schemes were in place at the time, as the research landscape in Cyprus was in infantile stage.

The two organisations involved in RTD policy development in Cyprus are the Planning Bureau and the Research Promotion Foundation. The Directorate General

for European Programmes, Coordination and Development (DGEPCD- former Planning Bureau) is the government agency engaged in the formulation of strategy, the identification of objectives and the introduction of policy measures aiming at the promotion of research activities in Cyprus. The DGEPCD, in collaboration with the Ministry of Finance, provides direct financing for research initiatives undertaken by the state research institutions/departments, through the annual Development Budget of the Republic. The Minister responsible for research activities in Cyprus is the Minister of Finance. In addition, the Planning Bureau is the national representative of Cyprus in the European Union's Framework Programmes on Research and Technological Development (FP) and concludes international (bilateral and multilateral) agreements aiming at the strengthening of the research capacity of Cyprus.

The establishment of the Research Promotion Foundation (RPF) in 1996 by the Cypriot government was another key milestone towards the enhancement of research funding and research in general. The RPF was founded with aim to promote scientific and technological research and provide opportunities for the development of research within both the academic and industrial sector. The Foundation is a non-governmental institution and is governed by a 12-member board, currently chaired by the Permanent Secretary of the Planning Bureau. The Foundation is fully supported by the Government and its resources are derived mostly from the Government but also from the Framework Programmes of the EU. The RPF has developed over the years a number of activities which fall into two broad categories: (a) the design, launching, funding and monitoring of National

Research Programmes, and (b) the promotion of the participation of Cypriot researchers in European Research Programmes and International Organisations.

In general, the Cypriot government funds research via two mechanisms: through direct funding to the public Universities and through a competitive scheme for both private and public research stakeholders through the programmes of the RPF. The RPF has in recent years created the Framework Programme for Research, Technological Development and Innovation (RTDI) 2008-2010 which consisted of five priority axes: The Development of Multi-thematic Research, the Development of Human Resources, the Development of Research and Innovation in Enterprises, the Enhancement of Research Infrastructures and the Promotion of International Collaboration and Networking. Its aim is to enhance RTDI activities at all levels: from improving research output, increasing the critical mass of researchers and infrastructures, developing applied research and innovation further through the provision of support to the enterprises and strengthening the links of Cypriot research institutions and researchers with international centres of research excellence.

The RPF Programmes cover a wide range of topics under the following Thematic Areas (TA): "Health and Biological Sciences", "Technology", "Sustainable Development", "Information and Telecommunication Technologies" and "Social, Economic Sciences and the Humanities". Horizontal initiatives have also been developed aiming at enhancing the limited research infrastructure in the country as well as to increase the human resources involved in research. Such initiatives include programmes addressed to young researchers and distinguished scientists from

abroad and are particularly important since they aim at enabling Cyprus to overcome the disadvantage of size and the consequent limited critical mass of researchers. Finally, the Foundation has developed several actions and measures especially for enterprises and international collaboration.

During the 2003-2007 period, the Foundation funded research projects with a total budget of approximately €68 million, while its own financial contribution was approximately €44 million (64.7%). Between October 2003 and December 2006, a total of 1871 proposals for research projects and research support actions were submitted to the Foundation. About 60% of those were eligible for funding and 597 (31.9%) were actually financed. This high success rate shows the importance attached to enhancing research in Cyprus and the funds disposed to that end. Indeed, during 2008-2010 the funds allocated for R&D were more than double through the Foundation's "Framework Programme for Research, Technological Development and Innovation 2008-2010" (DESMI 2008-2010) which carried a total budget of €120 million. The forthcoming DESMI programme is expected to have a duration from 2015-2020 and will allocate funds of around €100 million.

4.2.2.1 Evaluation process

The RPF opens calls for proposals annually and researchers submit their proposed research in standardised templates. These proposals are then evaluated to select the best and allocate funding grants until the budget is exhausted. Peer-review serves as the evaluation process of research proposals submitted to the RPF. From 2003 until 2008 the evaluation process of research proposals took place in Greece

with the assessment being undertaken by two physically-present peers. As Cyprus is a small country and most academics know their peers, all evaluators were selected from Greece. The final mark and the contents of the evaluation report were a result of a consensus process between the two evaluators. The evaluation criteria were divided in four parts: compatibility with the requirements of the relevant call of proposals, methodology, the competence of the Principal Investigator and the collaboration network and the potential of the proposal for producing innovative research results. If the evaluators could not concur on a common result, the average mark of the two would be considered as the final evaluation result. In the case where the two marks had a difference greater than 25% of the total, a third evaluator was called upon and the average of the two closest marks would replace the initial evaluation result. The evaluators could view and assess only the information that was included in the proposal and they did not have access to any additional information. If the evaluators had never heard of the principal investigators through their work in the relevant scientific field, they could not judge about their research ability using anything more than the research proposal itself. For example citation metrics that show the quality of research work were not available to them. This evaluation process created a special case where the information included in the proposal had to be true; otherwise the evaluators could not tell the difference had they judged solely from the content of the proposal.

This process changed from 2009 onwards and proposals were sent to evaluators from all over the world. The succeeding system resembles the mainstream system of peer-review where two evaluators are sent the proposal through email and

evaluate the proposals independently. Thereafter, the average mark of the two evaluation reports is considered as the final evaluation result. The process described above for a third evaluator was in effect as well. The difference in the whole process is that the evaluators have on average two-three weeks at their disposal to assess the proposals. Consequently, they have enough time to write a more thorough evaluation report since they have access to all resources available regarding the principal investigator, the collaboration network actors and the state-of-the-art of the scientific field. This fact may differentiate the importance of several factors in determining the evaluation result. One of these factors concerns the observable research output of the principal investigator. The evaluators can assess in depth the ability of the principal investigator to materialise the research project based upon his/her previous work. They can view citations, journal impact factors and other relevant qualitative metrics not accessible in the previous system. They can distinguish core contributions to the scientific field. Despite potential innovativeness and attractiveness of research proposals it is expected that evaluators would be amicable toward proposals submitted by researchers with richer research portfolios. Inexperienced researchers with no actual proof of their ability apart from a promising idea are arguably the second best choice for evaluators. This rationale reinforces the appeal for the economics of research funding and research productivity and is the central point of interest of this chapter. We want to examine to what extent this preference towards productive or reputable researchers is present and if it is based on aggregate research output or on research productivity.

As a first step, in the next section we form a reduced form production function for writing research proposals and incorporate the probability of success.

4.3 Theoretical background

The production function for submitting research proposals and gaining funding is complicated to construct as academic researchers produce multiple output such as journal publications, teaching material, funding proposals and other administrative output if they have such duties. We therefore consider a reduced-form production function to narrow the scope of our approach to funding proposals and take other output as given.

The preparation of a proposal for research funding requires dedicated resources. Simply put, for an academic researcher working for an institution, the capital K needed for the preparation of a proposal is an office, a computer and the relevant software. In some fields infrastructure may be needed, not for the preparation of the proposal *per se*, but for the proposal to meet eligibility criteria of the funding agency and/or have a reasonable probability for success. The labour needed concerns the researchers and any other collaborators in the proposed project, either internal or external. Labour-hours concern writing the proposal and communicating and collecting information from potential partners. The technical knowledge entails primarily the scientific know-how but also the experience in the specifics of the funding agency scheme. Usually, the knowledge of proposal call requirements requires extended expertise from administrators specialised in the bureaucratic procedures of different funding agencies. The production function is written down as below:

$$P_{i,t} = AK_{i,t}^{1-a} L_{i,t}^{a} H_{i,t}^{\beta} \quad (1)$$

In the production function for writing and submitting research proposals for funding, the core element that makes the difference is the skilled labour involved in the process, that is, scientists and administrators. Therefore, H is introduced in the equation to reflect this characteristic. The term A captures all existing knowledge available, upon which research proposals are based. This entails mostly scientific knowledge, *i.e.* the pool of scientific journal articles and books that reflect the state-of-the-art of scientific knowledge. The term L stands for the number of person-hours engaged into the process. Moreover, in writing a proposal, apart from the usual factors of production, there are other constituents that play a substantial role, such as social capital (networking). Having established good networks gives a comparative advantage to researchers since they can increase their participations in research proposals. Networks can also help them partner with high calibre partners thus strengthening their possibilities of acquiring funding. The networking factor could be included separately in the production function but for simplification it can be plausibly incorporated in H**.** We do so for two reasons. Firstly, the human capital that a scientist develops has much to do with the affiliations and collaborations with colleagues from other academic institutions, of which the knowledge and skills are included in writing a proposal if they participate. A somewhat similar situation applies for research administrators. A part of their job, besides helping in the making of a proposal, is to enhance the efforts of networking through continuous multidirectional partner searches. The second reason is that, unlike large scale projects (EU funded), usually the involvement of institutions other

than the coordinator, either domestic or local, in writing an RPF proposal is limited. Hence, the human capital can be written as follows:

$$H = F(S, C, N) = H_S + H_C + H_N \quad (2)$$

Where H_S represents the human capital of scientists, H_C the human capital of administrators and H_N the human capital of scientists and administrators from networking. In case where researchers write their own proposals without the participation of external partners, this results in $H_N = 0$ and H is limited to organisational resources H_S and H_C.

Human capital is the qualitative dimension of labour and the quantitative dimension expressed in person-hours devoted is expressed similarly as:

$$L = F(S, C, N) = L_S + L_C + L_N \quad (3)$$

We also take into account the probability nature of the process as well as the role of other external factors such as government budget, availability of funds and the specifics of the funding scheme. These usually vary with time and are accommodated in $G_{i,t}^{\gamma}$. Ultimately, the production function of a successful proposal is expressed as a combination of the production function of writing a proposal and the G term.

$$\Phi_{i,t} = AK_{i,t}^{1-a} L_{i,t}^{a} H_{i,t}^{\beta} G_{i,t}^{\gamma} = P_{i,t} G_{i,t}^{\gamma} \quad (4)$$

Our production function is aimed to model the process of funding allocation of the RPF to UCY researchers. Hence, some variables become fixed among researchers. The government budget given to the RPF to allocate for funding research is fixed. The allocation of this budget across different years can be a critical factor affecting success in securing funding. In a year with limited funding but the same number of

applications the success rate will be low and fewer researchers will be funded. This should be reflected in the empirical model using indicator variables for each year. Also, since only researchers from UCY are considered then the K and L elements are also kept fixed, under the assumption that the institution follows a fair policy for providing equal capital and labour (with standard working hours) to all researchers. In this way, the number of personnel and the density of their effort is uniform across faculty members. What is allowed to vary is the capital and labour from networking which can be accounted for through the inclusion of the number of external collaborators. The assumption made here is that since it is in the discretion of the researcher to choose partner institutions then the quality of these institutions should converge to be the same across researchers. Therefore, the main varying factor is $H_{i,t}^{\beta}$ which is approximated by the past research performance of the principal investigator. A three-year moving average of past publications is intuitively the most suitable and relevant measure in our view but also cumulative as well as career averages are used. The A term is field-specific and for simplification purposes we consider it as given and treat it through the inclusion of thematic-field dummies and the average number of references.

We also define another measure of success which is the probability for succeeding in at least a submitted proposal. This is expressed by

$$\Pr(\varphi_{i,t} > 0) = f(H_{i,t-k}, G_{i,t}) \tag{5}$$

Drawing from the explanation of the theoretical background, in the empirical model we look at three types of dependent variables:

1. The probability of securing at least one grant

2. The straight count of secured grants

3. The total secured grant amount

In this way we aim to secure robust inference for the extent to which the explanatory variables of interest shape success in securing funding from competitive funding schemes. In what follows, we will see in detail the methodological tools used towards that end and the findings produced by the estimation process.

4.4 Methodology and findings

This section outlines the methodology for estimating the model and the relevant findings. We structured it this way as we used a variety of model specifications and for making it more reader-friendly we addressed each model at a time and discuss the findings right thereafter. For the same reason, we include description of the theoretical bases of all model specifications we use.

The first part of methodology deals with the identification and collection of data and the explanation of the dependent and explanatory variables. Then we discuss the econometric models and the challenges that needed to be tackled, followed by each model and the findings thereof.

4.4.1 Data and Variables

The data used in the present study concern the calls for proposals of the RPF for the years 2003-2006, 2008-2009 and 2011 (for 2007 and 2010 there were not any calls for proposals mainly due to bureaucratic and design reasons but not due to lack of funding) and were collected from two sources: the "Research at the

University of Cyprus" publications from 1999 up to 2010 and the results and other relevant information from the RPF's website. The data concerned all priority axes of the RPF funding scheme but were limited to the ones that include participating researchers of the University of Cyprus so as to consider exclusively scientific research, retain homogeneity of the sample and exclude the institution factor from the model. Other key reasons for narrowing down the sample were that for the researchers of the University of Cyprus there were data available whereas not enough data existed from researchers coming from other Cypriot academic institutions. Another advantage of using Cyprus is that it is fairly comparable with other countries with similar characteristics. That is, countries with relatively small size, developing R&D systems and with Commonwealth influence and thus high literacy in English, which is considered as the language of science.

Table 4-1: Descriptive statistics of dependent variables

Dependent Variable		Mean	Std. Dev.	Min	Max	Observations
Count of funded projects	overall	0.484	0.98	0	8	N = 1083
	between	-	0.59	0	2.43	n = 171
	within	-	0.77	-1.94	6.2	T= 6.33
Funding amount in €000	overall	62.83	188.27	0	2329.37	N = 1083
	between	-	92.94	0	459.22	n = 171
	within	-	162.46	-396.38	1973.38	T= 6.33
Funded at least once in a year	overall	0.277	0.447	0	1	N=1083
	between	-	0.283	0	1	n = 171
	within	-	0.346	-0.58	1.13	T= 6.33

Table 4-1 summarises the dependent variables. The mean funding amount is around €63.000 and the average number of funded projects is 0.48 which is translated to almost one funded project every two call years or to one funded project per two researchers in the entirety of the time span of our study. Another interesting feature is that the mean rate of a researcher being funded for at least once in a year is

28%. It is a relatively high success rate and reflects the importance of research funding for Cyprus in the period under study.

The explanatory variables are summarised in detail in Table 4-10 in the Appendix of the chapter. Looking at the cumulated variables, we observe that the average h-index amounted to 9.3 whereas cumulated publications were nearly 23 and citations averaged at 534. Average publications per year of experience of the researchers were 1.74 and the corresponding figure for citations was found to be 42. It is worth noting that the average experience of the researchers participating in the funding scheme was 12.3 years. We now proceed to discuss the econometric model, the methods for its estimation and the results thereof.

4.4.2 Econometric models and findings

In order to estimate the models in the optimal manner we identify and address the challenges to be resolved. The first challenge is that the response variables are limited in their range. Some are binary but most are characterised by an explicit or implicit count nature. The hindrance in the non-linear form of our data is that estimation techniques for models with limited dependent variables are less advanced compared to the linear models. We nevertheless deploy a mixture of the most suitable methods to address these challenges as there is no single universally best solution. In this light, we attempt to tackle as many econometric problems as possible, although this is not feasible in all cases. Where this is the case, we refrain from placing extensive emphasis in the interpretation of the results and we resort in *ad hoc* selection of the method that treats the variables of interest as consistently, unbiasedly and efficiently as possible.

The econometric estimation and analysis of the data was employed at the researcher level, following a panel data approach. Hence, non-linear panel data analysis was carried out using a) the Logit model in order to capture the binary dimension of whether a researcher was approved for funding or not in a specific year, b) the Tobit model to account for the amount of funding and c) the Poisson and Negative Binomial models for the count of funded projects. However, we realised that the Tobit model had two restrictive assumptions for consistency of the estimates that could not be maintained: normality and homoskedasticity of the errors. In other models we use these restrictions limit efficiency but they produce consistent estimates. Another alternative to the Tobit model, which sidesteps its shortcomings, is to consider the dependent variables as counts of Euros or counts of thousands of Euros and estimate the model with either a Poisson or a Negative Binomial fixed effects estimator. This approach serves intuition quite well as it can reveal by how much researchers can increase their funding when they increase research productivity by one unit. When the straight count of projects funded is considered as dependent variable the use of either Poisson or Negative Binomial is dictated rather than just being an alternative option. The use of fixed effects is a key advantage of these models over Tobit, in which only random effects can be used. In addition, Poisson maintains consistency even if the data are not Poisson distributed, providing a highly desirable property. Also, both models allow for heteroskedasticity of arbitrary form and need not be normally distributed. We choose to run the Poisson and Negative Binomial models but we also report the findings of Tobit in the Appendix to secure robustness of the results.

The explanatory variables primarily entail the research output indices (interchangeably) of the researcher and other factors such as gender, domestic and international collaboration patterns, the quality of higher education, the post-doctoral experience, the year of the call of proposal, and the thematic area.

Experience and year dummies cannot be included simultaneously as independent variables since they are highly correlated and thus the corresponding matrix becomes singular and non-invertible. Therefore, we exclude experience from the model to secure a multicollinearity-free estimation process.

As regards endogeneity, it is not plausible to assume it out of our model. However, it is essential to examine and address its potential sources. At the individual level, we presume that funding is allocated to the best and most promising researchers and that this funding can help them produce more and better research. Thus, it can be argued that previous publishing activity is endogenous in the model. However, it is predetermined as funding precedes publications and the latter precede the decision for funding. As a result two-way causality is addressed adequately with the lagged values of the explanatory variables. The key concern is that potential simultaneity is not addressed with lagged values. A latent variable determining funding success and research productivity is still an impediment despite the lags. As a result the model is estimated inconsistently if simultaneity is not addressed in the model. We use the fixed effects to account for such simultaneity provided that it is time-invariant. The time-invariant fixed effect is allowed to be correlated with the regressors thus mimicking simultaneity. The desired property of the fixed effect

though is that it is integrated out of the model through the within-transformation, thereby not affecting consistency of the estimates.

The findings of the estimation of the models are also discussed in this section under each model to facilitate comparison. The tables within the chapter include information for the findings of the explanatory variables of interest. Due to their voluminous size, the full tables with information for all explanatory variables are situated in the Appendix. It is essential to note that our inference relies heavily on fixed effects models as they account for unobserved heterogeneity and simultaneity. The random effects models stand on stronger assumptions and are thus assigned lesser weight in our analysis. Lastly, multilevel modelling, albeit a very sophisticated methodological tool, assumes that both random effects and the errors are independent from the regressors and this imposes a restriction as to the extent they can be reliably trusted for statistical inference. However, as they capture the effect of different thematic fields on funding success they are discussed at some points of the chapter. We do so with caution and always in the frame of the alternative assumption of homogeneity of the researchers in the sample.

4.4.2.1 Logit model for Panel Data

Our model concerns the probability that a researcher secured at least one grant in a specific year. The Logit model for our data is derived through the statement that the probability of observing whether a researcher has secured at least one grant is dependent upon the explanatory variables, their coefficients and an incidental individual-specific parameter (Chamberlain, 1980) as follows:

$$Pr(y_{it} = 1|X_{it}, \tau_t, \beta, a_i) = G(a_i + \mathrm{X}'_{it}\beta)$$

where

$$G(a_i + \mathrm{X}'_{it}\beta) = \frac{\exp(a_i + \mathrm{X}'_{it}\beta)}{1 + \exp(a_i + \mathrm{X}'_{it}\beta)}$$

$\mathbf{X}'_{it}$ = the transpose of the explanatory variables

$\boldsymbol{\beta}$ = the coefficients of the explanatory variables

a_i = the individual random or fixed effect

τ_t = the time-specific effect

For our model the above specification is written more precisely as

$$\Pr(GRANTS_{it} = 1|X_{it}, \tau_t, \beta, a_i) = \frac{\exp(a_i + \tau_t + \mathrm{X}'_{it}\beta)}{1 + \exp(a_i + \tau_t + \mathrm{X}'_{it}\beta)}$$

Where the explanatory variables are as follows:

ROI: A Research Output Indicator (ROI) used as a human capital proxy (See Appendix, Section 4.6.2 for full explanation of all ROIs)

REF: The 3-year moving average of references of the researcher's articles to capture the breadth of the scientific field (or subfield)

INT: Number of international co-authors representing international social capital

LOC: Number of local co-authors representing local social capital

INTERNAL: The number of internally funded projects of a researcher in a year

EU: The number of EU funded projects of a researcher in a year

OTHER: The number of funded projects from miscellaneous sources of a researcher in a year

DEP: An indicator variable for the department in which the researcher is a faculty member

FEM: The gender of the researcher (female=1)

PHD: A dummy variable of whether the researcher obtained their PhD from a TOP-20 University

MASTER: A dummy variable of whether the researcher proceeded directly from a degree to a PhD without having a Master's degree
DEG: A dummy variable of whether the researcher obtained their first degree from a TOP-20 University

It is essential to have the model estimated (or at least a core version of the model) by providing for unobserved heterogeneity. This is due to the profound argument, featured widely in the literature, for simultaneity of funding and research output. It implies that there are latent factors that are time-invariant and affect the regressors, that is, inherent characteristics of individuals which cannot be neglected. We chose the Logit model since we wanted to avoid the incidental parameters problem caused by the corresponding Probit model (Wooldridge, 2002). Essentially, Probit estimates the incidental parameters α_i and as dictated by asymptotic theory when N tends to infinity the incidental parameters follow the same route. This causes severe problems in the consistency of the estimators (Chamberlain, 1980). In Logit, this incidental parameter is integrated out of the model. By using a within transformation of first-differencing to eliminate the individual effect, as the functional form of the Logit model excludes the fixed effects from the joint distribution of y and x, we obtain estimates via Conditional Maximum Likelihood (Andersen, 1970) with no concern of the incidental parameters problem.

The first approach is to estimate the model in a dichotomous setting showing whether previous research productivity is decisive in determining the success a researcher in securing funding at least once in a year. This is deployed using a Logit panel data model with Fixed and Random Effects used interchangeably. The Table

shows that most of the explanatory variables of interest are not statistically significant and a striking majority of the 3-year moving averages have signs counter to intuition. This can be a consequence of cyclical behaviour in producing research output. A possibility is that researchers that did not get funding, did not submit a research proposal. The shortcoming of our data is that we cannot distinguish between researchers that applied for funding and researchers that did not. Maybe researchers with high productivity in the last three-years before the call for proposals were taking a break from submitting proposals. Either because they published a high number of articles and shifted attention to other academic activities such as teaching and administration or because they had sufficient funds to continue their research. Another possibility could be that they were interested more in another type of funding, such as EU or funding coming from international collaborators.

The exception to this rule concerns the moving average of year-weighted publications. This variable is significant in determining success in securing funding and practically it implies that a knowledge depreciation pattern may be considered as a criterion for the evaluators. While all measures of recent research productivity expressed by moving averages fail to explain the outcome of the evaluation, this indicator is the exception providing evidence of a potential tendency for the rationale of the evaluators. Practically, this may mean that the evaluators do attach importance on recent research giving emphasis more on the previous year publications and decreasingly for the preceding two years. As for citations and the derivative indicators thereof maybe the reason they do not exhibit significance is

that the evaluators are not aware of the corresponding figures at the point of evaluation and that the number is relatively low and not commensurate of high reputation. We will see in the subsequent sections that these results are fairly robust for the count of funded projects and the funding amount secured.

Table 4-2 : Effect of past research output on the probability of securing funding at least once

Model	**Fixed Effects Logit**			**Random Effects Logit**		
Explanatory variables	**Moving average**	**Average**	**Cumulative**	**Moving average**	**Average**	**Cumulative**
Publications	-0.04	-0.698	-0.025	0.104*	0.253	-0.018
Fractional Publications	-0.156	-1.083	0.003	0.033	-0.995	
Pages	-0.501	-0.03	0.116	-0.082	-0.37**	-0.240**
Fractional Pages	-1.421	-0.036	0.122	-0.567	-0.12***	-0.639***
Citations	-0.043	-0.005	0.523	-0.131	0.13	0.084
h-index	-	-1.98*	0.22	-	1.39**	0.134**
Fractional JIF Weighted Pages	-0.012	-	-	-0.614*	-	-
Max Citations	-	-0.052	2.646	-	0.023	0.222
Fractional JIF Weighted Publications	-0.061	-	-	-0.011	-	-
Fractional Citations	-0.123	-0.024	1.279	0.001	0.045	0.175
Year-weighted Citations	-0.225	0.015	2.396	-0.030	0.122	1.248*
Year-weighted Fractional Citations	-0.348	-0.011	4.948	1.713	0.473*	3.186
Citations per page	-0.303	-	-	-0.162	-	-
Year-weighted publications	0.533*	-	-	0.693***	-	-
Year-weighted fractional publications	0.582	-	-	0.80*	-	-
First-authored publications	0.003	-	-	0.055	-	-
5-year JIF	-0.080	-	-	-0.270	-	-
JIF 2012	-0.065	-	-	0.799	-	-

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1
(b) All variables except h-index, are scaled at 1/100 at the cumulative levels.
(c) All citation-related variables at the moving average level are scaled at 1/100.
(d) Cluster-robust errors used in all models
(e) The full results along with the relevant specification tests can be found in Tables 4-12 - 4-19 in the Appendix

We now turn our attention to the estimation of the count of funded projects. We implement 4 different techniques to estimate the effect of our explanatory variables on funded projects. Below we see the models to be estimated for the number of

successful grants (Equation 8) and the number of thousands of Euros secured by a researcher (Equation 9).

$$GRANTS_{it} = \exp\big(\beta_0 + \beta_1 ROI_{it-1} + \beta_2 REF_{it-k} + \beta_3 INT_{it-1} + \beta_4 LOC_{it-1} + \beta_5 INTERNAL_{it-1} + \beta_6 EU_{it-1} + \beta_7 OTHER_{it-1} + \sum_{j=8}^{16}\sum_{i=1}^{9}\beta_j DEP_i + \beta_{17} FEM_i + \beta_{18} PHD_i + \beta_{19} DEG_i + \beta_{20} MASTER_i + \sum_{j=21}^{26}\sum_{t=1}^{6}\beta_j \tau_t + \alpha_i + \varepsilon_{it}\big) \quad (8)$$

$$MONEY_{it} = \exp\big(\beta_0 + \beta_1 ROI_{it-1} + \beta_2 REF_{it-k} + \beta_3 INT_{it-1} + \beta_4 LOC_{it-1} + \beta_5 INTERNAL_{it-1} + \beta_6 EU_{it-1} + \beta_7 OTHER_{it-1} + \sum_{j=8}^{16}\sum_{i=1}^{9}\beta_j DEP_i + \beta_{17} FEM_i + \beta_{18} PHD_i + \beta_{19} DEG_i + \beta_{20} MASTER_i + \sum_{j=21}^{26}\sum_{t=1}^{6}\beta_j \tau_t + \alpha_i + \varepsilon_{it}\big) \quad (9)$$

When the above models are estimated with the fixed effects method the time-invariant variables such as the gender, and the quality of higher education proxies are dropped from the model.

The background for each of models (8) and (9) is presented below along with the corresponding findings. These models are estimated using the estimation methodologies presented below.

4.4.2.2 Poisson Fixed Effects

The initial model we consider is the Poisson model with fixed effects (Hausman, et al., 1984; Palmgren, 1981). The non-linear character of the model allows us to accommodate the non-negative nature of the counts of funded projects per researcher and year as well as the counts of thousands of Euros they receive as grants. Tobit is very restrictive in its assumptions and therefore we prefer this

approach. The data present a significant number of zero observations, which are nonetheless a typical phenomenon in Poisson models. The model handles zeros due to the fact that the dependent variable is in fact the expected value (mean) and not zero as such. The model starts as follows:

$$Pr(Y_{it} = y_{it}) = \frac{e^{-\lambda_{it}} \lambda_{it}^{y_{it}}}{y_{it}!}$$

where λ_{it} is the mean value. The main assumption of Poisson, a highly restrictive one, states that there is equidispersion in the data, that is, the first and second moments are equal:

$$E(y_{it}) = V(y_{it}) = \lambda_{it}$$

It is unlikely for such a strong assumption to hold as in most cases overdispersion is present in a model. The same applies in the present chapter where our data are overdispersed with minor exceptions (See Table 4-1). The Poisson model however has the desirable property of providing consistent estimators even though the data are not Poisson distributed, given that $E(y_{it}) = \lambda_{it} = \exp(a_i + \mathrm{X}'_{it}\beta)$. The consistency of the estimator is derived from the first order conditions of the log-likelihood function for Poisson. The log-likelihood is as follows:

$$L(\beta) = \sum_{i=1}^{N} \sum_{i=1}^{T} (y_{it}! - e^{X_{it}\beta} + y_{it} X_{it}\beta)$$

where $y_{it}!$ is ignored in the maximisation process as it does not depend on the parameters to be estimated (Verbeek, 2008, p.225).

The first order conditions give:

$$\frac{\partial L}{\partial \beta} = \sum \sum X_{it}{}'(y_{it} - e^{X_{it}\beta}) = 0$$

where the second term in the parenthesis is equal to the statistical error ε_{it} and the equation becomes

$$\sum_{i=1}^{N}\sum_{i=1}^{T} \varepsilon_{it}\, X_{it} = 0$$

Therefore, we see that consistency is maintained if the conditional mean is properly defined and if there is strict exogeneity. However, the failure of the equidispersion property impinges on the efficiency of the estimator as the standard errors increase significantly through the adjustment to account for heteroskedasticity of arbitrary form. Such a development is necessary as consistency may be maintained without the prerequisite for data to be distributed as Poisson, but the default standard errors remain incorrect and cannot be used for reliable inference.

The fixed effects estimator adds an individual time-invariant effect which is allowed to be correlated with the regressors. This serves avoiding strict exogeneity in the model. It is essential that this effect is eliminated from estimation to avoid distorting the process and the first order conditions. The fixed effects are integrated out of the model using the condition for an individual i, $\sum_{i=1}^{T} y_{it} = 1$. This conditioning per individual conveys the drawback that individuals with only zero observations are dropped from the model. The estimator is derived from the following expression which is the first order condition above adjusted through the within transformation:

$$\sum_{i=1}^{N}\sum_{i=1}^{T} (X_{it}{}'(y_{it} - \frac{e^{X_{it}\beta}}{T^{-1}\sum_t e^{X_{it}\beta}}\, \bar{y}_{it}) = 0$$

According to Hausman et al (1984), the variance-covariance matrix of the asymptotic distribution is derived from the second order conditions below:

$$\frac{\partial^2 L}{\partial \beta \partial \beta'} = \sum \sum [-(X_{it}{}' X_{it}) e^{X_{it}\beta}]$$

The second order conditions correspond to the asymptotic variance-covariance matrix when the errors are independently and identically distributed. This is derived by

$$V(y_{it}) = \left[E(e^{X_{it}\beta} X_{it}{}' X_{it})\right]^{-1}$$

Allison and Waterman (2002) prefer this estimator over other estimators for panel count data such as the Negative Binomial, but point to the need to provide for the overdispersion by increasing the standard errors. Indeed if $E(\varepsilon_{it}^2) > e^{X_{it}\beta}$ then there is additional dispersion not explained by the above equation. We therefore adjust the variance-covariance matrix to produce cluster-robust errors and implement the multinomial quasi-conditional maximum likelihood (QMCL) estimator as proposed by Wooldridge (1999). This method proposes the following variance-covariance matrix - similar to White's sandwich errors - which is robust to both heteroskedasticity and serial correlation of arbitrary form:

$$V(\hat{\beta}) = \left[E(e^{X_{it}\beta} X_{it}{}' X_{it})\right]^{-1} E(\varepsilon_{it}^2 X_{it}{}' X_{it}) \left[E(e^{X_{it}\beta} X_{it}{}' X_{it})\right]^{-1}$$

The Fixed Effects Poisson estimator obtained using QCML will be our main point of reference in the interpretation of the results since, despite its limitations, it addresses a number of significant econometric problems such as unobserved heterogeneity, endogeneity due to simultaneity, heteroskedasticity and autocorrelation as well as the incidental parameters problem. Its limited efficiency due to the use of only within variance is the trade-off for being consistent and unbiased. In any case we endeavour to address the latter caveat using the random

effects Poisson estimator, albeit with caution as endogeneity is not provided for in the model. We explain this estimator in what follows.

4.4.2.3 Poisson Random Effects

We follow the setting of Cameron and Trivedi (2009) for the random effects Poisson model. Firstly, we adopt the assumption that $y_{it} \sim Poisson$ with mean

$$E(y_{it}|X_{it}, a_i) = \exp(\ln a_i + \beta X_{it}) = a_i \exp(\beta X_{it})$$

where a_i is the random effect and $a_i \sim Gamma(1, n)$ leading to the first order conditions:

$$\sum_{i=1}^{N}\sum_{i=1}^{T}(X_{it}(y_{it} - \lambda_{it}\frac{\bar{y}_i + n/T}{\bar{\lambda}_i + n/T}) = 0$$

and $\bar{\lambda}_i = T^{-1}\sum_t e^{X_{it}\beta}$.

In order to get pragmatic standard errors of the models we alleviate the probable downward bias of the default errors by running a cluster bootstrap on the data with a resampling process of 300 iterations.

The main caveat of the random effects model is detected in the presumed orthogonality of the regressors with the errors as a prerequisite for consistency. This implies that both the random effect and the errors of the model cannot be related to the explanatory variables. As a consequence, simultaneity is not addressed. Although explained in detail in Chapter 3 what the theoretical implications of relying on such a strong assumption are, we stress again that for the random effects to hold there must be homogeneity of sophistication amongst the researchers in the sample, stemming from a common threshold level of ability, in our case a PhD degree and some years of post-doctoral experience. The fact that we examine a

single institution reinforces this rationale as the selection process for all faculty members is uniform and reliant on threshold criteria. All researchers in our sample had a PhD and post-doctorate experience when hired.

4.4.2.4 Negative Binomial Model Fixed Effects

Another alternative to handle overdispersion is to use the Negative Binomial model. There are different variations of the model. Here we use the version known in the literature as "NB2" (Hausman, et al., 1984). But first we explain the development of the model starting with the original Negative Binomial Fixed Effect also known as NB1. It incorporates a parameter in the model to account for overdispersion which is proportional to the mean. This implies that the higher the mean of an observation, the greater the dispersion parameter (Verbeek, 2008, p.226). The Negative Binomial probability mass function is

$$f(y_{it}|\lambda_{it},\xi_{it}) = \frac{\Gamma(\lambda_{it}+y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it}+1)}\left(\frac{\xi_i}{1+\xi_i}\right)^{y_{it}}\left(\frac{1}{1+\xi_i}\right)^{\xi_i}$$

and the first and second moments are

$$E(y_{it}) = \xi_i\lambda_{it}$$

$$V(y_{it}) = (1+\xi_i)\xi_i\lambda_{it}$$

The NB1 conditions on the independence of y_{it} for any researcher of the sample across time periods (Hausman, et al., 1984) and thus the likelihood function for a researcher becomes

$$\frac{\Gamma(\sum_t y_{it}+1)\Gamma(\sum_t \lambda_{it})}{\Gamma(\sum_t y_{it}+\sum_t \lambda_{it})}\prod_t \frac{\Gamma(\lambda_{it}+y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it}+1)}$$

What is worthy of noting is that the dispersion parameter is integrated out of the model. The likelihood of all our sample is

$$\prod_i \left[\frac{\Gamma(\sum_t y_{it} + 1)\Gamma(\sum_t \lambda_{it})}{\Gamma(\sum_t y_{it} + \sum_t \lambda_{it})} \prod_t \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \right]$$

As explained before in the respective Poisson section, Allison and Waterman have initiated an on-going debate of whether NB1 can serve as an actual fixed effects estimator (Allison & Waterman, 2002). Their main argument lies with the failure of this estimator to tackle unobserved heterogeneity in the model as it applies the transformation on the dispersion parameter. As a result, in contrast to other fixed effects estimators, time-invariant explanatory variables are estimated since no within transformation takes place to eliminate them. Nonetheless, reliable inference cannot be drawn for these estimated coefficients and since our explanatory variables of interest are not included in this category, we refrain from discussing these findings. Instead, we do so for time-variant variables with the appropriate caution for their validity given the discussion for the unobserved heterogeneity.

A variation of NB1 where the dispersion parameter is adjusted is the so-called NB2, formed by Cameron and Trivedi (1998):

$$f(y_{it}|\lambda_{it}, \xi_{it}) = \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \left(\frac{\xi_i}{\lambda_{it} + \xi_i} \right)^{y_{it}} \left(\frac{1}{\lambda_{it} + \xi_i} \right)^{\xi_i}$$

The mean and dispersion being now

$$E(y_{it}) = \lambda_{it}$$

$$V(y_{it}) = (1 + \lambda_{it}/\xi_i)\lambda_{it}$$

and we observe that when ξ_i goes to infinity we obtain the Poisson fixed effects estimator. From Negative Binomial we estimate NB2. When standard errors are similar the dispersion is predicted by both models in the same manner, that is, the cluster-robust errors of Poisson and the dispersion parameter of NB2.

4.4.2.5 Negative Binomial Random Effects

We also use the Random Effects of the panel negative binomial. Again, we obtain standard errors that are robust to arbitrary heteroskedasticity using bootstrap resampling with 300 iterations.

Cameron and Trivedi (1998) summarise the model of Hausman et al (1984). The joint density of researcher i is

$$\Pr(y_{it}) = \prod_t \left(\frac{\Gamma(\lambda_{it} + y_{it})!}{\Gamma(\lambda_{it})!\,\Gamma(y_{it} + 1)!} \right) \frac{\Gamma(a+b)\Gamma(a + \sum_t \lambda_{it})\Gamma(b + \sum_t y_{it})}{\Gamma(a)\Gamma(b)\Gamma(a + b + \sum_t \lambda_{it} + \sum_t y_{it})}$$

with mean

$$E(y_{it}) = a_i\lambda_{it}/\varphi_i$$

and variance

$$V(y_{it}) = (1 + a_i/\varphi_i)(a_i\lambda_{it}/\varphi_i)$$

with

$$\frac{1}{(1 + a_i/\varphi_i)} \sim beta(a, b)$$

We will not elaborate further on this model as the process is similar with Poisson and in the discussion of our findings we do not place much emphasis on this model.

4.4.2.6 Multilevel modelling with two-level random effects

In addition to the Fixed and Random Effects estimation we also estimated a multilevel model where the thematic area is the second level of random effect, the first being the individuals. The use of multilevel modelling is necessary to have an alternative view of how the funding is allocated per department and individual. The assumption used is the same as discussed above and in Chapter 3 for the random effects models. We assume that tenured faculty are above a certain sophistication threshold which renders their ability to publish or get funding fairly homogeneous. This means that there may be a specific effect but this would tend to be random and unrelated to the explanatory variables as all researchers above that threshold have a similar talent to produce research output. Based upon this rationale, multilevel modelling accounts for the exploitation of the between variation of the data. Nevertheless, potential endogeneity problems may still be in place as, despite our assumption, it is likely that the regressors are not entirely independent of the model errors. However, overlooking important information provided by the data such as their between dimension is not a mild trade-off for the sake of treating unobserved heterogeneity and simultaneity. Therefore, we choose to implement both methods and check for potential robustness of the findings. The multilevel model below incorporates an intercept for the department of the researchers to capture idiosyncratic characteristics that influence the success in securing funding.

$$E\left(y_{ijt}\middle|X_{ijt},\varphi_{jk},\theta_k\right)=\exp\left(\beta_0+\beta_1X_{ijt}+\sum_{j=2}^{7}\sum_{t=1}^{6}\beta_j\tau_t+\theta_j+\varphi_{ij}+u_{ijt}\right)$$

where φ_{ij} is the second level random effect related to the department and it is assumed that it is normally distributed.

X_{ijt} = the explanatory variables that vary with time and across departments and individuals

β = the coefficients of the explanatory variables

τ_t = the time-specific dummy variables

θ_j = the department-specific random effect

φ_{ij} = the individual-specific random effect

u_{ij} = the errors of the model.

The results demonstrate a contrary landscape with all variables being statistically significant but only citations follow the intuitive rationale of having a positive effect on the number of projects secured for funding. Even so, the semi-elasticity appears as trivial for defining the evaluation result ranging from 0.047% to 1.9% on citation-related explanatory variables. Other than that, it is worth noting that the quantity of research output as measured by publications and number of pages is negatively associated with subsequent funded projects, albeit the thematic area is controlled for. It is important to underline that the multilevel modelling estimation process has some idiosyncratic features that render the process of interpreting the findings uncertain. Although heteroskedasticity-robust errors are obtained, the assumption of equidispersion is not bypassed. This means that the conditional mean may be correctly specified but it is not equal to the variance. The repercussions are that the estimates are unbiased but the standard errors may be inaccurate despite using White's sandwich errors. Therefore, discussions of the multilevel model results within the present chapter are carried out with caution.

Table 4-3 : Effect of past research output on the counts of funded projects

Explanatory variables: 3-year moving average	Fixed Effects Poisson	Fixed Effects Negative Binomial	Random Effects Poisson	Random Effects Negative Binomial	Multilevel Poisson
Publications	-0.648	-0.072	0.032	0.032	-0.609
Fractional Publications	-0.015	0.975	0.031	0.030	-0.072***
Pages	-0.245	-0.255	-0.020	-0.021	-0.394***
Fractional Pages	-0.193	-0.351	-0.129	-0.152	-0.867***
Citations	-0.013	-0.017	-0.002	-0.003	0.047**
Fractional JIF Weighted Pages	-0.561***	-0.611***	-0.360***	-0.359**	-0.331***
Max Citations	-	-	-	-	-
Fractional JIF Weighted Publications	-2.354	-2.263	-0.686	-0.680	0.018*
Fractional Citations	-0.053	-0.073	0.030	0.027	0.200*
Year-weighted Citations	0.051	0.024	0.105	0.097	0.358*
Year-weighted Fractional Citations	0.701	0.594	1.360	1.323	0.019**
Citations per page	-0.117	-0.129	-0.066	-0.067	0.172*
Year-weighted publications	0.153	0.181	0.208*	0.209*	0.049
Year-weighted fractional publications	0.361	0.399	0.404	0.405	-0.031
First-authored publications	-0.012	-0.006	0.018	0.018	-0.562
5-year JIF	-0.595	-0.002	0.010	0.011	0.598
JIF 2012	-0.114	0.002	0.013	0.015	0.014*

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) All variables are scaled at 1/100 except year-weighted publications, year-weighted fractional publications and First-authored publications.

(c) Cluster-robust errors used in all models

(d) The full results along with the relevant specification tests can be found in Tables 4-20 – 4-29 in the Appendix

Where the dependent variable is the count of funded projects in a call year the results remain more or less the same with the analysis of the findings of the Logit model. It is consistently observed that in the majority of the settings of the model past research productivity variables at the moving average level are statistically insignificant. This finding is in line with Van den Besselaar & Leydesdorff (2009).

The explanatory power of the independent variables is very low in our model and we could think of various reasons for this peculiarity. One reason could be that researchers at the lower end of the ladder may be more productive than their senior counterparts. A number of studies found that research productivity is related inversely to age and thus experience (Diamond, 1986; Levin & Stephan, 1991). This is usually due to limited motivation of senior faculty members as opposed to early stage researchers who are producing research output with view to achieve tenure. Therefore, for this to be the case we should observe a skewed distribution of successful proposals toward more experienced researchers. We will see later when we analyse career cumulative research output whether there is indeed a connection between experience and success.

Findings similar to the count case can be realised when the dependent variable of interest is the amount of funding received. Table 4-4 presents the findings for this model. The 3-year moving averages of previous research output are unable to provide a substantiated association with the grant amount and this finding may be worth elaborating in terms of potential causes. Do evaluators look at recent research or not? If the degree to which a researcher is active in a field with recent successes in producing journal articles is not relevant to the evaluators then perhaps the results explain just that. But it would sound unreasonable for recent research to not have essential weight in the decision of the evaluators for awarding a grant in the sense that state-of-the-art research is usually related to recent breakthroughs. An argument to support such a contention could be that recent research was not exposed to the research community for enough time for its quality to be adequately

assessed. Thus the evaluators are not aware of these recent developments in a researcher's career. Stepping on this viewpoint, we would expect to find other dimensions of research output to matter more for the decision for funding allocation. Therefore, it remains to be seen from the subsequent analysis whether reputation related to the whole career of a researcher or the density of that career make more difference in the judgement of the evaluators than up-to-date research.

Table 4-4 : The effect of past 3-year moving average research productivity upon funding amount secured

Explanatory variables: 3-year moving average	**Fixed Effects Poisson**	**Fixed Effects Negative Binomial**	**Random Effects Poisson**	**Random Effects Negative Binomial**	**Multilevel Poisson**
Publications	0.017	-0.005	0.017	0.057	0.15***
Fractional Publications	0.075	-0.116	0.076	-0.024	0.112***
Pages	-0.374	-0.202	-0.374	-0.063	0.578***
Fractional Pages	-0.306	-0.849	-0.305	-0.630	0.126***
Citations	0.033	-0.014	0.033	0.038	0.150***
Fractional JIF Weighted Pages	-0.600***	-0.667***	-0.597**	-0.169	-0.137***
Max Citations	-	-	-	-	-
Fractional JIF Weighted Publications	-0.015	-0.041	-0.015	0.025	0.030***
Fractional Citations	-0.208	-0.013	0.208	0.202	0.301***
Year-weighted Citations	0.579	-0.134	0.578	0.260	0.012***
Year-weighted Fractional Citations	3.275	-1.030	3.275	1.975	0.047***
Citations per page	0.059	-0.113	0.059	0.130	0.655***
Year-weighted publications	0.29	0.234	0.29	0.308*	0.44***
Year-weighted fractional publications	0.71***	0.046	0.707*	0.202	0.688***
First-authored publications	0.09	0.011	0.09	0.029	0.198***
5-year JIF	0.047	-0.034	0.039	0.017	0.099***
JIF 2012	0.052	-0.073	0.044	0.023	0.104***

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Pages, fractional pages, citations, fractional citations, citations per page and Fractional JIF Weighted Pages are scaled at 1/100.

(c) Cluster-robust errors used in all models

(d) The full results along with the relevant specification tests can be found in Tables 4-40 – 4-49 in the Appendix

We now turn to examine the importance of career related research output indicators. The findings demonstrate evidence of a positive association of reputation-related indicators to the success of obtaining funding and specifically to the number of grants. Citations are statistically significant at the 1% level of confidence in the fixed effects setting, although their impact is as much as 0.3% for

each additional citation. The h-index is important at the 10% level and its marginal impact is higher, around 18% on the funded projects for an increase of one unit. This is likely to be due to the slow-changing nature of the h-index especially in the higher levels. Indicatively, we can see that in order to increase h-index by one unit when it is equal to 1 it requires a journal article with at least two citations which is feasible more easily. When h-index is equal to 30 then for a one unit increase, an additional publication with at least 31 citations is required which is not frequently the case for all thematic fields and still it may not be enough. If of the 30 publications with at least 30 citations there are some that have exactly 30 citations then an additional publication which receives 3000 citations is not capable of changing the h-index to 31. This happens because the researcher will not have 31 publications with at least 31 citations as the h-index definition dictates. The h-index does not capture major breakthroughs and this is a well-known caveat which is sidestepped by ameliorating the list of output quality indices with the max-citations variable. In any case, h-index is a core measure of reputation of a researcher and consistency in producing high quality research and it seems that it matters for the decision of earmarking a research grant. The Journal Impact Factor is insignificant in all settings of the model.

Table 4-5 : The effect of past cumulative research productivity upon count of funded projects

Explanatory variables: Cumulative	Fixed Effects Poisson	Fixed Effects Negative Binomial	Random Effects Poisson	Random Effects Negative Binomial	Multilevel Poisson
H-Index	0.179*	0.186*	0.088***	0.09***	0.029***
Citations	0.302***	0.310*	0.056	0.057	0.043***
Publications	0.129	-0.095	-0.165	-0.180	-0.011***
Max Citations	0.028***	0.025***	0.108	0.111	0.037
Year-weighted Citations	0.795	0.860	0.456	0.468*	0.383***
Year-weighted Fractional Citations	0.034***	0.036*	0.016**	0.017*	0.01**
Pages	-0.019	-0.011	-0.089	-0.090	-0.155***
Fractional Pages	-0.180	-0.164	-0.303**	-0.304**	-0.426***
Fractional Citations	0.865***	0.920*	0.126	0.129	0.058**
Fractional Publications	-0.01	-0.013	-0.025	-0.026	-0.04***

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Citations, max citations, year weighted citations, pages, fractional pages and fractional citations are scaled at 1/100.

(c) Cluster-robust errors used in all models

(d) The full results along with the relevant specification tests can be found in Tables 4-30 – 4-34 in the Appendix

Table 4-6 presents the findings of the estimation process when the dependent variable is the secured funding amount. The h-index is significant at the 1% confidence level and with a semi-elasticity of 24,1%. This result is according to intuition and in line with the reputation factor and its probable role in the evaluation process. Another metric of reputation is the maximum citations in an article received during the career of a researcher up to the point of the evaluation of grant applications. Such a metric can proxy the influence of ground-breaking contributions to knowledge in shaping the decision of the evaluators, even if such novelties form the exception in a researcher's career. The result is robust for both count of funded projects and the funding amount and is situated around the region of 2,5 to 3% in the fixed effects models. Publications in absolute numbers do not seem to count for judging the potential of research proposals to be funded. Both the statistical

significance and the magnitude of the coefficients are at low levels expressing that research quality matters more than quantity for success in securing funding. The same non-significance applies for the number of pages.

The recentness of research output and the depreciation of knowledge relevance, are represented by year-weighted citations and the same metric normalised by co-authors. These metrics seem to matter for defining the grant amount whereas the latter also matters for the number of grants. The significance is at the 99% level of confidence showing high statistical value. The marginal effect on funding amount is at 1,3% for year-weighted citations and 4,6% for the fractional counterpart. For the counts of grants the semi-elasticity of the coauthor- and year-weighted citations is 3,4%. Fractional citations in both settings present a semi-elasticity of 1% at the 99% level of confidence.

Table 4-6 : The effect of past cumulative research productivity upon funding amount secured

Explanatory variables: Cumulative	**Fixed Effects Poisson**	**Fixed Effects Negative Binomial**	**Random Effects Poisson**	**Random Effects Negative Binomial**	**Multilevel Poisson**
H-Index	0.241**	0.101**	0.238*	0.091***	0.223***
Citations	0.318**	0.041	0.312*	0.042	0.057***
Publications	0.628	-1.011	0.628	-0.533	1.579***
Max Citations	0.024***	0.048	0.02*	0.096	0.163***
Year-weighted Citations	0.013***	0.010**	0.013*	0.609	0.01***
Year-weighted Fractional Citations	0.046***	0.030**	0.046	0.02	0.033*
Pages	-0.084	-0.059	-0.084	-0.116	0.182***
Fractional Pages	-0.43	-0.233	-0.427	-0.372	-0.254***
Fractional Citations	0.915**	0.207	-0.896	0.129	0.258***
Fractional Publications	-0.010	-0.025	-0.011	-0.033*	0.026***

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Citations, max citations, publications, pages, fractional pages and fractional citations are scaled at 1/100.

(c) Cluster-robust errors used in all models

(d) The full results along with the relevant specification tests are in Tables 4-50 – 4-54 in the Appendix

The analysis of the career-average of research productivity metrics as presented in Table 4-7 provides ambiguous results. It shows that the density or recentness of research output seem to play a secondary role for grant allocation in our sample. Only co-author-normalised quality variables are statistically significant for explaining grant success in the fixed effects models. H-index, citations and publications are not verified as determining factors of the number of grants secured. The quality of net research output along with its relevance are pivotal, judging from the findings. How this is practically translated is controversial. It is highly unlikely for evaluators to calculate such metrics and use them as criteria for their decision. A rational explanation could be that they tend to evaluate favourably single-authored publications or publications with just a few authors, which are more relevant and well-known to them more than all other types of publications. Another possible reason is that evaluation may be more amicable to specific subfields. These may, on the one hand, be of increased interest to the research community and thus receive many citations but, on the other hand, the norm may be to have a small number of authors thereby increasing the net score of these weighted indicators. We expect the control of average references to capture such tendencies but we acknowledge that this may not always be the case.

On the contrary, when we look at the random effects estimates we see that all major ROIs at the career-average level are statistically significant. This implies that if there is a threshold effect of researchers then the density of their career achievements makes an impactful difference in who gets the money.

Table 4-7 : The effect of past average research productivity upon count of funded projects

Explanatory variables: Average	Fixed Effects Poisson	Fixed Effects Negative Binomial	Random Effects Poisson	Random Effects Negative Binomial	Multilevel Poisson
H-Index	-0.202	-0.14	0.83**	0.852***	0.412**
Citations	0.935	0.910	0.796**	0.804**	0.715***
Publications	0.181	-0.161	0.286**	0.288**	-0.017
Max Citations	-0.487	0.134	0.904	0.931	0.689**
Year-weighted Citations	0.099	0.10	0.034	0.034	0.026***
Year-weighted Fractional Citations	0.705***	0.69***	0.245**	0.249**	0.151***
Pages	0.017	0.016	-0.01	-0.01	-0.023***
Fractional Pages	0.054	0.05	-0.055***	-0.055***	-0.074***
Fractional Citations	0.073***	0.071**	0.03**	0.03**	0.018***
Fractional Publications	0.536	0.465	-0.192	-0.197	-0.667***

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Citations and max citations are scaled at 1/100.

(c) Cluster-robust errors used in all models

(d) The full results along with the relevant specification tests can be found in Tables 4-35 – 4-39 in the Appendix

Taking a thorough look at the corresponding models that investigate the behaviour of the grant amount, we infer conflicting results for Poisson and Negative Binomial models. The coefficients are largely different for h-index and fractional publications showing a difficulty in safe interpretation of the results. The 1.09 coefficient of h-index observed in the Fixed Effects Negative Binomial model practically means that with an increase of 1 unit in the average h-index researchers more than double the average amount of funding they secure. Although striking, upon second reading this finding is plausible, in the sense that an increase in the average h-index of one unit means an absolute increase of roughly 12 units in the total h-index if we consider the average experience of 12 years of the researchers in the sample.

Table 4-8 : The effect of past average research productivity upon funding amount secured

Explanatory variables: Average	Fixed Effects Poisson	Fixed Effects Negative Binomial	Random Effects Poisson	Random Effects Negative Binomial	Multilevel Poisson
H-Index	0.082	1.091**	0.10	1.32***	2.676***
Citations	0.625	0.740	0.632	0.879**	0.015***
Publications	0.266	0.226	0.268	0.252	0.96***
Max Citations	-0.842	0.807	-0.770	0.015	0.028***
Year-weighted Citations	0.103	0.103*	0.102	0.044	0.068***
Year-weighted Fractional Citations	0.64**	0.487**	0.635*	0.297**	0.523***
Pages	2.292	-0.297	0.022	-0.016	0.057***
Fractional Pages	-0.051	-0.04	0.048	-0.073**	0.084***
Fractional Citations	0.059*	0.041***	0.059	0.033	0.056***
Fractional Publications	0.547	-0.034	0.537	-0.446	1.484***

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Citations, max citations and pages are scaled at 1/100 in the fixed effects settings.
(c) Cluster-robust errors used in all models
(d) The full results along with the relevant specification tests can be found in Tables 4-55 – 4-59 in the Appendix

4.5 Conclusions

The present chapter aimed at contributing to the existing economics literature by investigating the determinants of research funding allocation through an empirical approach at the researcher level. The foundations of this venture relied heavily upon the continuously developing field of the economics of science and its interrelation and importance to the process of economic growth.

Very few studies have investigated the dynamics of research funding allocation to individual researchers, let alone the role of past research productivity in the process. These studies have either explored specific thematic areas or have used methods that did not account adequately for past research productivity. Our approach to address these gaps utilised econometric methods that provided for important

econometric challenges such as simultaneity, double causality and unobserved heterogeneity.

The results are to a certain extent according to intuition: past research performance seems to have a significant effect upon funding success of researchers in our sample, but more solidly when measured in career-cumulative terms. However, the magnitude of this effect deviates from the general notion of the role that previous performance should play in the evaluation result. Also the recentness of previous research output was statistically insignificant and posed scepticism whether the evaluators are skewed towards experienced researchers regardless of being active in research or not.

If we accept the stronger assumption of a random individual-effect which is unrelated to previous research performance of researchers then the results for career-average productivity become both statistically significant and high in magnitude. Especially when the findings from multilevel modelling are the source of inference then the recentness of research output is also a positive and significant determinant of funding success but only in terms of the amount of funding secured. We should note though that reservations for the strong assumptions of random effects models should be maintained.

Intuitively, one would expect the best performing researchers to be the best in gaining funding as well. However, the funding system in the case considered may work in such a way that this is only partially true. Several other criteria are likely to play a substantial role aside from previous research portfolios such as priority axes, thematic areas and years of the call of proposals.

The findings seem to be counter to expectations for optimal research funding allocation based on best research performance. A relevant policy implication examined in Chapter 6 is that all aspects related to bureaucracy must be progressively reduced bringing research funding schemes to the essence of their existence, that is, to fund the most promising and worthy of trust research proposals. If the system is imperfect in evaluating best and most relevant research output, researchers that know very well the particulars of submitting a research proposal may outperform more competent researchers and secure the funding. Scientists who are exceptional at their research work but lack in terms of comprehending and applying the bureaucratic requirements of funding schemes may find difficulties in competing with their bureaucracy-literate peers.

The chapter has a number of limitations which are inherent in the process of examining competitive research funding schemes. The first is that we use data that are publicly available and we respect anonymity of researchers. Hence, we have data for which researchers obtained funding, how many projects they secured in each call and what was the amount of the successful proposals. We lack information for the researchers that did not secure funding or the ones that never applied for funding. This means that in the interpretation of the findings, we must take into account this dual probability as it is a potential source of selectivity bias. What we do know though is that the RPF funding scheme which we examine in this chapter is the most highly valued source of funding among the academics of the UCY as expressed by the findings of a related questionnaire (University of Cyprus, 2010).

This reinforces the notion that it is the norm in the academic environment of the researchers of our sample to apply for funding from the RPF funding scheme.

The other shortcoming of our chapter is that the count or dichotomous form of the data does not allow to estimate a dynamic model where we could use the previous successes in the same funding scheme as an explanatory variable. Log-transforming the dependent variable is not an option since there is a significant number of meaningful zeros that are dropped from the process. Nevertheless, the use of an individual-fixed effect captures potential autocorrelation and both the QCMLE and the NB models also provide for autocorrelation. In addition, we use as explanatory variables the number of funded projects from other funding schemes which can mitigate potential omitted variables problems.

Finally, the other difficulty in estimating the models is that we have a number of different thematic fields with different research output patterns. In the random effects setting we use a dummy variable for each field thus accounting for the problem. In the multilevel model the scientific field effects are estimated at a separate level. In the fixed effects models though the scientific field variable is dropped in the estimation process as it is time-invariant. An offsetting factor is that the within transformation at the level of the individual provides for the specific effect of the individual related to his/her scientific field. We also use the average number of references as a control in the model to account for the size of subfields. We use a number of different research output indicators to tackle this heterogeneity among fields and we also use the average number of references as a proxy of the size of the field. For example, the total number of publication pages tends to be uniform

across scientific fields, as when the norm is that only a few papers are published, these tend to be of many pages. On the contrary, in fields where the norm is to publish many articles, these tend to consist of just a few pages. We also tested whether demeaned variables (by the mean of the scientific field) could produce more reliable results. The findings do not differ much from the initial setting. In any case we discuss the findings with caution as despite the actions taken to mitigate the different patterns across scientific fields, they may still be persistent.

Therefore, in considering future research, it seems vital to explore larger and richer datasets, including both applications and successes of researchers, either from multiple national funding agencies or from a funding scheme with multiple participants from different countries. Undertaking such large-scale research could provide with solid evidence for the determinants of funding success at the researcher level and then such an approach could be extended to institutions and countries. These findings will unveil the unknown aspects of the research funding process and give directions to policy-makers to choose the right policies and funding schemes. From a normative economics point of view, the allocation of grants in funding schemes across different countries should be done optimally. Past research performance is a consistent signal for identifying the best researchers and can be used as a vehicle by policymakers to achieve optimal allocation of funding.

4.6 Appendix of Chapter 4

4.6.1 The Tobit model

The Tobit model censors the outcome either at a low or high threshold and even a combination of the two if applicable. In our model the censoring could take place at zero reflecting the latent variable of the evaluation outcome or the choice of researchers not to submit a research proposal. If this outcome is negative then it causes funding to become zero. In the opposite case, funding is positive and dependent on the budget of proposals and the availability of money. Nevertheless, Tobit carries two drawbacks that are difficult to either tackle or disregard. First, normality and homoskedasticity of the errors are prerequisite criteria for consistency of the estimators. Violating any of these two conditions leads to biased estimates. These assumptions are strong by definition and rarely does a model achieve compliance to that respect. In other more preferable estimation processes though, such as OLS or Poisson, these assumptions can be dealt with heteroskedasticity-robust errors as they do not have an impact on the consistency of the estimators. Second, in the panel data Tobit the individual effect cannot be fixed. The only option is to run a random-effects with individual dummies even though the problem is not solved. In our model this estimation process is burdensome and does not converge. Despite these deficiencies, we considered Tobit as the natural starting point since intuitively it is appealing. We use tests to check for these assumptions although we know that finding satisfactory values for their statistical validity is highly unlikely.

The model is as follows:

$$f_{it}^{*} = \beta X_{it}' + \alpha_i + \varepsilon_{it}$$

where f_{it}^{*} = a latent variable for the outcome of the evaluation processes

X_{it}' = the transpose of the explanatory variables

β = the coefficients of the explanatory variables

a = the individual random effect

$$f_{it} = \begin{cases} f_{it}^{*} \text{ if } f_{it}^{*} > E \\ 0 \text{ if } f_{it}^{*} < E \end{cases}$$

f_{it} = the amount of funding secured

E = the evaluation threshold for success

We do not ask for heteroskedasticity-robust errors in the process since homoskedasticity is a prerequisite for consistency of the estimated coefficients, unlike other models where this assumption can be relaxed and still obtain consistent estimates (Wooldridge, 2002). Therefore if the errors are not homoskedastic the model fails to provide reliable findings. The results are reported in Table 4-9 but they are strictly for informational purposes and given minor emphasis compared to the other estimators.

Table 4-9 : Random Effects Tobit model for the effect of past research output on the counts of funded projects

Model	**Random Effects Tobit**		
Explanatory variables	Moving average	Average	Cumulative
Publications	14.744*	51.57	-2.267
Fractional Publications	9.289	-132.74*	-10.40**
Pages	-0.167	-6.11**	-0.436***
Fractional Pages	-1.11	-19.03***	-1.075***
Citations	0.072	2.30***	0.157**
h-index	-	262.87***	22.27***
Fractional JIF Weighted Pages	-0.962**	-	-
Max Citations	-	4.50**	0.447**
Fractional JIF Weighted Publications	1.319	-	-
Fractional Citations	0.582	7.19**	0.309
Year-weighted Citations	0.70	11.22**	0.012*
Year-weighted Fractional Citations	7.35	66.15**	4.774**
Citations per page	0.112	-	-
Year-weighted publications	89.167***	-	-
Year-weighted fractional publications	149.844*	-	-
First-authored publications	18.128	-	-
5-year JIF	4.161	-	-
JIF 2012	5.432	-	-

From the Table we see that quality of research output is what matters for getting funding but at the career-aggregate and the average level. For the moving average, the quantity of publications, both straight count and knowledge depreciation-weighted, are the only dimensions of research output that are prominent in explaining the amount of successful grants.

Table 4-10 : Detailed descriptive statistics of explanatory variables

Variable		Mean	Std. Dev.	Obs.	Variable		Mean	Std. Dev.	Obs.
movavcitations	overall	88.39	176.65	N=1099	movavpubs	overall	4.34	4.37	N=1099
	between		122.38	n=157		between		3.55	n=157
	within		127.71	T=7		within		2.56	T=7
movavjifap	overall	47.8	61.98	N=1099	movavcitationspp	overall	11	34.05	N=1099
	between		48.54	n=157		between		23.35	n=157
	within		38.71	T=7		within		24.84	T=7
movavpages	overall	57.3	54.86	N=1099	moavwpubs	overall	0.64	0.84	N=1099
	between		44.02	n=157		between		0.54	n=157
	within		32.9	T=7		within		0.65	T=7
movavap	overall	24.3	26.03	N=1099	movavwfpubs	overall	0.25	0.31	N=1099
	between		20.5	n=157		between		0.2	n=157
	within		16.11	T=7		within		0.24	T=7
movavfrpubs	overall	1.72	1.69	N=1099	movavfirst	overall	1.32	1.76	N=1099
	between		1.34	n=157		between		1.24	n=157
	within		1.03	T=7		within		1.25	T=7
movavfrjifpubs	overall	3.79	5.21	N=1099	movavjif2012	overall	8.31	5.72	N=354
	between		4.21	n=157		between		6.37	n=108
	within		3.09	T=7		within		2.34	T-bar =3.3
movavfrcitations	overall	27.9	47.07	N=1099	movavjif5	overall	8.86	5.58	N=346
	between		33.83	n=157		between		6.38	n=106
	within		32.82	T=7		within		2.42	T-bar =3.3
movavwcitations	overall	9.95	20.21	N=1099	movavwfrcitations	overall	3.09	5.05	N=1099
	between		13.13	n=157		between		3.56	n=157
	within		15.39	T=7		within		3.59	T=7
frpages	overall	95.63	105.11	N=1120	avfrpages	overall	7.71	6.18	N=1120
	between		100.65	n=160		between		5.62	n=160
	within		31.17	T=7		within		2.59	T=7
frcitations	overall	96.89	146.29	N=1120	avfrcitations	overall	7.91	11.03	N=1120
	between		145.88	n=160		between		10.39	n=160
	within		15.34	T=7		within		3.79	T=7
avhindex	overall	0.62	0.52	N=1120	hindex	overall	6.44	5.66	N=1120
	between		0.44	n=160		between		5.58	n=160
	within		0.28	T=7		within		1.03	T=7
avcitations	overall	25.72	45.69	N=1120	citations	overall	298.82	539.54	N=1120
	between		43.44	n=160		between		537.76	n=160
	within		14.51	T=7		within		58.9	T=7
avpublications	overall	1.31	0.95	N=1120	publications	overall	16.39	17.28	N=1120
	between		0.89	n=160		between		16.36	n=160
	within		0.35	T=7		within		5.69	T=7
avfrpubs	overall	0.56	0.4	N=1120	frpublications	overall	7.07	7.51	N=1120
	between		0.37	n=160		between		7.22	n=160
	within		0.16	T=7		within		2.14	T = 7
avmaxcitations	overall	8.5	19.56	N=1120	maxcitations	overall	79.51	155.65	N=1120
	between		17.73	n=160		between		155.52	n=160
	within		8.37	T=7		within		13.07	T=7
avwcitations	overall	2.59	4.89	N=1120	wcitations	overall	27.31	46.77	N=1120
	between		4.27	n=160		between		44.44	n=160
	within		2.41	T=7		within		14.93	T=7
avwfrcitations	overall	0.77	1.08	N=1120	wfrcitations	overall	8.49	11.93	N=1120
	between		0.97	n=160		between		11.51	n=160
	within		0.49	T=7		within		3.24	T=7
avpages	overall	16.76	11.37	N=1120	pages	overall	206.43	210.5	N=1120
	between		10.23	n=160		between		197.45	n=160
	within		5.02	T=7		within		74.4	T=7

4.6.2 Research output Indicators

As it is asserted, different research output indicators may give different productivity results for the same researcher (Henrekson & Waldenstrom, 2011). This argument renders the use of diverse indicators mandatory for drawing reliable and robust inference. In this light, as dependent variables, we use several research output indicators, most of them composite. In what follows, it is explained how each variable is calculated and what it represents. We divide the analysis in cumulative, career average and 3-year moving average values. The calculation for each of the three weightings is explained in Table 4-11.

Publications: It is the straight publications count of a researcher regardless of coauthorship. The publications are the ones included in ISI Web of Science, thereby adding a minimum threshold of quality to the indicator since the database has the vast majority of top journals in the fields under study. It is denoted by $P_{rT} = \sum_{i=1}^{n} P_i$, where i stands for publications.

First-Authored Publications: It refers to the publication where the author's name is written first in the official journal. This indicator does not take into account the number of coauthors. It emphasises on the possibility that the first author is related to the originality of the idea as well as increased research effort and recognition compared to the coauthors. We assume that this is plausible for all scientific fields. It is denoted by Φ_i.

frpubs: It is the straight publications count of a researcher divided by the number of authors. The coauthorship is taken into account at the publication level and then the results are aggregated. The indicator is denoted by f_i.

wpubs: Weighted Publications are the average publications of a researcher for a three-year period before the evaluation year whereby each publication is weighted by the number of years passed since the publication year (t_0). In mathematical notation we have $WP_{rT} = \frac{1}{3}\sum_{i=t-3}^{t-1} P_i\,/(t - t_0)$.

wfpubs: Weighted Fractional Publications are the average fractional publications of a researcher for a three-year period before the evaluation year whereby each fractional publication is weighted by the number of years passed since the publication year (t_0). In mathematical notation we have $Wf_{rT} = \frac{1}{3}\sum_{i=t-3}^{t-1} f_i\,/(t - t_0)$.

citations: Denoted by C_i , it represents citations that a researcher received as measured in April 2014. This unweighted index is meaningful only if thematic field dummies are included as a control for the size of the thematic area. In the fixed effects models where time-invariant variables such as thematic field dummies are dropped, we use the number of average number of references as a control for the size of the field.

maxcitations: Denoted by x_i, it represents the maximum citations that a researcher received in a single paper measured in April 2014. This index aims at capturing if a researcher has published a paper with very high impact not captured by the other indices.

frcitations: Citations that an article received, as measured in April 2014, divided by the number of authors of the article. It is symbolised with $c_i = C_i/a_i$.

citationspp: Citations per page are the average citations of a researcher for a three-year period before the evaluation year per article page. It is symbolised with

$gc_{rt} = C_{rt}/g_{rt}$.

wcitations: Weighted Citations are the total citations for a researcher weighted by the number of years passed since the year of the publication or in mathematical notation, $w_i = C_i/(2014 - t_i)$. For example, a publication in year 2008 which received 10 citations will have a wcitations measure of 10/(2014-2008)=10/6=1.67.

wfcitations: Weighted Fractional Citations are Weighted Citations divided by the number of authors so that the net research output per researcher is measured. The equation is similar to the wcitations indicator only now C_i is replaced by c_i resulting in $\rho_i = c_i/(2014 - t_i)$. A publication in year 2008 which received 10 citations and had 3 coauthors will have a wfcitations measure of (10/3)÷(2014-2008)=10/18=0.56.

jif5 or jif2012: The 5-year (2008-2012) Journal Impact Factor (JIF) deviation of a publication is the deviation of the JIF of the journal -that includes the publication- from the average JIF of the scientific field divided by that same average. This gives an insight of the significance of the publication's journal as compared to the other journals of that field and dividing it by the average allows for comparison among thematic areas as it is transformed into a relative variable. The equation is $\Pi_i = (\pi_i - \bar{\pi})/\bar{\pi}$, where π_i is the JIF of the journal within which the article is published and $\bar{\pi}$ is the mean JIF of the scientific field as derived

from the ISI Web of Science. We also use JIF2012 as an alternative measure for checking robustness of the findings.

pages: It measures the pages of each publication and it is denoted by g_i.

frpages: It measures the pages of each publication divided by the number of authors. It is denoted by $k_i = g_i/a_i$.

jifap: JIF-Author-Pages measure multiplies the JIF deviation by the pages of the publication and divides by the authors but this time using the average JIF of the scientific field., that is $Y_i = (\pi_i - \bar{\pi})g_i/a_i$. A publication with 10 pages and 5 coauthors in a journal that has a JIF of 1.5, in a scientific field that has an average JIF of 1, will have the following avjifap: (10/5)*(1.5-1)=2*0.5=1.

jifauth: JIF-Author measure is expressed by $y_i = (\pi_i - \bar{\pi})/a_i$. Essentially, it divides the JIF deviation from the scientific field mean by the authors of an article. A publication with 5 coauthors in a journal that has a JIF of 1.5, in a scientific field that has an average JIF of 1, will have the following avjifap: (1.5-1)/5)=0.5-5=0.1

h-index: This indicator is measured directly at the aggregate level instead of the unit level as all other indicators. It is denoted by h_R and represents the h number of publications of researcher r that received at least h citations.

Table 4-11 below synopsises all research output indicators along with their notation and their corresponding calculation formulae as explained above.

Table 4-11: Research output indicators used as dependent variables

Dependent Variable	Cumulative	Career Average	3-year moving average
JIF5 (or JIF2012)	$\Pi_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} (\pi_{it} - \bar{\pi})/\bar{\pi}$	$y_r^{-1}\Pi_{rt}$	$\frac{1}{3}\sum_{i=1}^{n} \sum_{t=T-3}^{T-1} \Pi_{it}$
h-index	h_{rT-1}	$y_r^{-1}h_{rT-1}$	n/a
Citations	$C_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} C_{it}$	C_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} c_{rt}$
Maxcitations	x_{rT-1}	x_{rT-1}/y_r	n/a
wcitations	$w_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} C_{it}/(2014 - t_i)$	w_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} c_{rt}$
frcitations	$c_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} C_{it}/a_i w_{rt}$	c_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} c_{rt}$
wfcitations	$\rho_{rt} = c_i/(2014 - t_i)$	ρ_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} c_{rt}$
citationspp	$gc_{rt} = C_{rt}/g_{rt}$	n/a	$\frac{1}{3}\sum_{t=T-3}^{T-1} gc_{rt}$
publications	$P_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} P_{it}$	P_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} c_{rt}$
pages	$g_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} g_{it}$	g_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} g_{rt}$
frpages	$k_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} g_{it}/a_i$	k_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} k_{rt}$
jifap	$Y_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} (\pi_i - \bar{\pi}) g_i/a_i$	Y_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} Y_{rt}$
jifauthw	$y_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} (\pi_i - \bar{\pi})/a_i$	y_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} y_{rt}$
frpubs	$f_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} P_i/a_i$	f_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} f_{rt}$
first	$\varphi_{rt} = \sum_{i=1}^{n} \sum_{t=T-y}^{T-1} \varphi_{it}$	φ_{rT-1}/y_r	$\frac{1}{3}\sum_{t=T-3}^{T-1} \varphi_{rt}$

Notes: (a) i: publications, r: researcher, (b) wpubs and wfpubs are not included in the table but are described above.

4.6.3 Detailed findings

Table 4-12: Fixed Effects Logit model of funded at least once against 3-year moving averages of Research Output Indicators (ROI)

3-year moving averages of:	ROI used	citations		jifap		pages		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
ROI		-0.043	0.113	-0.012***	0.005	-0.501	0.593	-0.014	0.011	-0.156	0.157	-0.061	0.054	-0.123	0.474	-0.225	1.028
references		0.028	0.116	0.399**	0.161	0.195	0.179	0.002	0.002	0.188	0.176	0.224	0.178	0.098	0.161	0.097	0.161
INTNLCOAUTHORS		-0.010	0.014	-0.002	0.014	-0.012	0.013	-0.011	0.015	-0.013	0.015	-0.011	0.013	-0.011	0.013	-0.010	0.015
LOCALCOAUTHORS		0.029	0.023	0.017	0.022	0.031	0.020	0.027	0.025	0.029	0.023	0.026	0.022	0.029	0.020	0.028	0.023
2003		0.500	0.576	0.596	0.561	0.485	0.587	0.513	0.569	0.474	0.517	0.440	0.585	0.485	0.573	0.445	0.582
2004		1.330**	0.542	1.447**	0.573	1.342**	0.576	1.399**	0.566	1.333**	0.520	1.288**	0.577	1.321**	0.579	1.284**	0.552
2005		0.078	0.512	0.152	0.530	0.089	0.560	0.136	0.546	0.054	0.540	0.003	0.540	0.071	0.536	0.040	0.565
2006		0.479	0.482	0.605	0.469	0.534	0.453	0.594	0.487	0.493	0.471	0.435	0.477	0.476	0.449	0.456	0.473
2008		0.674**	0.328	0.772**	0.333	0.728**	0.344	0.747**	0.366	0.694**	0.331	0.654*	0.344	0.672**	0.306	0.653*	0.342
2009		-0.157	0.359	-0.074	0.398	-0.121	0.381	-0.114	0.392	-0.135	0.369	-0.150	0.402	-0.158	0.371	-0.171	0.374
EU funding		-0.020	0.133	-0.031	0.121	-0.037	0.139	-0.035	0.130	-0.019	0.141	-0.011	0.129	-0.021	0.133	-0.019	0.146
Other funding		-0.182	0.217	-0.166	0.186	-0.181	0.188	-0.180	0.193	-0.173	0.204	-0.179	0.184	-0.181	0.200	-0.183	0.197
Internal funding		-0.356	0.289	-0.260	0.306	-0.333	0.294	-0.304	0.278	-0.333	0.293	-0.350	0.310	-0.358	0.291	-0.358	0.292
Log-likelihood		-161.39		-156.76		-161.06		-160.27		-161.03		-160.21		-161.49		-161.53	
Wald X^2 test		15.98		27.05		19.47		20.27		20.97		18.00		18.74		15.50	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 440, Groups: 79
(c) Citations, pages, fractional pages, frpubs, frcitations, wcitations, wfcitations, citationspp, and references are scaled at 1/100.
(d) Cluster-robust errors used in all models

Table 4-13: Fixed Effects Logit model of funded at least once against 3-year moving averages of Research Output Indicators (ROI) - continued

3-year moving averages of:	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
ROI		-0.348	4.332	-0.037	0.085	-0.303	0.681	0.533	0.334	0.582	0.644	0.292	9.174	-0.065	0.202	-0.080	0.214
references		0.088	0.161	0.156	0.209	0.097	0.141	-0.148	0.188	-0.057	0.153	0.001	0.001	0.214	25.447	0.002	0.305
INTNLCOAUTHORS		-0.010	0.013	-0.012	0.014	-0.010	0.015	-0.009	0.013	-0.010	0.012	-0.010	0.014	-0.051	0.033	-0.051	0.038
LOCALCOAUTHORS		0.029	0.022	0.030	0.024	0.028	0.023	0.029	0.023	0.030	0.023	0.029	0.022	0.091	0.066	0.091	0.072
2003		0.443	0.568	0.453	0.532	0.520	0.533	0.887	0.626	0.622	0.611	0.442	0.616	-0.255	2.082	-0.281	2.286
2004		1.284**	0.560	1.296**	0.537	1.347**	0.538	1.712***	0.577	1.450**	0.578	1.284**	0.533	0.952	2.188	0.942	2.703
2005		0.039	0.550	0.039	0.537	0.087	0.550	0.455	0.575	0.210	0.570	0.039	0.526	-0.715	1.541	-0.749	1.507
2006		0.460	0.484	0.469	0.490	0.480	0.476	0.838	0.522	0.615	0.484	0.463	0.499	0.373	1.404	0.338	1.484
2008		0.654**	0.332	0.678**	0.328	0.672**	0.337	0.945**	0.423	0.773**	0.382	0.654*	0.345	1.402	0.941	1.345	0.888
2009		-0.169	0.371	-0.150	0.381	-0.159	0.362	0.076	0.412	-0.073	0.414	-0.169	0.367	-1.019	1.069	-1.036	0.957
EU funding		-0.019	0.125	-0.023	0.136	-0.015	0.130	-0.014	0.133	-0.020	0.133	-0.018	0.124	-0.280	0.311	-0.268	0.337
Other funding		-0.184	0.191	-0.180	0.199	-0.182	0.194	-0.187	0.214	-0.183	0.206	-0.185	0.222	-0.872	0.765	-0.888	1.162
Internal funding		-0.360	0.291	-0.355	0.290	-0.359	0.306	-0.363	0.319	-0.370	0.294	-0.360	0.303	-0.435	0.679	-0.426	0.830
Log-likelihood		-161.57		-161.46		-161.11		-160.19		-161.23		-161.58		-44.91		-44.66	
Wald X^2 test		16.30		16.59		15.64		17.15		17.70		16.55		7.41		6.85	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 440, Groups: 79, except JIF5 and JIF2012 where Observations: 149, Groups: 31
(c) wfcitations, citationspp and references are scaled at 1/100.
(d) Cluster-robust errors used in all models

Table 4-14: Fixed Effects Logit model of funded at least once against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Cum. ROI		0.220	0.237	0.523	0.479	-0.025	4.846	2.646	1.700	2.396	1.978	4.948	4.600	0.116	0.300	0.122	0.490	1.279	1.449	0.253	9.368
References		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		-0.010	0.014	-0.022	0.018	-0.010	0.022	-0.009	0.013	-0.023	0.016	-0.019	0.017	-0.013	0.014	-0.011	0.014	-0.019	0.016	-0.010	0.017
LOCALCOAUTHORS		0.025	0.025	0.022	0.025	0.029	0.029	0.028	0.022	0.021	0.021	0.026	0.022	0.027	0.027	0.028	0.023	0.025	0.024	0.029	0.024
2003		0.730	0.567	0.526	0.543	0.441	0.704	0.576	0.607	0.479	0.557	0.525	0.563	0.626	0.718	0.541	0.751	0.590	0.598	0.453	0.701
2004		1.489**	0.593	1.286**	0.609	1.283**	0.637	1.372**	0.573	1.287**	0.538	1.331**	0.576	1.449**	0.631	1.370**	0.651	1.339**	0.605	1.293**	0.631
2005		0.110	0.526	-0.067	0.596	0.037	0.590	0.047	0.537	-0.027	0.526	0.019	0.529	0.157	0.576	0.098	0.588	-0.021	0.536	0.045	0.564
2006		0.495	0.514	0.340	0.482	0.462	0.494	0.469	0.498	0.402	0.486	0.446	0.484	0.568	0.538	0.515	0.498	0.392	0.462	0.468	0.482
2008		0.643*	0.353	0.523	0.341	0.653*	0.341	0.653*	0.365	0.583*	0.345	0.620*	0.333	0.702*	0.373	0.678*	0.348	0.564*	0.337	0.656*	0.357
2009		-0.191	0.420	-0.295	0.412	-0.169	0.376	-0.169	0.395	-0.241	0.393	-0.206	0.371	-0.135	0.391	-0.151	0.395	-0.257	0.383	-0.167	0.376
EU funding		-0.029	0.130	-0.012	0.126	-0.018	0.128	-0.014	0.122	-0.009	0.124	-0.013	0.131	-0.017	0.146	-0.017	0.133	-0.015	0.122	-0.018	0.130
Other funding		-0.204	0.198	-0.197	0.203	-0.184	0.211	-0.195	0.213	-0.200	0.208	-0.200	0.196	-0.197	0.214	-0.191	0.187	-0.201	0.199	-0.185	0.203
Internal funding		-0.381	0.303	-0.374	0.288	-0.361	0.289	-0.363	0.270	-0.362	0.276	-0.350	0.277	-0.361	0.287	-0.361	0.284	-0.361	0.291	-0.360	0.277
Log-likelihood		-160.92		-160.16		-161.58		-160.80		-160.16		-160.89		-161.48		-161.55		-160.59		-161.58	
Wald X^2 test		16.38		19.33		14.94		16.63		19.31		19.41		20.09		16.47		15.80		16.51	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 440, Groups: 79

(c) All ROIs, except h-index, are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-15: Fixed Effects Logit model of funded at least once against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cum. ROI		-1.976*	1.195	-0.527	1.561	-0.698	0.779	-0.052	0.039	0.015	0.153	-0.110	0.751	-0.030	0.050	-0.036	0.118	-0.024	0.089	-1.083	1.821
References		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		-0.014	0.014	-0.010	0.013	-0.003	0.015	-0.011	0.014	-0.011	0.015	-0.010	0.015	-0.008	0.016	-0.010	0.014	-0.011	0.015	-0.007	0.015
LOCALCOAUTHORS		0.028	0.022	0.028	0.024	0.032	0.023	0.026	0.023	0.029	0.022	0.029	0.022	0.030	0.025	0.029	0.023	0.028	0.024	0.029	0.023
2003		0.840	0.606	0.475	0.544	0.450	0.547	0.576	0.584	0.434	0.523	0.458	0.549	0.380	0.555	0.403	0.589	0.492	0.626	0.421	0.573
2004		1.631***	0.602	1.315**	0.567	1.292**	0.564	1.406**	0.602	1.276**	0.561	1.301**	0.575	1.231**	0.547	1.257**	0.580	1.332**	0.653	1.277**	0.553
2005		0.445	0.606	0.087	0.587	0.084	0.549	0.192	0.559	0.024	0.582	0.064	0.553	0.017	0.520	0.028	0.534	0.096	0.575	0.049	0.496
2006		0.787	0.516	0.499	0.503	0.483	0.481	0.571	0.518	0.451	0.489	0.482	0.480	0.433	0.469	0.448	0.488	0.507	0.557	0.462	0.484
2008		0.894**	0.389	0.677**	0.317	0.710**	0.355	0.719**	0.346	0.645*	0.364	0.669*	0.342	0.672**	0.335	0.655*	0.347	0.682*	0.380	0.670*	0.348
2009		-0.026	0.399	-0.155	0.365	-0.160	0.376	-0.136	0.385	-0.175	0.416	-0.159	0.400	-0.171	0.370	-0.174	0.379	-0.151	0.398	-0.175	0.396
EU funding		-0.006	0.134	-0.015	0.128	-0.008	0.146	-0.014	0.143	-0.019	0.126	-0.017	0.133	-0.012	0.145	-0.015	0.142	-0.015	0.134	-0.014	0.128
Other funding		-0.166	0.214	-0.185	0.209	-0.147	0.188	-0.189	0.203	-0.184	0.184	-0.183	0.208	-0.164	0.221	-0.177	0.195	-0.184	0.217	-0.166	0.192
Internal funding		-0.357	0.277	-0.362	0.294	-0.398	0.299	-0.370	0.286	-0.360	0.286	-0.364	0.309	-0.374	0.319	-0.369	0.283	-0.364	0.273	-0.383	0.306
Log-likelihood		-159.82		-161.52		-160.74		-161.03		-161.57		-161.57		-161.16		-161.48		-161.54		-161.28	
Wald X^2 test		20.87		14.72		17.22		17.64		16.01		16.01		17.05		16.94		16.77		17.70	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 440, Groups: 79
(c) Citations are scaled at 1/100.
(d) Cluster-robust errors used in all models

Table 4-16: Random Effects Logit model of funded at least once against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		-0.005	0.120	-0.614*	0.331	0.082	0.391	-0.567	0.671	0.033	0.118	-0.011	0.034	0.131	0.467	-0.030	0.863
References		0.028	0.116	0.002	0.001	0.008	0.117	0.065	0.102	0.047	0.109	0.051	0.120	0.007	0.105	0.028	0.098
Department		-0.046	0.075	-0.041	0.075	-0.045	0.074	-0.050	0.073	-0.044	0.073	-0.046	0.078	-0.043	0.077	-0.046	0.076
PhD – Top 20		0.365	0.447	0.278	0.441	0.373	0.458	0.315	0.489	0.373	0.452	0.368	0.466	0.357	0.473	0.364	0.442
Degree – Top 20		0.278	0.595	0.502	0.638	0.255	0.613	0.375	0.594	0.254	0.576	0.290	0.578	0.280	0.548	0.278	0.590
No Master		0.978**	0.477	0.988**	0.492	0.978**	0.470	0.991**	0.477	0.980**	0.486	0.981**	0.441	0.983**	0.463	0.978**	0.472
Female		0.726	0.698	0.712	0.765	0.723	0.718	0.709	0.721	0.730	0.729	0.725	0.731	0.721	0.743	0.726	0.752
INTNLCOAUTHORS		0.012*	0.007	0.014*	0.007	0.012*	0.007	0.013*	0.007	0.013	0.008	0.012	0.008	0.013*	0.007	0.012*	0.007
LOCALCOAUTHORS		0.009	0.007	0.008	0.007	0.009	0.007	0.008	0.007	0.008	0.007	0.009	0.008	0.008	0.007	0.009	0.006
2003		0.208	0.437	0.283	0.439	0.196	0.425	0.236	0.428	0.188	0.423	0.216	0.419	0.155	0.420	0.203	0.442
2004		0.948**	0.436	1.055**	0.421	0.934*	0.477	0.989**	0.474	0.925**	0.435	0.960**	0.460	0.896**	0.456	0.943*	0.498
2005		-0.154	0.438	-0.088	0.439	-0.165	0.461	-0.119	0.446	-0.169	0.444	-0.150	0.439	-0.199	0.434	-0.158	0.461
2006		0.249	0.381	0.334	0.390	0.238	0.386	0.297	0.405	0.235	0.389	0.255	0.406	0.224	0.378	0.247	0.412
2008		0.654**	0.306	0.718**	0.294	0.640**	0.295	0.695**	0.285	0.641**	0.298	0.659**	0.308	0.634**	0.296	0.652**	0.296
2009		-0.133	0.348	-0.093	0.364	-0.144	0.362	-0.101	0.321	-0.144	0.364	-0.128	0.373	-0.147	0.363	-0.135	0.355
EU funding		0.076	0.100	0.068	0.104	0.078	0.121	0.074	0.110	0.076	0.111	0.077	0.104	0.077	0.116	0.076	0.111
Other funding		0.028	0.144	0.019	0.155	0.029	0.141	0.028	0.148	0.025	0.144	0.026	0.151	0.027	0.147	0.028	0.139
Internal funding		0.032	0.270	0.037	0.252	0.027	0.263	0.051	0.269	0.024	0.268	0.031	0.264	0.028	0.279	0.031	0.264
Constant		-2.002***	0.620	-2.018***	0.581	-2.024***	0.621	-1.922***	0.665	-2.026***	0.618	-2.004***	0.594	-1.999***	0.611	-2.001***	0.644
$\ln\sigma^2$		1.108***	0.311	1.203***	0.315	1.103***	0.312	1.109***	0.319	1.101***	0.302	1.124***	0.308	1.095***	0.297	1.107***	0.329
Log-likelihood		-402.93		-400.10		-402.90		-402.44		-402.88		-402.88		-402.83		-402.93	
Wald X^2 test		35.99		40.72		40.97		38.05		33.67		39.04		37.93		36.62	
LR test		75.62		80.96		76.66		75.08		76.66		74.46		74.94		76.12	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 766, Groups: 153
(c) References and all ROIs except frpubs and jifauth are scaled at 1/100.
(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-17: Random Effects Logit model of funded at least once against 3-year moving averages of Research Output Indicators (ROI)-continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.017	0.041	0.104*	0.056	-0.162	0.842	0.693**	0.273	0.800	0.552	0.055	0.073	0.799	4.651	-0.270	7.224
References		-0.011	0.114	-0.185	0.137	0.034	0.107	-0.252**	0.128	-0.071	0.094	0.010	0.091	0.020	0.118	0.028	0.114
Department		-0.044	0.073	-0.039	0.066	-0.048	0.080	-0.044	0.068	-0.042	0.080	-0.048	0.074	0.071	0.122	0.065	0.113
PhD – Top 20		0.361	0.467	0.373	0.454	0.365	0.447	0.419	0.477	0.413	0.417	0.381	0.473	0.753	0.619	0.783	0.597
Degree – Top 20		0.280	0.582	0.177	0.552	0.276	0.553	0.173	0.587	0.189	0.579	0.237	0.604	0.019	0.794	0.028	0.807
No Master		0.987**	0.473	0.982**	0.458	0.977**	0.443	1.000**	0.453	0.987**	0.464	0.985**	0.453	1.290*	0.752	1.216*	0.640
Female		0.717	0.697	0.697	0.716	0.736	0.771	0.685	0.778	0.729	0.720	0.673	0.735	0.404	0.925	0.269	0.981
INTNLCOAUTHORS		0.013*	0.007	0.013*	0.007	0.012	0.008	0.013*	0.007	0.013*	0.008	0.013*	0.007	0.010	0.011	0.009	0.012
LOCALCOAUTHORS		0.008	0.006	0.008	0.007	0.009	0.007	0.008	0.007	0.008	0.007	0.008	0.008	0.007	0.010	0.007	0.010
2003		0.189	0.454	0.115	0.424	0.233	0.420	0.731	0.481	0.419	0.496	0.172	0.442	-0.055	0.849	-0.100	0.862
2004		0.927**	0.472	0.855**	0.433	0.972**	0.474	1.452***	0.511	1.144**	0.479	0.917**	0.454	0.600	0.679	0.592	0.704
2005		-0.173	0.429	-0.204	0.413	-0.137	0.409	0.342	0.446	0.045	0.488	-0.170	0.421	-0.866	0.776	-0.868	0.707
2006		0.247	0.390	0.199	0.363	0.256	0.385	0.710*	0.431	0.433	0.434	0.238	0.376	-0.056	0.668	-0.049	0.676
2008		0.651**	0.308	0.576*	0.309	0.659**	0.291	1.014***	0.366	0.800**	0.357	0.646**	0.298	0.781*	0.448	0.664	0.445
2009		-0.134	0.350	-0.202	0.349	-0.131	0.346	0.162	0.388	-0.017	0.372	-0.135	0.345	-0.666	0.621	-0.656	0.586
EU funding		0.077	0.109	0.077	0.101	0.077	0.108	0.076	0.095	0.073	0.105	0.081	0.111	-0.005	0.169	-0.020	0.160
Other funding		0.028	0.152	0.032	0.144	0.029	0.154	0.035	0.145	0.025	0.151	0.022	0.148	0.047	0.229	0.027	0.225
Internal funding		0.028	0.260	-0.001	0.257	0.032	0.267	0.017	0.277	0.018	0.263	0.038	0.262	0.184	0.382	0.164	0.376
Constant		-2.014***	0.615	-2.148***	0.555	-2.001***	0.650	-2.478***	0.632	-2.251***	0.643	-2.026***	0.619	-2.354**	1.032	-2.154**	1.008
$\ln\sigma^2$		1.092***	0.302	1.038***	0.311	1.120***	0.326	1.080***	0.299	1.101***	0.296	1.099***	0.318	0.532	3.098	0.509	2.938
Log-likelihood		-402.73		-401.04		-402.80		-399.09		-401.70		-402.65		-159.14		-157.52	
Wald X^2 test		39.51		46.46		40.53		48.44		41.58		35.05		27.67		20.08	
LR test		74.81		72.89		76.35		75.62		77.17		76.55		11.04		10.17	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 766, Groups: 153 except ji2012 where Observations: 275, Groups: 96 and jif5 where Observations: 267, Groups: 94

(c) References and citationspp, jif2012 and jif5 are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-18: Random Effects Logit model of funded at least once against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.134**	0.062	0.084	0.089	-0.018	0.024	0.222	0.200	1.248*	0.700	3.186	2.300	-0.240**	0.100	-0.64***	0.200	0.175	0.300	-0.070**	0.031
References		0.010	0.087	0.024	0.094	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Department		-0.068	0.070	-0.053	0.082	-0.027	0.074	-0.043	0.075	-0.050	0.074	-0.061	0.071	-0.017	0.074	-0.004	0.070	-0.059	0.078	-0.010	0.073
PhD – Top 20		0.140	0.438	0.314	0.451	0.433	0.440	0.379	0.434	0.274	0.454	0.254	0.465	0.376	0.417	0.329	0.447	0.314	0.443	0.492	0.442
Degree – Top 20		0.320	0.614	0.299	0.638	0.305	0.541	0.298	0.630	0.321	0.605	0.250	0.561	0.364	0.552	0.373	0.537	0.252	0.575	0.299	0.508
No Master		0.826*	0.463	0.929**	0.469	0.984**	0.475	0.912*	0.471	0.879*	0.460	0.915*	0.475	0.874**	0.434	0.872**	0.428	0.945*	0.499	0.973**	0.452
Female		0.819	0.708	0.814	0.729	0.638	0.697	0.829	0.774	0.716	0.729	0.781	0.708	0.532	0.692	0.415	0.642	0.805	0.737	0.500	0.692
INTNLCOAUTHORS		0.511	0.755	0.921	0.700	0.019*	0.011	0.011	0.007	0.007	0.008	0.008	0.008	0.020**	0.010	0.018**	0.008	0.011	0.008	0.020**	0.009
LOCALCOAUTHORS		0.017	0.806	0.002	1.124	0.010	0.010	0.005	0.009	0.001	0.008	0.005	0.007	0.009	0.007	0.008	0.007	0.006	0.008	0.010	0.007
2003		0.009	0.434	0.090	0.447	0.136	0.432	0.128	0.432	0.220	0.436	0.239	0.417	-0.039	0.411	-0.090	0.450	0.151	0.424	0.042	0.403
2004		0.726	0.459	0.831*	0.480	0.890*	0.454	0.873**	0.442	0.947*	0.494	0.958**	0.442	0.738	0.450	0.713	0.443	0.886**	0.428	0.822*	0.421
2005		-0.388	0.415	-0.285	0.434	-0.206	0.434	-0.241	0.439	-0.180	0.443	-0.163	0.428	-0.329	0.411	-0.347	0.412	-0.219	0.413	-0.266	0.408
2006		0.027	0.385	0.133	0.366	0.208	0.384	0.177	0.370	0.227	0.389	0.239	0.385	0.100	0.366	0.089	0.397	0.191	0.384	0.160	0.368
2008		0.511*	0.309	0.581*	0.312	0.633**	0.295	0.610**	0.296	0.640**	0.293	0.642**	0.316	0.576*	0.309	0.568*	0.295	0.616**	0.283	0.606**	0.306
2009		-0.249	0.360	-0.190	0.349	-0.144	0.344	-0.166	0.368	-0.144	0.347	-0.146	0.337	-0.178	0.349	-0.179	0.343	-0.163	0.350	-0.157	0.343
EU funding		0.094	0.108	0.089	0.115	0.071	0.110	0.082	0.106	0.095	0.103	0.094	0.099	0.080	0.105	0.079	0.114	0.086	0.105	0.065	0.105
Other funding		0.018	0.141	0.022	0.146	0.034	0.140	0.024	0.130	0.021	0.148	0.019	0.149	0.042	0.147	0.045	0.140	0.022	0.144	0.041	0.154
Internal funding		-0.084	0.262	-0.021	0.274	0.057	0.267	0.015	0.267	-0.035	0.270	-0.009	0.265	0.101	0.273	0.106	0.270	-0.001	0.266	0.073	0.243
Constant		-2.188***	0.580	-1.890***	0.611	-1.934***	0.585	-2.022***	0.583	-1.982***	0.597	-1.989***	0.599	-1.632***	0.584	-1.470**	0.625	-1.941***	0.614	-1.760***	0.548
$\ln\sigma^2$		1.034***	0.305	1.086***	0.302	1.084***	0.318	1.092***	0.292	1.059***	0.309	1.072***	0.307	0.995***	0.353	0.907***	0.309	1.098***	0.313	1.011***	0.322
Log-likelihood		-398.96		-401.45		-402.27		-401.67		-399.63		-401.22		-400.25		-396.97		-402.28		-399.63	
Wald X^2 test		47.63		39.78		37.22		35.68		37.70		36.70		32.77		37.55		37.23		36.32	
LR test		69.17		73.85		74.51		74.48		70.64		72.69		68.40		62.25		75.30		68.85	

Notes:

(e) *** p<0.01, ** p<0.05, * p<0.1

(f) Observations: 766, Groups: 153

(g) Localcoauthors, intnlcoauthors, references and all ROIs, except h-index are scaled at 1/100.

(h) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-19: Random Effects Logit model of funded at least once against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		1.390**	0.608	0.013	0.008	0.253	0.403	0.023	0.019	0.122	0.084	0.473	0.295	-0.037*	0.020	-0.119***	0.038	0.045	0.029	-0.995	0.647
References		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Department		-0.032	0.067	-0.039	0.075	-0.048	0.078	-0.038	0.073	-0.034	0.073	-0.046	0.076	-0.041	0.070	-0.026	0.069	-0.054	0.081	-0.036	0.077
PhD – Top 20		0.254	0.426	0.264	0.434	0.321	0.502	0.363	0.445	0.274	0.450	0.226	0.457	0.300	0.437	0.220	0.456	0.246	0.443	0.446	0.487
Degree – Top 20		0.344	0.557	0.378	0.589	0.264	0.621	0.323	0.543	0.366	0.582	0.310	0.607	0.362	0.577	0.422	0.586	0.304	0.630	0.304	0.580
No Master		0.843*	0.442	0.883**	0.431	0.978**	0.461	0.890*	0.468	0.853*	0.439	0.870*	0.462	0.839*	0.444	0.776*	0.420	0.902*	0.474	0.936**	0.433
Female		0.578	0.663	0.774	0.763	0.731	0.670	0.783	0.649	0.645	0.726	0.701	0.682	0.592	0.697	0.393	0.666	0.824	0.675	0.606	0.676
INTNLCOAUTHORS		0.011	0.007	0.011	0.007	0.009	0.010	0.012	0.008	0.011	0.007	0.011	0.007	0.017**	0.008	0.016**	0.007	0.011	0.008	0.016**	0.008
LOCALCOAUTHORS		0.003	0.006	0.002	0.009	0.007	0.009	0.006	0.007	0.003	0.007	0.005	0.007	0.009	0.007	0.007	0.006	0.005	0.007	0.009	0.008
2003		-0.236	0.482	-0.022	0.445	0.147	0.459	0.092	0.413	0.155	0.464	0.146	0.459	0.177	0.416	0.179	0.459	-0.020	0.504	0.262	0.450
2004		0.526	0.476	0.731*	0.444	0.888*	0.466	0.840*	0.475	0.889**	0.439	0.874**	0.429	0.939**	0.425	0.970**	0.484	0.731	0.526	1.013**	0.426
2005		-0.575	0.478	-0.407	0.444	-0.211	0.431	-0.279	0.457	-0.248	0.442	-0.252	0.457	-0.156	0.421	-0.136	0.435	-0.377	0.460	-0.096	0.458
2006		-0.090	0.406	0.046	0.409	0.209	0.398	0.154	0.374	0.182	0.384	0.176	0.411	0.235	0.377	0.240	0.400	0.068	0.400	0.288	0.380
2008		0.435	0.291	0.529*	0.286	0.620**	0.297	0.591*	0.310	0.612**	0.303	0.605*	0.320	0.666**	0.304	0.653**	0.308	0.543*	0.328	0.681**	0.301
2009		-0.261	0.351	-0.210	0.319	-0.149	0.326	-0.171	0.341	-0.144	0.346	-0.157	0.339	-0.133	0.345	-0.133	0.349	-0.205	0.364	-0.116	0.339
EU funding		0.098	0.097	0.091	0.099	0.079	0.111	0.081	0.111	0.089	0.102	0.094	0.099	0.083	0.115	0.078	0.118	0.093	0.119	0.067	0.105
Other funding		0.035	0.153	0.030	0.143	0.019	0.144	0.030	0.151	0.029	0.140	0.022	0.148	0.044	0.143	0.046	0.148	0.023	0.151	0.045	0.149
Internal funding		0.014	0.271	-0.003	0.263	0.026	0.255	0.036	0.259	0.010	0.245	0.011	0.260	0.056	0.259	0.059	0.279	-0.005	0.264	0.038	0.261
Constant		-2.398***	0.606	-1.961***	0.590	-2.180***	0.708	-2.057***	0.597	-2.098***	0.636	-2.112***	0.632	-1.400**	0.655	-1.019*	0.605	-1.975***	0.685	-1.583**	0.635
$\ln\sigma^2$		0.833**	0.330	1.003***	0.304	1.067***	0.298	1.055***	0.316	1.000***	0.324	1.008***	0.303	1.068***	0.317	0.916***	0.336	1.032***	0.302	1.079***	0.287
Log-likelihood		-399.06		-400.23		-402.48		-401.73		-399.78		-400.21		-400.73		-395.36		-400.69		-400.93	
Wald X^2 test		48.09		40.29		35.53		41.06		46.48		40.97		39.55		41.92		44.79		37.51	
LR test		53.32		67.50		73.80		71.63		65.95		67.63		73.18		61.83		70.05		73.65	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 766, Groups: 153

(c) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-20: Fixed Effects Poisson model of counts of funded projects against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		-0.013	0.029	-0.562***	0.195	-0.245	0.316	-0.193	0.483	-0.015	7.394	-2.354	0.025	-0.053	0.162	0.051	0.379
references		-0.017	0.001	0.001*	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001
INTNLCOAUTHORS		-0.003	0.005	-0.002	0.004	-0.004	0.005	-0.003	0.005	-0.003	0.005	-0.003	0.005	-0.003	0.005	-0.003	0.005
LOCALCOAUTHORS		0.007	0.007	0.005	0.006	0.008	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
2003		-0.458	0.363	-0.347	0.362	-0.435	0.360	-0.462	0.349	-0.479	0.340	-0.448	0.338	-0.457	0.363	-0.482	0.348
2004		0.005	0.327	0.130	0.346	0.038	0.343	0.007	0.335	-0.017	0.321	0.025	0.317	0.007	0.331	-0.020	0.320
2005		-0.817**	0.348	-0.733**	0.361	-0.794**	0.361	-0.816**	0.355	-0.832**	0.344	-0.817**	0.342	-0.817**	0.350	-0.834**	0.342
2006		-0.346	0.296	-0.264	0.309	-0.310	0.314	-0.335	0.304	-0.353	0.292	-0.344	0.283	-0.346	0.296	-0.353	0.292
2008		0.005	0.195	0.061	0.207	0.040	0.210	0.011	0.200	0.001	0.193	0.004	0.193	0.005	0.195	0.001	0.192
2009		-0.629***	0.205	-0.558**	0.221	-0.599***	0.215	-0.623***	0.210	-0.634***	0.205	-0.620***	0.206	-0.629***	0.206	-0.634***	0.204
EU funding		-0.045	0.054	-0.035	0.052	-0.048	0.055	-0.046	0.054	-0.046	0.053	-0.039	0.053	-0.045	0.054	-0.046	0.053
Other funding		0.017	0.074	0.016	0.070	0.008	0.075	0.012	0.074	0.014	0.074	0.021	0.073	0.017	0.074	0.014	0.075
Internal funding		0.025	0.125	0.051	0.126	0.032	0.125	0.030	0.127	0.023	0.125	0.017	0.125	0.024	0.125	0.023	0.125
Log-likelihood		-372.51		-367.57		-372.10		-372.48		-372.59		-371.77		-372.53		-372.58	
Wald X^2 test		46.17		62.66		47.41		45.85		44.24		47.53		45.37		44.37	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 495, Groups: 94
(c) Citations, pages, fractional pages, frpubs, frcitations, wcitations, wfcitations, citationspp, jifauth, intlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.
(d) Cluster-robust errors used in all models

Table 4-21: Fixed Effects Poisson model of counts of funded projects against 3-year moving averages of Research Output Indicators (ROI) - continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.701	1.620	-0.648	3.539	-0.117	0.079	0.153	0.120	0.361	0.231	-0.012	0.046	-0.114	3.979	-0.595	3.704
references		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		-0.003	0.005	-0.004	0.005	-0.003	0.005	-0.003	0.005	-0.003	0.005	-0.004	0.005	-0.027***	0.007	-0.027***	0.007
LOCALCOAUTHORS		0.007	0.007	0.007	0.007	0.007	0.007	0.006	0.007	0.007	0.007	0.007	0.007	0.027***	0.007	0.028***	0.007
2003		-0.487	0.345	-0.474	0.342	-0.440	0.359	-0.371	0.371	-0.387	0.362	-0.469	0.334	-1.071*	0.608	-1.072*	0.606
2004		-0.027	0.321	-0.010	0.318	0.024	0.324	0.082	0.350	0.065	0.334	-0.008	0.314	-0.410	0.497	-0.397	0.494
2005		-0.838**	0.342	-0.829**	0.343	-0.805**	0.345	-0.738**	0.366	-0.746**	0.355	-0.832**	0.340	-1.531**	0.616	-1.522**	0.611
2006		-0.350	0.291	-0.349	0.290	-0.340	0.294	-0.268	0.318	-0.275	0.307	-0.355	0.292	-0.550	0.504	-0.543	0.493
2008		0.003	0.191	0.004	0.192	0.007	0.194	0.076	0.217	0.076	0.207	-0.001	0.193	-0.119	0.257	-0.144	0.259
2009		-0.632***	0.203	-0.630***	0.204	-0.627***	0.204	-0.568***	0.220	-0.572***	0.211	-0.635***	0.205	-0.981***	0.351	-0.985***	0.352
EU funding		-0.047	0.053	-0.046	0.054	-0.043	0.054	-0.046	0.051	-0.047	0.052	-0.047	0.054	-0.140*	0.072	-0.141**	0.072
Other funding		0.011	0.075	0.015	0.075	0.018	0.074	0.014	0.075	0.014	0.075	0.016	0.074	-0.126	0.146	-0.124	0.148
Internal funding		0.023	0.125	0.023	0.125	0.024	0.125	0.031	0.130	0.027	0.129	0.020	0.126	0.059	0.171	0.053	0.172
Log-likelihood		-372.46		-372.57		-372.26		-371.82		-371.49		-372.55		-126.66		-125.31	
Wald X^2 test		44.37		44.61		53.65		46.22		48.04		44.29		88.48		85.03	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 495, Groups: 94, except JIF5 and JIF2012 where Observations: 172, Groups: 39
(c) wfcitations, citationspp, intnlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.
(d) Cluster-robust errors used in all models

Table 4-22: Fixed Effects Negative Binomial model of counts of funded projects against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov av. ROI		-0.017	0.796	-0.611***	0.238	-0.255	0.339	-0.351	0.598	0.975	10.275	-2.263	3.146	0.073	0.266	0.024	0.690
references		-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	-0.002*	0.001	-0.001	0.001	-0.001	0.001	-0.001*	0.001
INTNLCOAUTHORS		-0.008	0.007	-0.006	0.006	-0.009	0.007	-0.008	0.007	-0.007	0.007	-0.008	0.007	-0.008	0.007	-0.008	0.007
LOCALCOAUTHORS		0.005	0.009	0.003	0.008	0.006	0.009	0.005	0.009	0.005	0.010	0.005	0.009	0.005	0.009	0.005	0.009
2003		-1.414***	0.525	-1.221**	0.528	-1.295**	0.512	-1.336***	0.509	-1.393***	0.502	-1.345***	0.501	-1.452***	0.523	-1.391***	0.499
2004		-0.536	0.446	-0.333	0.473	-0.405	0.440	-0.450	0.441	-0.520	0.433	-0.461	0.433	-0.578	0.451	-0.521	0.435
2005		-1.556***	0.436	-1.411***	0.457	-1.463***	0.435	-1.497***	0.438	-1.536***	0.434	-1.522***	0.430	-1.577***	0.437	-1.541***	0.427
2006		-0.817**	0.397	-0.699*	0.418	-0.734*	0.402	-0.773*	0.398	-0.813**	0.395	-0.802**	0.391	-0.825**	0.396	-0.798**	0.389
2008		0.453	0.296	0.518	0.316	0.517*	0.309	0.477	0.304	0.458	0.295	0.462	0.296	0.447	0.295	0.468	0.291
2009		-0.600**	0.251	-0.521*	0.270	-0.544**	0.256	-0.574**	0.256	-0.602**	0.249	-0.584**	0.252	-0.604**	0.252	-0.591**	0.248
EU funding		-0.017	0.063	0.001	0.062	-0.019	0.064	-0.014	0.063	-0.018	0.062	-0.010	0.063	-0.017	0.062	-0.018	0.062
Other funding		0.064	0.091	0.070	0.085	0.057	0.087	0.065	0.088	0.063	0.091	0.074	0.088	0.057	0.093	0.060	0.091
Internal funding		-0.120	0.151	-0.107	0.150	-0.103	0.151	-0.105	0.154	-0.126	0.156	-0.126	0.151	-0.118	0.151	-0.121	0.150
Log-likelihood		-369.82		-364.16		-369.46		-369.69		-369.94		-369.28		-369.83		-369.95	
Wald X^2 test		51.43		60.84		51.63		52.13		41.97		48.24		48.58		50.59	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 495, Groups: 94
(c) Citations, pages, fractional pages, frpubs, frcitations, wcitations, wfcitations, citationspp, intlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.
(d) Cluster-robust errors used in all models

Table 4-23: Fixed Effects Negative Binomial model of counts of funded projects against 3-year moving averages of Research Output Indicators (ROI) - continued

Variables	ROI used	wfcitations		publications		Citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov Av. ROI		0.594	2.215	0.072	4.659	-0.129	0.477	0.181	0.177	0.399	0.301	0.01	0.054	-0.227	6.605	-0.210	6.627
references		0.001	0.001	0.001	0.001	0.001	0.001	-0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		0.005	0.005	0.005	0.004	0.005	0.004	0.006	0.004	0.005	0.004	0.005	0.004	-0.004	0.007	-0.004	0.005
LOCALCOAUTHORS		0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.005	0.003	0.004	0.007	0.008	0.007	0.007
2003		-0.132	0.310	-0.148	0.313	-0.124	0.313	0.101	0.374	-0.091	0.343	-0.145	0.316	-0.514	1.112	-0.520	0.700
2004		0.449	0.321	0.431	0.321	0.462	0.339	0.654*	0.359	0.478	0.349	0.430	0.308	0.200	0.609	0.196	0.618
2005		-0.384	0.336	-0.399	0.327	-0.377	0.332	-0.184	0.349	-0.353	0.360	-0.392	0.318	-1.207*	0.673	-1.197*	0.711
2006		0.002	0.264	-0.010	0.260	0.004	0.272	0.185	0.296	0.033	0.275	-0.004	0.276	-0.303	0.542	-0.290	0.506
2008		0.494**	0.195	0.478**	0.195	0.495***	0.180	0.628***	0.226	0.515**	0.208	0.490**	0.199	0.629	0.383	0.609	0.384
2009		-0.140	0.236	-0.161	0.259	-0.140	0.227	-0.050	0.246	-0.133	0.231	-0.145	0.246	-0.662	0.500	-0.665	0.476
EU funding		-0.057	0.059	-0.057	0.058	-0.057	0.061	-0.060	0.053	-0.058	0.060	-0.056	0.063	-0.155*	0.094	-0.149	0.099
Other funding		0.093	0.097	0.090	0.104	0.093	0.101	0.088	0.102	0.089	0.103	0.090	0.096	0.010	0.305	0.015	0.275
Internal funding		0.071	0.184	0.061	0.170	0.071	0.178	0.054	0.188	0.065	0.187	0.071	0.193	0.228	0.286	0.232	0.271
Constant		-2.588***	0.299	-2.598***	0.305	-2.588***	0.301	-2.775***	0.346	-2.622***	0.313	-2.596***	0.305	-1.613**	0.714	-1.629**	0.709
Log-likelihood		-369.86		-369.95		-369.55		-368.97		-369.21		-369.94		-123.30		-121.62	
Wald X^2 test		43.74		40.17		53.40		51.66		46.73		44.02		64.83		60.05	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94, except JIF5 and JIF2012 where Observations: 172, Groups: 39

(c) wfcitations, citationspp, intnlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.

(d) Cluster-robust errors used in all models

Table 4-24: Random Effects Poisson model of the counts of funded projects against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	Se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		-0.072	0.123	-0.004**	0.001	-0.255	0.002	-0.351	0.438	0.031	0.064	-0.007	0.021	0.001	0.002	0.001	0.005
References		-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.037	0.042	-0.032	0.041	-0.037	0.043	-0.038	0.043	-0.035	0.041	-0.036	0.042	-0.036	0.041	-0.036	0.041
PhD – Top 20		0.164	0.284	0.099	0.246	0.163	0.262	0.153	0.275	0.178	0.261	0.164	0.251	0.163	0.241	0.165	0.277
Degree – Top 20		0.156	0.289	0.285	0.320	0.161	0.277	0.177	0.312	0.130	0.298	0.166	0.301	0.158	0.274	0.159	0.319
No Master		0.516*	0.269	0.508**	0.253	0.519**	0.220	0.520**	0.251	0.522**	0.245	0.516**	0.223	0.520**	0.241	0.524**	0.236
Female		0.404	0.328	0.415	0.357	0.408	0.343	0.415	0.351	0.382	0.319	0.403	0.337	0.400	0.401	0.398	0.368
INTNLCOAUTHORS		0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.003	0.002	0.003	0.002
LOCALCOAUTHORS		0.006**	0.003	0.006**	0.002	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003
2003		-0.312	0.290	-0.260	0.304	-0.313	0.262	-0.306	0.277	-0.330	0.257	-0.306	0.285	-0.327	0.284	-0.318	0.294
2004		0.133	0.229	0.201	0.261	0.133	0.230	0.143	0.252	0.113	0.235	0.143	0.254	0.118	0.246	0.126	0.242
2005		-0.680**	0.282	-0.628**	0.275	-0.680**	0.269	-0.673**	0.282	-0.690**	0.277	-0.676**	0.271	-0.690**	0.275	-0.684***	0.257
2006		-0.219	0.245	-0.171	0.242	-0.218	0.233	-0.209	0.254	-0.228	0.229	-0.216	0.231	-0.223	0.238	-0.217	0.218
2008		0.137	0.159	0.167	0.185	0.139	0.166	0.144	0.181	0.129	0.160	0.138	0.167	0.134	0.166	0.138	0.168
2009		-0.516***	0.170	-0.480**	0.189	-0.514***	0.169	-0.509***	0.188	-0.523***	0.195	-0.512**	0.193	-0.518***	0.180	-0.515***	0.175
EU funding		0.025	0.050	0.024	0.048	0.025	0.052	0.026	0.056	0.025	0.052	0.026	0.049	0.026	0.055	0.025	0.050
Other funding		0.055	0.069	0.053	0.076	0.054	0.068	0.054	0.068	0.053	0.071	0.055	0.068	0.053	0.069	0.054	0.067
Internal funding		0.136	0.134	0.137	0.123	0.136	0.123	0.139	0.125	0.132	0.128	0.133	0.132	0.135	0.121	0.134	0.131
Constant		-0.776**	0.364	-0.779**	0.383	-0.771**	0.361	-0.757*	0.405	-0.804**	0.355	-0.776**	0.363	-0.780**	0.377	-0.782**	0.363
Lnα		0.139	0.221	0.175	0.225	0.140	0.218	0.137	0.236	0.135	0.217	0.148	0.210	0.135	0.207	0.135	0.205
Log-likelihood		-700.41		-696.97		-700.41		-700.32		-700.23		-700.33		-700.39		-700.36	
Wald X^2 test		66.71		73.20		67.34		77.19		68.52		68.42		72.65		70.35	
LR test		156.14		162.12		157.58		152.89		158.12		156.46		156.69		156.33	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 761, Groups: 152
(c) References and all ROIs except frpubs and jifauth are scaled at 1/100.
(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-25: Random Effects Poisson model of the counts of funded projects against 3-year moving averages of Research Output Indicators (ROI)- continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.014	0.020	0.032	0.029	-0.001	0.006	0.208*	0.117	0.404	0.262	0.018	0.043	0.013	0.022	0.009	0.025
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001*	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.035	0.040	-0.035	0.042	-0.038	0.043	-0.036	0.039	-0.036	0.041	-0.038	0.042	0.034	0.061	0.034	0.061
PhD – Top 20		0.165	0.248	0.169	0.248	0.162	0.262	0.187	0.251	0.202	0.266	0.169	0.262	0.312	0.324	0.339	0.333
Degree – Top 20		0.162	0.279	0.127	0.282	0.157	0.283	0.122	0.272	0.106	0.282	0.141	0.293	0.047	0.336	0.060	0.375
No Master		0.536**	0.244	0.528**	0.228	0.513**	0.234	0.538**	0.218	0.535**	0.257	0.519**	0.240	0.633**	0.312	0.597*	0.329
Female		0.375	0.331	0.355	0.347	0.407	0.377	0.325	0.335	0.311	0.294	0.361	0.314	0.484	0.546	0.391	0.559
INTNLCOAUTHORS		0.003	0.002	0.003	0.002	0.002	0.002	0.003	0.002	0.003	0.002	0.003	0.003	0.004	0.005	0.003	0.005
LOCALCOAUTHORS		0.006*	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.004	0.003	0.004	0.004
2003		-0.327	0.291	-0.340	0.277	-0.300	0.293	-0.149	0.296	-0.203	0.293	-0.329	0.283	-0.179	0.465	-0.194	0.494
2004		0.113	0.253	0.103	0.245	0.147	0.248	0.287	0.257	0.232	0.261	0.119	0.245	0.227	0.352	0.231	0.376
2005		-0.691**	0.287	-0.690**	0.291	-0.672**	0.301	-0.525*	0.293	-0.575**	0.284	-0.683**	0.288	-1.134**	0.477	-1.126**	0.456
2006		-0.212	0.243	-0.229	0.236	-0.218	0.245	-0.078	0.256	-0.123	0.242	-0.217	0.243	-0.342	0.418	-0.330	0.452
2008		0.142	0.177	0.119	0.195	0.137	0.170	0.252	0.198	0.221	0.183	0.137	0.177	0.159	0.241	0.114	0.254
2009		-0.513**	0.200	-0.531***	0.185	-0.515***	0.188	-0.419**	0.206	-0.448**	0.187	-0.515***	0.185	-0.825**	0.341	-0.819**	0.360
EU funding		0.026	0.049	0.026	0.050	0.026	0.051	0.025	0.048	0.025	0.048	0.027	0.047	0.033	0.068	0.022	0.070
Other funding		0.052	0.071	0.055	0.069	0.056	0.074	0.056	0.070	0.054	0.073	0.053	0.064	0.016	0.128	0.003	0.127
Internal funding		0.134	0.133	0.132	0.129	0.135	0.135	0.139	0.130	0.137	0.122	0.137	0.142	0.272	0.205	0.255	0.209
Constant		-0.800**	0.385	-0.837**	0.373	-0.770**	0.362	-0.925**	0.409	-0.901**	0.421	-0.782**	0.396	-1.270**	0.545	-1.208**	0.557
$\ln\sigma^2$		0.122	0.211	0.113	0.219	0.145	0.216	0.117	0.204	0.127	0.210	0.130	0.225	-0.549	3.940	-0.508	4.495
Log-likelihood		-699.85		-699.71		-700.30		-698.51		-698.57		-700.28		-291.57		-286.63	
Wald X^2 test		78.34		69.02		73.09		78.57		75.01		73.23		66.52		49.42	
LR test		155.74		158.81		156.73		160.17		162.01		158.47		19.09		19.17	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 766, Groups: 153 except ji2012 where Observations: 275, Groups: 96 and jif5 where Observations: 267, Groups: 94

(c) References and citationspp, jif2012 and jif5 are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-26: Random Effects Negative Binomial model of the counts of funded projects against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	Citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	Se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		-0.003	0.120	-0.359**	0.101	-0.021	0.233	-0.152	0.422	0.030	0.069	-0.68	2.302	0.027	0.238	0.097	0.495
References		-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.036	0.041	-0.031	0.045	-0.036	0.044	-0.037	0.043	-0.035	0.040	-0.036	0.040	-0.035	0.046	-0.036	0.039
PhD – Top 20		0.182	0.256	0.107	0.265	0.181	0.240	0.171	0.264	0.192	0.251	0.181	0.252	0.180	0.273	0.182	0.257
Degree – Top 20		0.125	0.276	0.273	0.308	0.130	0.312	0.146	0.316	0.103	0.282	0.137	0.307	0.127	0.347	0.129	0.308
No Master		0.527**	0.257	0.512**	0.234	0.530**	0.252	0.533**	0.248	0.531**	0.232	0.527**	0.240	0.531**	0.246	0.534**	0.225
Female		0.413	0.345	0.417	0.368	0.418	0.378	0.423	0.358	0.396	0.369	0.411	0.352	0.410	0.362	0.408	0.360
INTNLCOAUTHORS		0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002
LOCALCOAUTHORS		0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003
2003		-0.300	0.259	-0.253	0.268	-0.301	0.282	-0.291	0.266	-0.318	0.264	-0.294	0.281	-0.314	0.323	-0.307	0.278
2004		0.149	0.248	0.209	0.237	0.149	0.246	0.163	0.243	0.127	0.235	0.158	0.249	0.135	0.244	0.141	0.241
2005		-0.656**	0.266	-0.617**	0.269	-0.657**	0.299	-0.644**	0.282	-0.670**	0.281	-0.654**	0.274	-0.667**	0.278	-0.662**	0.268
2006		-0.204	0.227	-0.162	0.234	-0.203	0.239	-0.190	0.225	-0.215	0.237	-0.201	0.220	-0.208	0.244	-0.203	0.231
2008		0.154	0.159	0.176	0.169	0.156	0.196	0.165	0.171	0.144	0.165	0.155	0.176	0.151	0.175	0.154	0.156
2009		-0.499***	0.176	-0.472**	0.205	-0.496**	0.211	-0.487***	0.182	-0.509**	0.199	-0.496**	0.198	-0.502***	0.180	-0.499***	0.181
EU funding		0.027	0.056	0.025	0.051	0.027	0.052	0.028	0.056	0.026	0.051	0.028	0.051	0.027	0.054	0.027	0.051
Other funding		0.056	0.077	0.054	0.069	0.055	0.073	0.056	0.072	0.054	0.067	0.056	0.077	0.055	0.073	0.055	0.071
Internal funding		0.129	0.117	0.134	0.138	0.130	0.138	0.133	0.128	0.126	0.131	0.127	0.122	0.129	0.131	0.128	0.119
Constant		3.002	6.329	3.763	6.184	3.005	6.189	2.891	6.289	3.136	6.059	3.037	6.284	3.021	6.401	3.043	6.142
lnr		3.726	6.190	4.411	6.073	3.724	6.069	3.608	6.192	3.877	6.038	3.749	6.199	3.750	6.290	3.772	6.027
lns		-0.105	0.243	-0.158	0.246	-0.105	0.232	-0.096	0.241	-0.105	0.240	-0.114	0.253	-0.101	0.241	-0.102	0.231
Log-likelihood		-700.31		-696.94		-700.30		-700.19		-700.15		-700.23		-700.29		-700.26	
Wald X^2 test		59.48		92.56		73.59		82.27		78.63		68.49		67.80		69.72	
LR test		86.56		92.11		87.40		82.49		87.16		86.77		87.06		87.02	

Notes:

(e) *** p<0.01, ** p<0.05, * p<0.1

(f) Observations: 766, Groups: 153

(g) References and all ROIs except frpubs and jifauth are scaled at 1/100.

(h) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-27: Random Effects Negative Binomial model of the counts of funded projects against 3-year moving averages of Research Output Indicators (ROI)-continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		1.323	2.105	0.032	0.029	-0.067	0.640	0.209*	0.119	0.405	0.303	0.018	0.044	0.015	0.023	0.011	0.025
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001*	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.034	0.039	-0.034	0.040	-0.037	0.043	-0.036	0.039	-0.036	0.041	-0.038	0.041	0.035	0.060	0.034	0.061
PhD – Top 20		0.176	0.265	0.186	0.252	0.180	0.264	0.201	0.239	0.213	0.272	0.186	0.257	0.350	0.346	0.382	0.320
Degree – Top 20		0.140	0.308	0.093	0.283	0.125	0.287	0.092	0.293	0.083	0.303	0.110	0.300	0.005	0.351	0.026	0.334
No Master		0.543**	0.241	0.536**	0.230	0.523**	0.244	0.542**	0.242	0.540**	0.245	0.529**	0.237	0.675**	0.308	0.630*	0.336
Female		0.386	0.350	0.370	0.335	0.416	0.371	0.342	0.372	0.328	0.337	0.375	0.310	0.448	0.457	0.359	2.642
INTNLCOAUTHORS		0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.005	0.005	0.004	0.005
LOCALCOAUTHORS		0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.006**	0.003	0.003	0.003	0.004	0.003
2003		-0.319	0.292	-0.329	0.259	-0.288	0.284	-0.137	0.319	-0.195	0.285	-0.316	0.254	-0.181	0.465	-0.198	0.488
2004		0.124	0.239	0.119	0.229	0.162	0.232	0.301	0.286	0.242	0.248	0.134	0.230	0.255	0.376	0.262	0.383
2005		-0.675**	0.274	-0.667**	0.278	-0.648**	0.271	-0.504	0.307	-0.559**	0.283	-0.661**	0.266	-1.038**	0.446	-1.026**	0.451
2006		-0.203	0.226	-0.214	0.235	-0.203	0.228	-0.063	0.262	-0.113	0.245	-0.203	0.226	-0.285	0.409	-0.267	0.378
2008		0.153	0.163	0.135	0.163	0.154	0.171	0.267	0.195	0.232	0.165	0.154	0.158	0.223	0.253	0.174	0.269
2009		-0.502***	0.181	-0.515***	0.193	-0.498***	0.189	-0.404**	0.204	-0.438***	0.169	-0.499***	0.173	-0.757**	0.346	-0.749*	0.383
EU funding		0.027	0.051	0.028	0.048	0.028	0.052	0.027	0.050	0.026	0.047	0.029	0.057	0.038	0.064	0.026	0.068
Other funding		0.053	0.075	0.056	0.071	0.057	0.074	0.057	0.074	0.055	0.075	0.054	0.070	0.030	0.123	0.015	0.131
Internal funding		0.131	0.120	0.126	0.125	0.129	0.130	0.133	0.132	0.132	0.137	0.131	0.129	0.244	0.208	0.227	0.209
Constant		3.343	6.122	2.920	6.159	3.022	6.274	3.007	6.143	3.337	6.180	3.027	6.185	1.008	6.186	1.053	6.097
lnr		4.082	6.030	3.733	6.082	3.732	6.164	3.892	6.083	4.168	6.072	3.764	6.141	3.226	6.087	3.161	6.240
lns		-0.098	0.233	-0.076	0.231	-0.111	0.222	-0.087	0.226	-0.105	0.247	-0.096	0.240	0.830	6.309	0.788	6.099
Log-likelihood		-699.80		-699.61		-700.20		-698.44		-698.53		-700.17		-291.18		-286.21	
Wald X^2 test		83.94		76.97		74.39		87.26		66.48		66.74		68.09		58.87	
LR test		87.50		87.61		87.08		89.18		91.45		88.11		5.87		5.85	

Notes:

(i) *** p<0.01, ** p<0.05, * p<0.1

(j) Observations: 766, Groups: 153 except ji2012 where Observations: 275, Groups: 96 and jif5 where Observations: 267, Groups: 94

(k) References and citationspp, jif2012 and jif5 are scaled at 1/100.

(l) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-28: Multilevel Poisson model with two-level Random Effects of count of funded projects against 3-year moving average Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov Av. ROI		0.047*	0.122	-0.331***	0.104	-0.394***	0.098	-0.867***	0.214	-0.072***	0.036	0.018	0.015	0.200*	0.113	0.358	0.196
References		-0.001***	0.001	0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001**	0.001	-0.001***	0.001	-0.001***	0.001
EU funding		0.024	0.027	0.032	0.024	0.038	0.025	0.041*	0.021	0.034	0.024	0.025	0.024	0.024	0.025	0.028	0.022
Other funding		0.054	0.050	0.050	0.053	0.052	0.044	0.065	0.045	0.057	0.044	0.073	0.052	0.062	0.050	0.059	0.049
Internal funding		0.164**	0.074	0.159**	0.069	0.214***	0.067	0.209***	0.071	0.197***	0.059	0.159**	0.069	0.161**	0.067	0.160**	0.070
INTNL COAUTH.		0.007***	0.001	0.007***	0.001	0.008***	0.001	0.008***	0.001	0.007***	0.001	0.007***	0.001	0.007***	0.001	0.007***	0.001
LOCAL COAUTH.		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Degree – Top 20		0.225*	0.125	0.321**	0.146	0.363***	0.135	0.402***	0.140	0.276**	0.136	0.176	0.114	0.216	0.136	0.224	0.144
PhD – Top 20		-0.028	0.104	-0.066	0.118	-0.084	0.105	-0.114	0.099	-0.042	0.118	-0.019	0.086	-0.042	0.113	-0.039	0.112
No Master		0.246**	0.096	0.271***	0.097	0.297***	0.099	0.321***	0.093	0.268***	0.095	0.274***	0.096	0.269***	0.098	0.281***	0.082
2003		-1.219***	0.218	-1.141***	0.198	-1.159***	0.184	-1.152***	0.217	-1.161***	0.193	-1.263***	0.198	-1.246***	0.204	-1.253***	0.205
2004		-0.788***	0.162	-0.725***	0.161	-0.700***	0.168	-0.699***	0.170	-0.699***	0.161	-0.787***	0.164	-0.828***	0.168	-0.780***	0.160
2005		-1.474***	0.176	-1.419***	0.166	-1.395***	0.195	-1.363***	0.175	-1.375***	0.161	-1.458***	0.174	-1.491***	0.184	-1.460***	0.181
2006		-1.013***	0.132	-0.942***	0.140	-0.911***	0.144	-0.881***	0.157	-0.947***	0.152	-0.986***	0.155	-1.022***	0.141	-1.011***	0.153
2009		-1.107***	0.133	-1.077***	0.140	-1.028***	0.131	-1.021***	0.134	-1.067***	0.145	-1.123***	0.143	-1.081***	0.141	-1.112***	0.128
2011		-0.555***	0.116	-0.570***	0.104	-0.577***	0.110	-0.579***	0.104	-0.556***	0.099	-0.571***	0.112	-0.548***	0.122	-0.588***	0.108
Bayesian DIC		1661.8		1654.45		1651.62		1647.50		1658.20		1662.89		1662.75		1662.79	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models

(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models

(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

Table 4-29: Multilevel Poisson model with two-level Random Effects of count of funded projects against 3-year moving average Research Output Indicators (ROI)-continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov Av. ROI		0.019**	0.010	-0.006	0.012	0.002	0.001	0.049	0.070	-0.031	0.154	-0.006	0.025	0.014	0.009	0.006	0.013
References		-0.001***	0.001	-0.001	0.001	-0.001**	0.001	-0.001**	0.001	-0.001*	0.001	-0.001**	0.001	-0.001***	0.001	-0.001***	0.001
EU funding		0.021	0.023	0.025	0.025	0.025	0.025	0.024	0.023	0.029	0.024	0.028	0.023	0.020	0.038	0.010	0.033
Other funding		0.052	0.051	0.059	0.051	0.050	0.047	0.055	0.049	0.060	0.050	0.057	0.052	-0.021	0.071	-0.049	0.089
Internal funding		0.160**	0.077	0.176**	0.070	0.172***	0.066	0.149*	0.076	0.154*	0.082	0.179***	0.068	0.187	0.116	0.185*	0.101
INTNL COAUTH.		0.007***	0.001	0.007***	0.001	0.007***	0.001	0.007***	0.001	0.007***	0.001	0.006***	0.001	0.006***	0.002	0.006***	0.002
LOCAL COAUTH.		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-0.001	0.002	-0.001	0.002
Degree – Top 20		0.218*	0.130	0.213	0.152	0.227*	0.132	0.191	0.129	0.206	0.142	0.218	0.143	0.115	0.179	0.063	0.214
PhD – Top 20		-0.033	0.108	-0.034	0.118	-0.052	0.091	-0.020	0.108	-0.023	0.105	-0.046	0.119	0.123	0.178	0.183	0.197
No Master		0.239**	0.100	0.257***	0.088	0.261***	0.081	0.248**	0.097	0.264***	0.087	0.267***	0.093	0.313**	0.159	0.245*	0.141
2003		-1.185***	0.198	-1.216***	0.240	-1.188***	0.198	-1.194***	0.201	-1.211***	0.196	-1.248***	0.226	-0.800***	0.299	-0.693**	0.306
2004		-0.751***	0.154	-0.722***	0.175	-0.738***	0.159	-0.738***	0.159	-0.769***	0.154	-0.735***	0.166	-0.412*	0.212	-0.243	0.197
2005		-1.478***	0.179	-1.459***	0.193	-1.504***	0.195	-1.464***	0.177	-1.460***	0.194	-1.465***	0.202	-1.694***	0.365	-1.584***	0.368
2006		-0.998***	0.137	-0.969***	0.141	-0.980***	0.141	-1.000***	0.146	-0.998***	0.141	-0.964***	0.147	-0.871***	0.246	-0.774***	0.241
2009		-1.109***	0.131	-1.088***	0.161	-1.086***	0.135	-1.125***	0.150	-1.084***	0.115	-1.100***	0.135	-1.318***	0.234	-1.105***	0.242
2011		-0.571***	0.103	-0.566***	0.113	-0.564***	0.119	-0.617***	0.108	-0.551***	0.109	-0.569***	0.089	-0.378**	0.189	-0.242	0.180
Bayesian DIC		1659.59		1666.96		1661.15		1663.57		1664.07		1665.82		648.49		637.51	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 761, Groups: 152
(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.
(d) Cluster-robust errors used in all models
(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models
(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

Table 4-30: Fixed Effects Poisson model of counts of funded projects against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Cum. ROI		0.179*	0.100	0.302***	0.101	0.129	1.712	0.028***	0.008	0.795	0.522	0.034***	0.012	-0.019	0.120	-0.180	0.277	0.865***	0.265	-0.010	0.039
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
INTNLCOAUTHORS		-0.005	0.005	-0.008	0.005	-0.004	0.005	-0.003	0.005	-0.007	0.005	-0.008	0.005	-0.003	0.004	-0.003	0.005	-0.007	0.005	-0.003	0.004
LOCALCOAUTHORS		0.006	0.008	0.003	0.008	0.007	0.008	0.006	0.007	0.003	0.008	0.005	0.007	0.007	0.008	0.008	0.007	0.005	0.007	0.007	0.007
2003		-0.238	0.334	-0.369	0.333	-0.470	0.385	-0.399	0.315	-0.470	0.343	-0.405	0.341	-0.505	0.439	-0.593	0.435	-0.335	0.331	-0.517	0.396
2004		0.133	0.322	0.042	0.326	-0.008	0.358	0.006	0.307	-0.015	0.324	0.037	0.327	-0.039	0.397	-0.115	0.384	0.064	0.328	-0.049	0.363
2005		-0.759**	0.334	-0.841**	0.351	-0.826**	0.361	-0.809**	0.332	-0.852**	0.348	-0.822**	0.351	-0.849**	0.371	-0.902**	0.369	-0.829**	0.351	-0.855**	0.363
2006		-0.317	0.281	-0.391	0.292	-0.348	0.303	-0.328	0.281	-0.376	0.292	-0.351	0.293	-0.367	0.324	-0.412	0.319	-0.374	0.292	-0.371	0.305
2008		-0.027	0.192	-0.095	0.196	0.003	0.197	-0.013	0.188	-0.042	0.194	-0.029	0.193	-0.007	0.206	-0.030	0.203	-0.066	0.193	-0.010	0.197
2009		-0.676***	0.205	-0.723***	0.207	-0.632***	0.207	-0.645***	0.200	-0.670***	0.207	-0.669***	0.205	-0.638***	0.212	-0.654***	0.210	-0.700***	0.205	-0.640***	0.207
EU funding		-0.056	0.049	-0.046	0.051	-0.046	0.053	-0.060	0.053	-0.042	0.053	-0.046	0.052	-0.046	0.053	-0.045	0.054	-0.047	0.051	-0.046	0.054
Other funding		-0.003	0.070	0.006	0.071	0.014	0.074	-0.005	0.077	0.013	0.072	0.004	0.072	0.015	0.073	0.018	0.074	0.004	0.071	0.016	0.074
Internal funding		-0.036	0.128	-0.006	0.115	0.024	0.124	0.001	0.126	-0.006	0.119	0.023	0.117	0.023	0.125	0.020	0.126	0.015	0.117	0.021	0.124
Log-likelihood		-370.43		-369.83		-372.59		-370.44		-371.12		-370.71		-372.58		-372.41		-370.15		-372.56	
Wald X^2 test		42.84		52.63		44.57		109.21		42.63		50.49		45.11		45.01		55.66		44.39	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Localcoauthors, intnlcoauthors, references and all ROIs, except h-index, maxcitations and frpubs, are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-31: Fixed Effects Negative Binomial model of counts of funded projects against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cum. ROI		0.186*	0.109	0.310**	0.211	-0.129	2.223	0.025***	0.009	0.860	0.737	0.036*	0.021	-0.011	0.214	-0.164	0.301	0.920	0.561	-0.013	0.050
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
INTNLCOAUTHORS		-0.004	0.006	-0.007	0.007	-0.003	0.006	-0.002	0.006	-0.006	0.006	-0.007	0.006	-0.003	0.005	-0.003	0.005	-0.006	0.006	-0.002	0.005
LOCALCOAUTHORS		0.005	0.009	0.003	0.009	0.008	0.009	0.006	0.008	0.002	0.009	0.004	0.008	0.008	0.008	0.008	0.007	0.004	0.009	0.008	0.007
2003		-0.110	0.358	-0.251	0.348	-0.424	0.464	-0.316	0.369	-0.391	0.394	-0.319	0.381	-0.435	0.488	-0.546	0.463	-0.205	0.369	-0.473	0.472
2004		0.241	0.350	0.138	0.339	0.049	0.394	0.077	0.356	0.072	0.373	0.127	0.346	0.039	0.431	-0.053	0.414	0.171	0.370	0.009	0.439
2005		-0.639*	0.360	-0.733**	0.346	-0.763*	0.404	-0.723**	0.368	-0.765**	0.379	-0.734*	0.379	-0.770*	0.403	-0.840**	0.404	-0.716*	0.398	-0.792**	0.402
2006		-0.213	0.294	-0.296	0.300	-0.290	0.327	-0.252	0.308	-0.295	0.319	-0.266	0.323	-0.296	0.334	-0.357	0.344	-0.271	0.317	-0.315	0.341
2008		0.050	0.197	-0.034	0.195	0.038	0.235	0.037	0.211	0.001	0.213	0.015	0.212	0.034	0.216	0.001	0.221	-0.006	0.221	0.023	0.228
2009		-0.620***	0.201	-0.672***	0.193	-0.594***	0.217	-0.600***	0.218	-0.623***	0.208	-0.624***	0.228	-0.597***	0.231	-0.621***	0.208	-0.648***	0.222	-0.604***	0.233
EU funding		-0.053	0.057	-0.043	0.054	-0.046	0.059	-0.055	0.055	-0.041	0.056	-0.045	0.059	-0.046	0.063	-0.046	0.060	-0.044	0.057	-0.047	0.064
Other funding		-0.008	0.083	0.002	0.079	0.010	0.076	-0.007	0.079	0.006	0.075	-0.004	0.083	0.010	0.083	0.013	0.081	-0.001	0.078	0.010	0.078
Internal funding		-0.058	0.138	-0.025	0.130	0.007	0.138	-0.024	0.130	-0.025	0.132	0.010	0.131	0.008	0.124	0.007	0.141	-0.004	0.120	0.004	0.139
Constant		1.376	5.739	2.093	4.816	2.770	5.912	1.614	2.877	2.574	6.291	2.502	5.782	2.794	6.197	3.022	6.091	2.017	4.996	2.848	6.047
Log-likelihood		-369.73		-369.16		-372.14		-369.74		-370.49		-370.14		-372.13		-372.00		-369.47		-372.09	
Wald X^2 test		43.58		44.59		45.22		54.15		36.89		44.29		34.37		43.33		41.58		37.43	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index, maxcitations, wfcitations and frpubs are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-32: Random Effects Poisson model of counts of funded projects against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.088***	0.027	0.056	0.125	-0.165	0.010	0.108	0.122	0.456*	0.336	0.016*	0.009	-0.089	0.132	-0.303**	0.140	0.126	0.131	-0.026	0.018
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.040	0.045	-0.029	0.039	-0.035	0.040	-0.024	0.044	-0.032	0.043	-0.042	0.043	-0.028	0.044	-0.017	0.042	-0.042	0.040	-0.022	0.044
PhD – Top 20		0.012	0.262	0.102	0.261	0.169	0.259	0.151	0.254	0.109	0.272	0.111	0.260	0.181	0.261	0.176	0.283	0.129	0.278	0.207	0.246
Degree – Top 20		0.311	0.318	0.258	0.309	0.157	0.287	0.224	0.300	0.247	0.333	0.211	0.301	0.149	0.280	0.150	0.287	0.200	0.305	0.145	0.248
No Master		0.488**	0.239	0.487**	0.227	0.512**	0.247	0.447*	0.242	0.465**	0.236	0.499*	0.255	0.442*	0.246	0.413	0.253	0.516**	0.244	0.480**	0.231
Female		0.358	0.339	0.459	0.380	0.395	0.376	0.461	0.339	0.374	0.340	0.416	0.345	0.325	0.349	0.232	0.329	0.460	0.347	0.311	0.385
INTNLCOAUTHORS		0.001	0.003	0.002	0.002	0.003	0.003	0.003	0.002	0.001	0.002	0.001	0.002	0.004	0.003	0.005*	0.002	0.002	0.002	0.004*	0.003
LOCALCOAUTHORS		-0.001	0.004	0.001	0.004	0.006	0.004	0.004	0.004	0.002	0.004	0.003	0.003	0.007**	0.003	0.006**	0.003	0.003	0.003	0.007**	0.003
2003		-0.439	0.277	-0.371	0.273	-0.321	0.297	-0.332	0.304	-0.292	0.279	-0.282	0.288	-0.390	0.302	-0.416	0.278	-0.344	0.280	-0.363	0.312
2004		-0.025	0.288	0.068	0.248	0.126	0.253	0.112	0.253	0.148	0.239	0.152	0.229	0.069	0.231	0.057	0.236	0.094	0.258	0.096	0.250
2005		-0.861***	0.287	-0.768***	0.297	-0.685**	0.292	-0.711***	0.269	-0.683**	0.267	-0.685**	0.274	-0.729***	0.274	-0.737***	0.271	-0.733**	0.288	-0.705**	0.289
2006		-0.400*	0.232	-0.303	0.238	-0.222	0.269	-0.246	0.254	-0.223	0.234	-0.226	0.245	-0.256	0.241	-0.261	0.233	-0.270	0.238	-0.235	0.233
2008		0.016	0.175	0.076	0.175	0.135	0.175	0.119	0.174	0.124	0.162	0.124	0.165	0.120	0.166	0.118	0.161	0.102	0.167	0.129	0.170
2009		-0.616***	0.189	-0.564***	0.192	-0.516***	0.193	-0.530***	0.192	-0.526***	0.172	-0.530***	0.181	-0.525***	0.173	-0.523***	0.192	-0.544***	0.199	-0.518***	0.194
EU funding		0.035	0.049	0.032	0.053	0.025	0.053	0.025	0.053	0.031	0.047	0.032	0.057	0.029	0.053	0.028	0.052	0.030	0.051	0.023	0.051
Other funding		0.041	0.061	0.047	0.070	0.055	0.067	0.051	0.066	0.050	0.068	0.043	0.062	0.060	0.074	0.063	0.073	0.046	0.068	0.060	0.068
Internal funding		0.089	0.145	0.124	0.125	0.136	0.127	0.140	0.130	0.119	0.133	0.134	0.129	0.148	0.119	0.151	0.126	0.131	0.129	0.138	0.125
Constant		-1.011***	0.371	-0.799**	0.380	-0.771**	0.368	-0.879**	0.378	-0.805**	0.369	-0.796**	0.388	-0.656	0.403	-0.596	0.365	-0.765**	0.362	-0.724*	0.393
$\ln\sigma^2$		0.035	0.242	0.108	0.232	0.137	0.211	0.114	0.237	0.110	0.229	0.105	0.226	0.101	0.210	0.032	0.232	0.113	0.218	0.099	0.228
Log-likelihood		-694.97		-698.50		-700.40		-699.13		-698.70		-698.42		-699.37		-696.88		-699.01		-699.20	
Wald X^2 test		91.27		67.80		70.92		73.19		70.81		82.97		76.38		72.50		74.71		63.71	
LR test		133.68		154.11		158.60		157.94		148.87		144.16		153.51		139.25		149.08		150.81	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-33: Random Effects Negative Binomial model of counts of funded projects against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.090***	0.028	0.057	0.091	-0.180	1.014	0.111	0.089	0.468*	0.325	0.017*	0.009	-0.090	0.135	-0.304**	0.141	0.129	0.125	-0.026	0.018
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.041	0.045	-0.029	0.043	-0.034	0.046	-0.024	0.044	-0.032	0.045	-0.042	0.038	-0.027	0.043	-0.016	0.039	-0.043	0.039	-0.021	0.046
PhD – Top 20		0.038	0.262	0.122	0.266	0.188	0.250	0.172	0.257	0.131	0.258	0.133	0.255	0.199	0.245	0.191	0.236	0.149	0.263	0.224	0.263
Degree – Top 20		0.274	0.319	0.227	0.325	0.126	0.269	0.189	0.325	0.208	0.330	0.171	0.305	0.119	0.274	0.126	0.269	0.167	0.311	0.116	0.295
No Master		0.496**	0.243	0.498**	0.252	0.523**	0.258	0.458*	0.249	0.475*	0.251	0.511**	0.252	0.453*	0.252	0.422*	0.252	0.528**	0.243	0.491**	0.249
Female		0.378	0.362	0.471	0.361	0.404	0.352	0.473	0.367	0.384	0.390	0.430	0.343	0.336	0.373	0.242	0.348	0.474	0.368	0.321	0.356
INTNLCOAUTHORS		0.001	0.003	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.003	0.002	0.003	0.005*	0.003	0.005*	0.003	0.002	0.002	0.005	0.003
LOCALCOAUTHORS		-0.001	0.004	0.001	0.005	0.006	0.004	0.004	0.004	0.002	0.004	0.003	0.003	0.007**	0.003	0.006**	0.003	0.003	0.004	0.007**	0.003
2003		-0.418	0.268	-0.358	0.279	-0.310	0.289	-0.321	0.296	-0.274	0.289	-0.263	0.261	-0.384	0.286	-0.413	0.284	-0.328	0.279	-0.355	0.291
2004		-0.009	0.267	0.082	0.254	0.141	0.243	0.127	0.252	0.170	0.250	0.174	0.254	0.082	0.242	0.068	0.238	0.111	0.253	0.111	0.251
2005		-0.827***	0.291	-0.744***	0.272	-0.662***	0.250	-0.686**	0.278	-0.652**	0.288	-0.652**	0.265	-0.707**	0.289	-0.718***	0.260	-0.706**	0.281	-0.682**	0.290
2006		-0.377*	0.225	-0.287	0.231	-0.207	0.247	-0.229	0.235	-0.200	0.232	-0.202	0.225	-0.244	0.232	-0.249	0.237	-0.251	0.247	-0.220	0.234
2008		0.042	0.181	0.093	0.170	0.153	0.158	0.136	0.183	0.147	0.174	0.147	0.163	0.135	0.166	0.131	0.168	0.122	0.176	0.145	0.176
2009		-0.596***	0.205	-0.549***	0.185	-0.499***	0.178	-0.512***	0.186	-0.504***	0.190	-0.508***	0.190	-0.509***	0.187	-0.509***	0.189	-0.526***	0.190	-0.500***	0.184
EU funding		0.038	0.051	0.034	0.051	0.027	0.047	0.028	0.049	0.034	0.055	0.035	0.050	0.031	0.054	0.030	0.048	0.033	0.047	0.025	0.051
Other funding		0.045	0.066	0.049	0.071	0.056	0.076	0.053	0.069	0.053	0.075	0.046	0.069	0.062	0.066	0.064	0.071	0.048	0.073	0.061	0.074
Internal funding		0.076	0.128	0.116	0.127	0.129	0.135	0.132	0.134	0.109	0.128	0.125	0.131	0.143	0.132	0.147	0.120	0.123	0.130	0.132	0.130
Constant		2.351	6.081	2.952	6.137	2.995	6.241	2.752	6.174	2.716	6.134	2.676	6.243	3.115	6.231	3.212	6.197	2.871	6.111	3.004	6.207
lnr		3.459	6.000	3.729	6.015	3.717	6.159	3.613	6.108	3.521	6.058	3.485	6.124	3.757	6.100	3.857	6.100	3.622	6.026	3.717	6.065
lns		0.023	0.248	-0.071	0.249	-0.102	0.234	-0.074	0.266	-0.063	0.264	-0.055	0.247	-0.065	0.255	0.004	0.254	-0.071	0.248	-0.062	0.244
Log-likelihood		-694.74		-698.39		-700.29		-698.99		-698.53		-698.24		-699.26		-696.78		-698.87		-699.08	
Wald X^2 test		87.09		72.25		59.73		63.48		94.58		84.02		73.51		85.87		69.61		71.56	
LR test		71.90		86.44		87.79		88.63		80.72		78.36		84.89		76.59		82.83		82.81	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-34: Multilevel Poisson model with two-level Random Effects of count of funded projects against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulative ROI		0.029***	0.01	0.043***	0.018	-0.011***	0.003	0.037	0.038	0.383***	0.102	0.882**	0.353	-0.155***	0.026	-0.426***	0.054	0.058**	0.033	-0.040***	0.008
References		-0.069***	0.024	-0.055**	0.027	-0.046**	0.025	-0.058***	0.022	-0.058***	0.024	-0.065***	0.024	-0.044**	0.025	-0.037**	0.021	-0.054**	0.026	-0.001	0.001
EU funding		0.047	0.06	0.053	0.044	0.074*	0.053	0.048	0.053	0.048	0.051	0.055	0.052	0.089**	0.054	0.1**	0.042	0.048	0.051	0.033	0.025
Other funding		0.123*	0.082	0.127*	0.078	0.225***	0.076	0.167**	0.077	0.119*	0.078	0.142**	0.072	0.286***	0.072	0.261***	0.068	0.151*	0.087	0.086	0.053
Internal funding		0.5***	0.152	0.62***	0.114	0.965***	0.126	0.67***	0.112	0.616***	0.123	0.6***	0.131	0.97***	0.131	0.844***	0.113	0.667***	0.12	0.218***	0.072
INTNL COAUTH.		0.229	0.148	0.187*	0.137	0.254**	0.127	0.211*	0.125	0.248**	0.125	0.2*	0.146	0.24**	0.126	0.261**	0.134	0.213*	0.147	0.009***	0.001
LOCAL COAUTH.		-0.130	0.112	-0.041	0.108	0.059	0.107	-0.013	0.115	-0.073	0.106	-0.072	0.141	0.101	0.122	0.096	0.101	-0.081	0.117	0.002**	0.001
Degree – Top 20		0.201**	0.086	0.263***	0.088	0.261***	0.081	0.232**	0.091	0.227***	0.086	0.244**	0.093	0.257***	0.098	0.333***	0.085	0.244***	0.079	0.288**	0.126
PhD – Top 20		-1.29***	0.209	-1.215***	0.202	-1.155***	0.205	-1.203***	0.223	-1.17***	0.189	-1.21***	0.182	-1.081***	0.199	-0.987***	0.222	-1.219***	0.168	0.079	0.112
No Master		-0.812***	0.168	-0.719***	0.154	-0.706***	0.169	-0.716***	0.153	-0.709***	0.149	-0.761***	0.161	-0.627***	0.154	-0.499***	0.174	-0.786***	0.149	0.290***	0.092
2003		-1.584***	0.196	-1.458***	0.18	-1.434***	0.175	-1.489***	0.202	-1.449***	0.182	-1.507***	0.189	-1.334***	0.176	-1.253***	0.174	-1.494***	0.188	-1.066***	0.221
2004		-1.076***	0.153	-1.023***	0.155	-0.969***	0.141	-0.972***	0.162	-1.004***	0.132	-0.996***	0.148	-0.873***	0.178	-0.784***	0.148	-1.015***	0.167	-0.607***	0.155
2005		-1.146***	0.132	-1.078***	0.142	-1.067***	0.157	-1.104***	0.149	-1.101***	0.136	-1.139***	0.142	-0.944***	0.139	-0.891***	0.132	-1.128***	0.126	-1.369***	0.194
2006		-0.565***	0.095	-0.495***	0.123	-0.537***	0.105	-0.557***	0.098	-0.578***	0.103	-0.603***	0.116	-0.414***	0.108	-0.387***	0.123	-0.563***	0.099	-0.873***	0.141
2009		0.029***	0.01	0.043***	0.018	-0.011***	0.003	0.037	0.038	0.383***	0.102	0.882**	0.353	-0.155***	0.026	-0.426***	0.054	0.059**	0.033	-0.987***	0.144
2011		-0.069***	0.024	-0.055**	0.027	-0.046**	0.025	-0.058***	0.022	-0.058***	0.024	-0.065***	0.024	-0.044**	0.025	-0.037**	0.021	-0.054**	0.026	-0.472***	0.108
Bayesian DIC		1661.31		1663.18		1653.75		1664.90		1651.63		1659.07		1627.18		1590.69		1663.61		1627.87	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models

(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models

(f) Bayesian Deviance Information Criterion (DIC) is reported as a measure of goodness of fit

Table 4-35: Fixed Effects Poisson model of counts of funded projects against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Average ROI		-0.202	0.621	0.935	0.822	0.181	0.295	-0.487	1.182	0.099	0.066	0.705***	0.215	0.017	0.030	0.054	0.069	0.073***	0.025	0.536	0.908
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
INTNLCOAUTHORS		-0.004	0.005	-0.004	0.005	-0.006	0.006	-0.003	0.005	-0.006	0.005	-0.009*	0.005	-0.005	0.005	-0.005	0.005	-0.007	0.005	-0.005	0.005
LOCALCOAUTHORS		0.007	0.007	0.009	0.007	0.007	0.007	0.007	0.007	0.006	0.007	0.009	0.006	0.007	0.007	0.007	0.007	0.013**	0.006	0.007	0.007
2003		-0.427	0.427	-0.589	0.362	-0.519	0.351	-0.462	0.361	-0.584*	0.353	-0.645*	0.351	-0.474	0.340	-0.456	0.345	-0.738**	0.366	-0.500	0.344
2004		0.032	0.390	-0.122	0.345	-0.049	0.330	0.001	0.336	-0.122	0.337	-0.195	0.338	-0.008	0.316	0.004	0.318	-0.270	0.354	-0.033	0.322
2005		-0.779*	0.417	-0.977***	0.378	-0.873**	0.361	-0.811**	0.362	-0.978***	0.376	-1.062***	0.367	-0.840**	0.342	-0.829**	0.338	-1.122***	0.375	-0.856**	0.348
2006		-0.310	0.359	-0.463	0.320	-0.383	0.305	-0.336	0.309	-0.469	0.309	-0.532*	0.303	-0.353	0.289	-0.343	0.288	-0.567*	0.313	-0.369	0.296
2008		0.029	0.230	-0.072	0.205	-0.021	0.202	0.011	0.202	-0.095	0.208	-0.150	0.203	-0.009	0.194	-0.001	0.193	-0.137	0.202	-0.011	0.198
2009		-0.614***	0.217	-0.682***	0.209	-0.644***	0.207	-0.626***	0.210	-0.701***	0.213	-0.751***	0.212	-0.635***	0.204	-0.631***	0.204	-0.727***	0.208	-0.639***	0.206
EU funding		-0.045	0.054	-0.052	0.053	-0.049	0.052	-0.044	0.055	-0.051	0.052	-0.056	0.050	-0.049	0.052	-0.049	0.051	-0.054	0.051	-0.047	0.052
Other funding		0.015	0.074	0.017	0.074	0.011	0.072	0.014	0.074	0.016	0.073	-0.001	0.074	0.009	0.072	0.007	0.071	0.009	0.074	0.008	0.072
Internal funding		0.030	0.127	-0.005	0.125	0.023	0.125	0.026	0.126	-0.016	0.123	-0.029	0.118	0.017	0.124	0.023	0.125	-0.046	0.126	0.027	0.125
Log-likelihood		-372.52		-371.63		-372.35		-372.55		-371.28		-369.33		-372.28		-372.11		-369.42		-372.33	
Wald X^2 test		44.28		45.70		44.55		47.40		42.45		49.09		44.20		44.80		53.12		45.59	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Citations and maxcitations, are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-36: Fixed Effects Negative Binomial model of counts of funded projects against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Average ROI		-0.140	0.613	0.910	0.904	0.161	0.353	0.134	1.812	0.100	0.078	0.690***	0.240	0.016	0.034	0.050	0.079	0.071**	0.033	0.465	1.056
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	0.001	0.001
INTNLCOAUTHORS		-0.003	0.005	-0.003	0.005	-0.005	0.006	-0.003	0.005	-0.005	0.005	-0.008	0.005	-0.004	0.006	-0.004	0.005	-0.005	0.006	0.007	0.006
LOCALCOAUTHORS		0.007	0.008	0.009	0.008	0.007	0.008	0.008	0.008	0.006	0.007	0.009	0.007	0.007	0.008	0.008	0.008	0.012*	0.007	0.004	0.004
2003		-0.384	0.427	-0.512	0.390	-0.447	0.386	-0.419	0.392	-0.517	0.373	-0.573	0.365	-0.399	0.367	-0.374	0.384	-0.654	0.409	-0.181	0.305
2004		0.086	0.391	-0.045	0.383	0.028	0.340	0.053	0.370	-0.047	0.377	-0.118	0.348	0.069	0.351	0.087	0.359	-0.193	0.391	0.417	0.348
2005		-0.725*	0.419	-0.895**	0.374	-0.794**	0.378	-0.761**	0.385	-0.902**	0.392	-0.988***	0.372	-0.761**	0.368	-0.747*	0.384	-1.041**	0.419	-0.423	0.334
2006		-0.259	0.388	-0.390	0.329	-0.312	0.326	-0.288	0.330	-0.400	0.334	-0.461	0.319	-0.281	0.302	-0.266	0.328	-0.493	0.329	-0.040	0.284
2008		0.057	0.235	-0.027	0.220	0.022	0.216	0.038	0.216	-0.057	0.224	-0.111	0.214	0.036	0.188	0.047	0.208	-0.093	0.205	0.475**	0.197
2009		-0.581**	0.233	-0.640***	0.225	-0.604***	0.201	-0.594***	0.220	-0.659***	0.216	-0.712***	0.222	-0.593***	0.208	-0.587***	0.210	-0.688***	0.201	-0.148	0.238
EU funding		-0.046	0.061	-0.051	0.058	-0.048	0.061	-0.046	0.062	-0.049	0.056	-0.053	0.053	-0.048	0.059	-0.048	0.057	-0.051	0.063	-0.058	0.058
Other funding		0.010	0.081	0.013	0.080	0.008	0.081	0.010	0.082	0.011	0.079	-0.005	0.080	0.005	0.084	0.003	0.080	0.006	0.085	0.081	0.099
Internal funding		0.013	0.145	-0.019	0.134	0.010	0.155	0.007	0.140	-0.031	0.133	-0.036	0.133	0.005	0.150	0.011	0.135	-0.058	0.148	0.075	0.192
Constant		2.885	6.702	2.595	6.041	2.670	6.545	2.722	6.737	2.624	5.862	2.610	6.326	2.636	6.468	2.580	6.112	2.620	6.706	-2.409***	0.320
Log-likelihood		-372.10		-371.18		-371.97		-372.14		-370.75		-368.94		-371.90		-371.75		-369.12		-371.95	
Wald X^2 test		39.09		38.55		43.82		43.69		41.76		38.82		44.20		43.69		47.56		35.44	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Citations and maxcitations, are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-37: Random Effects Poisson model of counts of funded projects against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.830***	0.296	0.796**	0.377	0.286**	0.146	0.904	0.727	0.034	0.037	0.245**	0.114	-0.01	0.011	-0.055**	0.022	0.030**	0.014	-0.192	0.280
References		-0.001	0.001	-0.001	0.000	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.026	0.040	-0.020	0.042	-0.041	0.046	-0.026	0.041	-0.030	0.038	-0.035	0.041	-0.036	0.044	-0.025	0.042	-0.036	0.045	-0.033	0.042
PhD – Top 20		0.120	0.270	0.098	0.241	0.164	0.269	0.158	0.234	0.132	0.244	0.113	0.272	0.151	0.255	0.113	0.249	0.102	0.274	0.172	0.270
Degree – Top 20		0.272	0.321	0.298	0.300	0.143	0.319	0.212	0.293	0.230	0.299	0.242	0.314	0.164	0.291	0.213	0.283	0.263	0.319	0.164	0.295
No Master		0.467**	0.231	0.448*	0.238	0.558**	0.236	0.449*	0.236	0.455*	0.258	0.456*	0.248	0.473*	0.245	0.363	0.247	0.481**	0.241	0.494**	0.227
Female		0.201	0.326	0.402	0.310	0.374	0.362	0.429	0.339	0.329	0.346	0.336	0.342	0.377	0.321	0.217	0.346	0.435	0.329	0.379	0.393
INTNLCOAUTHORS		0.003	0.003	0.003	0.003	-0.001	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.004*	0.003	0.003	0.002	0.003	0.003
LOCALCOAUTHORS		0.002	0.003	0.001	0.004	0.003	0.003	0.005*	0.003	0.004	0.003	0.004	0.003	0.006**	0.003	0.005*	0.003	0.002	0.003	0.006**	0.003
2003		-0.622**	0.294	-0.465*	0.266	-0.404	0.278	-0.350	0.291	-0.329	0.274	-0.350	0.287	-0.312	0.288	-0.300	0.283	-0.476	0.297	-0.299	0.289
2004		-0.147	0.265	-0.013	0.271	0.053	0.239	0.098	0.275	0.116	0.239	0.088	0.244	0.133	0.248	0.153	0.265	-0.027	0.294	0.146	0.245
2005		-1.002***	0.296	-0.891***	0.306	-0.781***	0.268	-0.734**	0.293	-0.722**	0.296	-0.762***	0.295	-0.673**	0.280	-0.654**	0.295	-0.880***	0.293	-0.664**	0.290
2006		-0.479*	0.246	-0.388	0.241	-0.297	0.248	-0.261	0.249	-0.249	0.245	-0.281	0.240	-0.214	0.230	-0.203	0.242	-0.380	0.256	-0.207	0.231
2008		-0.022	0.165	0.035	0.178	0.087	0.166	0.108	0.175	0.113	0.173	0.091	0.176	0.143	0.178	0.151	0.162	0.042	0.182	0.145	0.164
2009		-0.621***	0.187	-0.585***	0.193	-0.545***	0.195	-0.534***	0.190	-0.529***	0.199	-0.548***	0.191	-0.513***	0.188	-0.506***	0.194	-0.581***	0.198	-0.510***	0.178
EU funding		0.039	0.053	0.032	0.052	0.026	0.050	0.024	0.048	0.027	0.050	0.033	0.053	0.027	0.055	0.028	0.052	0.036	0.050	0.024	0.053
Other funding		0.053	0.066	0.050	0.071	0.045	0.067	0.054	0.069	0.051	0.071	0.041	0.069	0.058	0.072	0.067	0.077	0.040	0.067	0.058	0.063
Internal funding		0.118	0.118	0.122	0.132	0.131	0.125	0.141	0.119	0.127	0.124	0.127	0.128	0.141	0.132	0.148	0.130	0.117	0.134	0.137	0.117
Constant		-1.088***	0.362	-0.843**	0.369	-0.985**	0.419	-0.861**	0.379	-0.823**	0.355	-0.853**	0.368	-0.667	0.425	-0.406	0.415	-0.812**	0.399	-0.709*	0.397
$\ln\sigma^2$		-0.052	0.231	0.053	0.228	0.088	0.210	0.102	0.217	0.116	0.208	0.086	0.233	0.123	0.225	-0.005	0.237	0.065	0.242	0.127	0.216
Log-likelihood		-696.15		-697.17		-698.37		-699.45		-699.29		-697.67		-700.20		-696.49		-696.69		-700.19	
Wald X^2 test		94.63		87.20		91.92		71.82		76.66		89.65		70.35		84.92		90.86		77.21	
LR test		109.87		137.18		148.12		152.14		149.67		138.53		156.46		133.37		133.46		155.98	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Citations and maxcitations, are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-38: Random Effects Negative Binomial model of counts of funded projects against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.852***	0.307	0.804**	0.378	0.288*	0.152	0.931	0.722	0.034	0.037	0.249**	0.126	-0.01	0.011	-0.055***	0.018	0.030**	0.013	-0.197	0.316
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.025	0.039	-0.021	0.044	-0.040	0.042	-0.025	0.040	-0.030	0.042	-0.034	0.038	-0.035	0.042	-0.024	0.039	-0.036	0.041	-0.033	0.042
PhD – Top 20		0.140	0.237	0.116	0.255	0.177	0.272	0.178	0.252	0.151	0.272	0.132	0.252	0.171	0.269	0.133	0.232	0.123	0.234	0.192	0.284
Degree – Top 20		0.237	0.304	0.268	0.308	0.111	0.293	0.177	0.293	0.196	0.314	0.205	0.296	0.131	0.319	0.181	0.290	0.230	0.289	0.133	0.286
No Master		0.476**	0.237	0.460*	0.251	0.567**	0.260	0.459*	0.247	0.465*	0.254	0.465*	0.250	0.484*	0.252	0.377	0.252	0.494**	0.236	0.505**	0.257
Female		0.214	0.321	0.415	0.358	0.381	0.373	0.441	0.329	0.336	0.356	0.346	0.357	0.387	0.365	0.228	0.335	0.452	0.294	0.388	0.357
INTNLCOAUTHORS		0.003	0.002	0.003	0.002	-0.001	0.003	0.003	0.002	0.003	0.003	0.002	0.002	0.003	0.003	0.004*	0.002	0.003	0.002	0.003	0.003
LOCALCOAUTHORS		0.002	0.003	0.001	0.004	0.003	0.003	0.005*	0.003	0.004	0.003	0.004	0.003	0.006**	0.003	0.006*	0.003	0.002	0.003	0.006**	0.003
2003		-0.605**	0.295	-0.451	0.292	-0.389	0.278	-0.338	0.273	-0.313	0.301	-0.331	0.273	-0.302	0.280	-0.295	0.306	-0.459*	0.277	-0.287	0.293
2004		-0.129	0.268	0.002	0.274	0.069	0.229	0.114	0.245	0.135	0.260	0.111	0.262	0.149	0.242	0.166	0.249	-0.010	0.249	0.162	0.235
2005		-0.968***	0.315	-0.866***	0.305	-0.757***	0.291	-0.709**	0.276	-0.694**	0.291	-0.730**	0.284	-0.648**	0.265	-0.629**	0.278	-0.850***	0.299	-0.640**	0.287
2006		-0.457*	0.244	-0.372	0.240	-0.282	0.255	-0.244	0.238	-0.230	0.252	-0.257	0.237	-0.199	0.234	-0.189	0.240	-0.359	0.233	-0.191	0.239
2008		0.005	0.172	0.053	0.174	0.105	0.165	0.126	0.167	0.134	0.178	0.115	0.177	0.160	0.164	0.167	0.170	0.063	0.168	0.162	0.179
2009		-0.597***	0.191	-0.568***	0.183	-0.529***	0.189	-0.515***	0.165	-0.509**	0.207	-0.525***	0.188	-0.495***	0.187	-0.488***	0.187	-0.561***	0.182	-0.492***	0.190
EU funding		0.044	0.050	0.034	0.055	0.029	0.051	0.026	0.048	0.030	0.048	0.035	0.049	0.030	0.055	0.030	0.054	0.039	0.048	0.026	0.051
Other funding		0.056	0.064	0.053	0.069	0.047	0.064	0.056	0.068	0.053	0.070	0.043	0.070	0.060	0.069	0.068	0.074	0.043	0.065	0.060	0.072
Internal funding		0.110	0.138	0.114	0.126	0.128	0.122	0.134	0.121	0.120	0.126	0.120	0.133	0.134	0.129	0.140	0.126	0.108	0.129	0.130	0.122
Constant		2.073	5.945	2.776	6.153	2.734	6.108	2.727	6.034	2.848	6.234	2.621	5.897	3.030	6.046	3.110	5.985	2.661	6.199	3.023	6.148
lnr		3.388	5.760	3.666	6.033	3.728	6.005	3.589	5.946	3.653	6.087	3.508	5.774	3.664	5.911	3.625	5.887	3.526	6.107	3.693	6.060
lns		0.133	0.288	-0.008	0.272	-0.049	0.262	-0.059	0.241	-0.076	0.255	-0.036	0.254	-0.084	0.252	0.055	0.279	-0.013	0.251	-0.089	0.238
Log-likelihood		-695.85		-697.02		-698.26		-699.29		-699.16		-697.49		-700.07		-696.32		-696.50		-700.07	
Wald X^2 test		114.86		106.55		100.19		58.56		85.93		86.24		84.08		93.98		80.46		84.17	
LR test		55.08		75.76		81.86		84.27		81.01		74.44		86.39		72.43		73.10		85.80	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Citations and maxcitations, are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-39: Multilevel Poisson model with two-level Random Effects of count of funded projects against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Average ROI		0.412***	0.128	0.715***	0.107	-0.017	0.047	0.689**	0.336	0.026***	0.006	0.151***	0.046	-0.023***	0.004	-0.074***	0.010	0.018***	0.003	-0.667***	0.125
References		-0.001***	0.001	-0.001**	0.001	-0.001**	0.001	-0.001***	0.001	-0.001**	0.001	-0.001***	0.001	-0.001	0.001	-0.001	0.001	-0.001***	0.001	-0.001	0.001
EU funding		0.022	0.022	0.033	0.026	0.026	0.022	0.027	0.025	0.029	0.023	0.034	0.022	0.049**	0.024	0.048**	0.021	0.031	0.025	0.030	0.022
Other funding		0.036	0.051	0.049	0.053	0.047	0.049	0.056	0.060	0.057	0.050	0.034	0.052	0.087*	0.049	0.090*	0.047	0.031	0.043	0.078	0.052
Internal funding		0.138*	0.078	0.148**	0.065	0.172**	0.078	0.159**	0.070	0.146*	0.077	0.141*	0.079	0.222***	0.063	0.250***	0.078	0.145*	0.076	0.212***	0.071
INTNL COAUTH.		0.006***	0.001	0.006***	0.001	0.007***	0.001	0.007***	0.001	0.007***	0.001	0.006***	0.001	0.009***	0.001	0.008***	0.001	0.007***	0.001	0.009***	0.001
LOCAL COAUTH.		-0.001	0.001	-0.004***	0.001	0.001	0.001	0.001	0.001	-0.001	0.001	0.001	0.001	0.002**	0.001	0.001	0.001	-0.001	0.001	0.002**	0.001
Degree – Top 20		0.203	0.131	0.260*	0.135	0.221	0.143	0.221*	0.130	0.276*	0.151	0.257**	0.129	0.272**	0.135	0.274**	0.137	0.231**	0.109	0.235*	0.125
PhD – Top 20		-0.085	0.103	-0.115	0.125	-0.029	0.120	-0.029	0.120	-0.093	0.110	-0.130	0.105	0.020	0.106	0.038	0.120	-0.113	0.096	0.095	0.114
No Master		0.147	0.090	0.206**	0.095	0.260***	0.093	0.218**	0.104	0.221***	0.081	0.216**	0.096	0.304***	0.080	0.321***	0.090	0.219**	0.099	0.338***	0.087
2003		-1.321***	0.189	-1.237***	0.212	-1.193***	0.224	-1.184***	0.199	-1.208***	0.194	-1.189***	0.181	-0.983***	0.218	-0.766***	0.214	-1.243***	0.173	-0.955***	0.211
2004		-0.853***	0.162	-0.768***	0.162	-0.754***	0.165	-0.754***	0.172	-0.732***	0.144	-0.752***	0.152	-0.493***	0.158	-0.282	0.179	-0.815***	0.149	-0.506***	0.176
2005		-1.615***	0.178	-1.563***	0.218	-1.482***	0.193	-1.488***	0.180	-1.459***	0.189	-1.494***	0.177	-1.178***	0.204	-1.051***	0.200	-1.543***	0.167	-1.183***	0.203
2006		-1.111***	0.152	-1.048***	0.144	-0.978***	0.151	-0.989***	0.154	-1.019***	0.141	-1.004***	0.147	-0.737***	0.147	-0.620***	0.145	-1.059***	0.151	-0.782***	0.152
2009		-1.164***	0.126	-1.098***	0.131	-1.102***	0.143	-1.095***	0.136	-1.098***	0.135	-1.140***	0.131	-0.895***	0.142	-0.785***	0.138	-1.123***	0.141	-0.926***	0.126
2011		-0.575***	0.103	-0.480***	0.118	-0.551***	0.107	-0.534***	0.097	-0.584***	0.107	-0.576***	0.106	-0.377***	0.120	-0.302***	0.110	-0.552***	0.099	-0.468***	0.104
Bayesian DIC		1653.68		1644.55		1666.40		1661.40		1653.70		1651.25		1627.59		1576.76		1647.34		1632.35	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models

(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models

(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

Table 4-40: Fixed Effects Poisson model of amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.033	0.048	-0.600**	0.244	-0.374	0.427	-0.306	0.691	0.075	0.112	-0.015	0.022	0.208	0252	0.579	0.562
references		-0.116	0.001	0.066	0.001	-0.010	0.001	-0.074	0.001	-0.002*	0.001	-0.001	0.001	-0.067	0.001	-0.001*	0.001
INTNLCOAUTHORS		-0.796	0.007	-0.572	0.006	-0.863	0.007	-0.779	0.007	-0.007	0.007	-0.008	0.007	-0.772	0.007	-0.008	0.007
LOCALCOAUTHORS		0.523	0.009	0.268	0.008	0.648	0.009	0.480	0.009	0.005	0.010	0.005	0.009	0.493	0.009	0.005	0.009
2003		-1.414***	0.525	-1.221**	0.528	-1.295**	0.512	-1.336***	0.509	-1.393***	0.502	-1.345***	0.501	-1.452***	0.523	-1.391***	0.499
2004		-0.536	0.446	-0.333	0.473	-0.405	0.440	-0.450	0.441	-0.520	0.433	-0.461	0.433	-0.578	0.451	-0.521	0.435
2005		-1.556***	0.436	-1.411***	0.457	-1.463***	0.435	-1.497***	0.438	-1.536***	0.434	-1.522***	0.430	-1.577***	0.437	-1.541***	0.427
2006		-0.817**	0.397	-0.699*	0.418	-0.734*	0.402	-0.773*	0.398	-0.813**	0.395	-0.802**	0.391	-0.825**	0.396	-0.798**	0.389
2008		0.453	0.296	0.518	0.316	0.517*	0.309	0.477	0.304	0.458	0.295	0.462	0.296	0.447	0.295	0.468	0.291
2009		-0.600**	0.251	-0.521*	0.270	-0.544**	0.256	-0.574**	0.256	-0.602**	0.249	-0.584**	0.252	-0.604**	0.252	-0.591**	0.248
EU funding		-0.017	0.063	0.001	0.062	-0.019	0.064	-0.014	0.063	-0.018	0.062	-0.010	0.063	-0.017	0.062	-0.018	0.062
Other funding		0.064	0.091	0.070	0.085	0.057	0.087	0.065	0.088	0.063	0.091	0.074	0.088	0.057	0.093	0.060	0.091
Internal funding		-0.120	0.151	-0.107	0.150	-0.103	0.151	-0.105	0.154	-0.126	0.156	-0.126	0.151	-0.118	0.151	-0.121	0.150
Log-likelihood		-30260.37		-29676.70		-30178.13		-30270.88		-30225.06		-30258.79		-30208.58		-30162.99	
Wald X^2 test		80.06		81.32		80.68		79.82		76.37		78.59		78.45		80.15	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 495, Groups: 94
(c) Citations, pages, fractional pages, frcitations, wcitations, wfcitations, citationspp, intlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.
(d) Cluster-robust errors used in all models

Table 4-41: Fixed Effects Poisson model of amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI) - continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		3.275	2.218	0.017	0.056	0.059	0.233	0.290	0.194	0.710***	0.265	0.090	0.066	0.052	4.010	0.047	0.037
references		-0.002**	0.001	-0.001	0.001	-0.001	0.001	-0.002**	0.001	-0.002***	0.001	-0.002**	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		-0.008	0.007	-0.007	0.007	-0.008	0.007	-0.007	0.007	-0.007	0.007	-0.007	0.007	-0.027***	0.007	-0.027***	0.007
LOCALCOAUTHORS		0.005	0.010	0.005	0.009	0.005	0.009	0.004	0.009	0.005	0.010	0.006	0.010	0.027***	0.007	0.028***	0.007
2003		-1.394***	0.494	-1.377***	0.499	-1.380***	0.521	-1.145**	0.555	-1.171**	0.530	-1.477***	0.498	-1.071*	0.608	-1.072*	0.606
2004		-0.537	0.435	-0.499	0.424	-0.503	0.445	-0.296	0.493	-0.324	0.463	-0.568	0.434	-0.410	0.497	-0.397	0.494
2005		-1.541***	0.426	-1.531***	0.430	-1.535***	0.434	-1.352***	0.477	-1.355***	0.456	-1.542***	0.443	-1.531**	0.616	-1.522**	0.611
2006		-0.788**	0.389	-0.809**	0.391	-0.806**	0.398	-0.643	0.441	-0.647	0.421	-0.806**	0.405	-0.550	0.504	-0.543	0.493
2008		0.482*	0.287	0.455	0.293	0.462	0.296	0.603*	0.339	0.614*	0.318	0.460	0.296	-0.119	0.257	-0.144	0.259
2009		-0.580**	0.244	-0.598**	0.250	-0.592**	0.251	-0.475*	0.274	-0.478*	0.259	-0.590**	0.253	-0.981***	0.351	-0.985***	0.352
EU funding		-0.020	0.061	-0.015	0.063	-0.016	0.063	-0.015	0.060	-0.018	0.060	-0.011	0.063	-0.140*	0.072	-0.141**	0.072
Other funding		0.050	0.093	0.068	0.090	0.068	0.090	0.067	0.088	0.063	0.088	0.060	0.092	-0.126	0.146	-0.124	0.148
Internal funding		-0.111	0.151	-0.116	0.152	-0.117	0.150	-0.096	0.155	-0.109	0.158	-0.096	0.150	0.059	0.171	0.053	0.172
Log-likelihood		-29,965.5		-30,288.18		-30,296.23		-30,004.55		-29,748.7		-29,972.79		-8,987.59		-8,987.67	
Wald X^2 test		82.09		77.18		82.38		76.22		81.68		80.39		82.79		79.65	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 495, Groups: 94, except JIF5 and JIF2012 where Observations: 172, Groups: 39
(c) wfcitations, citationspp, intlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.
(d) Cluster-robust errors used in all models

Table 4-42: Fixed Effects Negative Binomial model of amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		-0.014	0.089	-0.667**	0.259	-0.202	0.263	-0.849	0.539	-0.116	0.107	-0.041	0.035	-0.134	0.285	-0.134	0.721
references		0.001	0.001	0.002***	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		0.005	0.005	0.006	0.004	0.005	0.004	0.006	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.005	0.004
LOCALCOAUTHORS		0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.004
2003		-0.124	0.299	-0.064	0.301	-0.127	0.301	-0.096	0.292	-0.084	0.324	-0.063	0.306	-0.110	0.304	-0.137	0.302
2004		0.457	0.333	0.558	0.340	0.459	0.309	0.516	0.333	0.505	0.337	0.526*	0.311	0.469	0.329	0.445	0.313
2005		-0.378	0.314	-0.301	0.323	-0.369	0.337	-0.310	0.346	-0.330	0.351	-0.335	0.318	-0.368	0.320	-0.388	0.331
2006		0.007	0.290	0.111	0.280	0.029	0.255	0.103	0.271	0.065	0.265	0.049	0.267	0.014	0.297	-0.001	0.259
2008		0.497**	0.202	0.578***	0.191	0.520***	0.192	0.571***	0.199	0.550***	0.195	0.532***	0.187	0.503***	0.188	0.491**	0.194
2009		-0.139	0.230	-0.078	0.228	-0.115	0.246	-0.067	0.236	-0.078	0.246	-0.088	0.229	-0.133	0.242	-0.144	0.240
EU funding		-0.057	0.061	-0.073	0.061	-0.058	0.059	-0.059	0.053	-0.053	0.061	-0.057	0.061	-0.057	0.062	-0.057	0.056
Other funding		0.093	0.098	0.101	0.099	0.093	0.093	0.102	0.093	0.104	0.098	0.093	0.097	0.094	0.098	0.092	0.105
Internal funding		0.071	0.175	0.055	0.175	0.079	0.180	0.093	0.189	0.099	0.181	0.076	0.176	0.072	0.194	0.071	0.186
Constant		-2.589***	0.330	-2.607***	0.277	-2.566***	0.303	-2.566***	0.306	-2.590***	0.316	-2.623***	0.306	-2.596***	0.308	-2.583***	0.302
Log-likelihood		-1342.35		-1335.15		-1341.77		-1338.73		-1340.57		-1340.97		-1342.11		-1342.36	
Wald X^2 test		50.17		65.73		46.49		48.96		55.72		44.11		39.11		48.09	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 495, Groups: 94
(c) Citations, pages, fractional pages, frcitations, wcitations, wfcitations, citationspp, intlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.
(d) Cluster-robust errors used in all models

Table 4-43: Fixed Effects Negative Binomial model of amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI) - continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		Coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		-1.030	2.759	-0.005	0.053	-0.113	0.658	0.234	0.187	0.046	0.501	-0.011	0.056	-0.073	0.041	-0.034	0.049
references		0.001	0.001	0.001	0.001	0.001	0.001	-0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		0.005	0.005	0.005	0.004	0.005	0.004	0.006	0.004	0.005	0.004	0.005	0.004	-0.004	0.007	-0.004	0.005
LOCALCOAUTHORS		0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.005	0.003	0.004	0.007	0.008	0.007	0.007
2003		-0.132	0.310	-0.148	0.313	-0.124	0.313	0.101	0.374	-0.091	0.343	-0.145	0.316	-0.514	1.112	-0.520	0.700
2004		0.449	0.321	0.431	0.321	0.462	0.339	0.654*	0.359	0.478	0.349	0.430	0.308	0.200	0.609	0.196	0.618
2005		-0.384	0.336	-0.399	0.327	-0.377	0.332	-0.184	0.349	-0.353	0.360	-0.392	0.318	-1.207*	0.673	-1.197*	0.711
2006		0.002	0.264	-0.010	0.260	0.004	0.272	0.185	0.296	0.033	0.275	-0.004	0.276	-0.303	0.542	-0.290	0.506
2008		0.494**	0.195	0.478**	0.195	0.495***	0.180	0.628***	0.226	0.515**	0.208	0.490**	0.199	0.629	0.383	0.609	0.384
2009		-0.140	0.236	-0.161	0.259	-0.140	0.227	-0.050	0.246	-0.133	0.231	-0.145	0.246	-0.662	0.500	-0.665	0.476
EU funding		-0.057	0.059	-0.057	0.058	-0.057	0.061	-0.060	0.053	-0.058	0.060	-0.056	0.063	-0.155*	0.094	-0.149	0.099
Other funding		0.093	0.097	0.090	0.104	0.093	0.101	0.088	0.102	0.089	0.103	0.090	0.096	0.010	0.305	0.015	0.275
Internal funding		0.071	0.184	0.061	0.170	0.071	0.178	0.054	0.188	0.065	0.187	0.071	0.193	0.228	0.286	0.232	0.271
Constant		-2.588***	0.299	-2.598***	0.305	-2.588***	0.301	-2.775***	0.346	-2.622***	0.313	-2.596***	0.305	-1.613**	0.714	-1.629**	0.709
Log-likelihood		-1342.20		-1342.41		-1342.2		-1341.14		-1342.42		-1342.38		-491.99		-485.96	
Wald X^2 test		46.12		38.71		42.78		54.20		43.08		53.93		48.78		44.61	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94, except JIF5 and JIF2012 where Observations: 172, Groups: 39

(c) wfcitations, citationspp, intlcoauthors, localcoauthors and references are scaled at 1/100 at the cumulative levels.

(d) Cluster-robust errors used in all models

Table 4-44: Random Effects Poisson model of the amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	Se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.033	0.104	-0.597**	0.291	-0.374	0.422	-0.305	0.756	0.076	0.125	-0.015	0.034	0.208	0.396	0.578	0.925
References		-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	-0.002	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.031	0.113	-0.004	0.116	-0.047	0.117	-0.036	0.112	-0.018	0.116	-0.027	0.104	-0.030	0.118	-0.032	0.109
PhD – Top 20		0.490	0.501	0.325	0.540	0.493	0.505	0.452	0.503	0.541	0.537	0.468	0.525	0.488	0.513	0.488	0.529
Degree – Top 20		-0.248	0.568	0.068	0.590	-0.170	0.579	-0.192	0.602	-0.332	0.570	-0.208	0.619	-0.244	0.527	-0.234	0.542
No Master		0.586	0.525	0.578	0.507	0.606	0.570	0.587	0.531	0.582	0.485	0.582	0.546	0.578	0.535	0.599	0.561
Female		0.552	0.563	0.478	0.587	0.652	0.524	0.561	0.592	0.557	0.544	0.551	0.555	0.544	0.520	0.520	0.556
INTNLCOAUTHORS		-0.008	0.008	-0.006	0.008	-0.009	0.008	-0.008	0.008	-0.007	0.009	-0.008	0.008	-0.008	0.009	-0.008	0.008
LOCALCOAUTHORS		0.005	0.010	0.003	0.011	0.007	0.011	0.005	0.011	0.005	0.011	0.005	0.011	0.005	0.012	0.005	0.010
2003		-1.409***	0.534	-1.215**	0.572	-1.290**	0.564	-1.330**	0.543	-1.388**	0.578	-1.340***	0.504	-1.446**	0.573	-1.385**	0.558
2004		-0.531	0.468	-0.327	0.479	-0.400	0.476	-0.444	0.469	-0.515	0.490	-0.455	0.429	-0.572	0.476	-0.515	0.462
2005		-1.551***	0.437	-1.405***	0.467	-1.458***	0.471	-1.492***	0.461	-1.531***	0.474	-1.517***	0.473	-1.572***	0.463	-1.535***	0.480
2006		-0.812**	0.408	-0.694	0.437	-0.730*	0.433	-0.768*	0.421	-0.808*	0.416	-0.797**	0.398	-0.820**	0.406	-0.793*	0.410
2008		0.456	0.300	0.521	0.325	0.520	0.332	0.480	0.333	0.461	0.298	0.465	0.311	0.450	0.304	0.471	0.329
2009		-0.598**	0.241	-0.519*	0.286	-0.542*	0.277	-0.572**	0.264	-0.600**	0.267	-0.582**	0.259	-0.602**	0.255	-0.588**	0.275
EU funding		-0.016	0.076	0.001	0.073	-0.018	0.077	-0.014	0.069	-0.018	0.077	-0.010	0.075	-0.017	0.073	-0.018	0.070
Other funding		0.064	0.107	0.070	0.105	0.057	0.111	0.066	0.100	0.063	0.101	0.074	0.105	0.057	0.105	0.060	0.099
Internal funding		-0.120	0.168	-0.107	0.166	-0.103	0.167	-0.104	0.172	-0.125	0.181	-0.125	0.166	-0.117	0.190	-0.120	0.167
Constant		4.729***	1.040	4.602***	1.002	4.833***	1.085	4.785***	1.098	4.566***	1.044	4.708***	0.985	4.724***	1.047	4.738***	0.982
lnα		1.757***	0.160	1.760***	0.154	1.761***	0.163	1.758***	0.160	1.748***	0.157	1.759***	0.166	1.755***	0.163	1.759***	0.153
Log-likelihood		-31128.34		-30544.91		-31046.4		-31138.95		-31092.32		-31126.91		-31076.38		-31031.09	
Wald X^2 test		78.14		80.01		86.39		74.27		89.86		78.21		81.59		76.62	
LR test		$7.9e^4$		$8e^4$		$7.9e^4$		$7.9e^4$		$7.9e^4$		$7.9e^4$		$7.8e^4$		$7.9e^4$	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) References and all ROIs except frpubs and jifauth are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-45: Random Effects Poisson model of the amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI)-continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		3.275	2.521	0.072	0.063	0.059	0.811	0.290	0.217	0.707	0.484	0.090	0.079	0.044	0.094	0.039	0.089
References		-0.002*	0.001	-0.001	0.001	-0.001	0.001	-0.002**	0.001	-0.002**	0.001	-0.002*	0.001	0.001	0.001	0.001	0.001
Department		-0.031	0.110	-0.023	0.108	-0.030	0.111	-0.017	0.108	-0.017	0.101	-0.036	0.112	0.027	0.508	0.191	0.570
PhD – Top 20		0.493	0.545	0.491	0.508	0.492	0.531	0.514	0.483	0.569	0.497	0.544	0.504	-1.355	3.490	-0.791	2.072
Degree – Top 20		-0.226	0.557	-0.269	0.539	-0.253	0.628	-0.288	0.575	-0.346	0.558	-0.337	0.555	0.318	3.637	0.196	1.743
No Master		0.592	0.548	0.583	0.491	0.579	0.478	0.631	0.487	0.611	0.478	0.541	0.527	0.225	1.948	1.520	2.189
Female		0.498	0.505	0.542	0.539	0.564	0.542	0.465	0.540	0.483	0.599	0.400	0.526	0.278	2.267	-2.098	2.816
INTNLCOAUTHORS		-0.008	0.008	-0.007	0.008	-0.008	0.008	-0.007	0.008	-0.007	0.008	-0.007	0.008	-0.035**	0.014	-0.035**	0.014
LOCALCOAUTHORS		0.005	0.011	0.005	0.010	0.005	0.010	0.004	0.011	0.005	0.011	0.006	0.012	0.031	0.025	0.031	0.026
2003		-1.389***	0.498	-1.372**	0.538	-1.375**	0.538	-1.139*	0.591	-1.166**	0.533	-1.472***	0.484	-1.814**	0.921	-1.815*	1.018
2004		-0.531	0.462	-0.494	0.460	-0.497	0.465	-0.291	0.520	-0.319	0.495	-0.563	0.431	-0.775	0.847	-0.756	0.836
2005		-1.536***	0.460	-1.526***	0.466	-1.529***	0.434	-1.346***	0.505	-1.350***	0.440	-1.537***	0.444	-2.005**	0.821	-1.982**	0.904
2006		-0.783*	0.405	-0.804*	0.421	-0.801**	0.389	-0.638	0.464	-0.642	0.428	-0.802**	0.393	-1.041	0.752	-1.018	0.782
2008		0.485*	0.282	0.458	0.301	0.465	0.289	0.606*	0.353	0.616*	0.322	0.462	0.314	0.181	0.396	0.186	0.427
2009		-0.578**	0.243	-0.596**	0.261	-0.590**	0.240	-0.473*	0.277	-0.475*	0.264	-0.588**	0.246	-0.964**	0.445	-0.957**	0.467
EU funding		-0.020	0.072	-0.015	0.071	-0.016	0.081	-0.015	0.062	-0.017	0.073	-0.011	0.075	-0.154	0.114	-0.158	0.111
Other funding		0.051	0.105	0.068	0.099	0.068	0.114	0.067	0.102	0.063	0.110	0.060	0.118	-0.229	0.308	-0.229	0.312
Internal funding		-0.110	0.164	-0.116	0.178	-0.117	0.171	-0.095	0.173	-0.109	0.178	-0.096	0.177	-0.099	0.329	-0.105	0.321
Constant		4.719***	1.035	4.645***	1.054	4.711***	0.955	4.484***	1.053	4.441***	0.969	4.676***	0.996	6.344*	3.240	4.872*	2.933
lnα		1.754***	0.154	1.752***	0.158	1.755***	0.157	1.752***	0.162	1.748***	0.162	1.747***	0.159	2.481***	0.265	2.434***	0.277
Log-likelihood		-30833.21		-31155.73		-31164.08		-30872.12		-30616.01		-30869.96		-9458.26		-9446.04	
Wald X^2 test		88.09		83.20		74.00		65.95		75.65		88.58		62.21		50.55	
LR test		$7.8e^4$		$7.9e^4$		$7.9e^4$		$7.9e^4$		$8e^4$		$7.8e^4$		$7.8e^4$		$7.9e^4$	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 766, Groups: 153 except ji2012 where Observations: 275, Groups: 96 and jif5 where Observations: 267, Groups: 94
(c) References and citationspp, jif2012 and jif5 are scaled at 1/100.
(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-46: Random Effects Negative Binomial model of the amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.038	0.127	-0.169	0.205	-0.063	0.194	-0.63	0.510	-0.024	0.085	0.025	0.027	0.202	0.247	0.260	0.514
References		-0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.046	0.042	-0.044	0.045	-0.049	0.044	-0.053	0.044	-0.050	0.043	-0.048	0.038	-0.043	0.042	-0.048	0.041
PhD – Top 20		0.331	0.319	0.311	0.319	0.325	0.296	0.270	0.314	0.321	0.299	0.340	0.296	0.315	0.281	0.334	0.322
Degree – Top 20		0.067	0.343	0.137	0.347	0.078	0.338	0.195	0.346	0.079	0.348	0.021	0.349	0.070	0.323	0.064	0.372
No Master		0.592**	0.266	0.584**	0.294	0.591*	0.306	0.612**	0.253	0.594**	0.261	0.586**	0.275	0.580**	0.277	0.592**	0.272
Female		0.358	0.459	0.354	0.491	0.372	0.528	0.307	0.474	0.361	0.468	0.389	0.447	0.376	0.440	0.364	0.510
INTNLCOAUTHORS		0.011***	0.004	0.011***	0.004	0.011***	0.004	0.012***	0.004	0.011***	0.004	0.011***	0.004	0.011***	0.004	0.011***	0.004
LOCALCOAUTHORS		0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.003	0.003	0.003
2003		-0.376	0.313	-0.334	0.332	-0.347	0.302	-0.308	0.309	-0.337	0.291	-0.383	0.332	-0.425	0.310	-0.344	0.317
2004		0.057	0.286	0.119	0.322	0.099	0.316	0.156	0.316	0.107	0.290	0.059	0.310	0.020	0.327	0.091	0.316
2005		-0.490*	0.290	-0.425	0.349	-0.447	0.344	-0.383	0.321	-0.439	0.320	-0.486	0.318	-0.528*	0.319	-0.457	0.334
2006		-0.149	0.247	-0.099	0.281	-0.124	0.270	-0.025	0.253	-0.114	0.249	-0.165	0.276	-0.175	0.273	-0.128	0.252
2008		0.492**	0.193	0.505**	0.209	0.511**	0.207	0.572***	0.216	0.513**	0.200	0.488**	0.200	0.477**	0.194	0.507**	0.209
2009		-0.159	0.207	-0.145	0.235	-0.139	0.228	-0.085	0.224	-0.136	0.225	-0.181	0.216	-0.177	0.211	-0.146	0.252
EU funding		0.058	0.054	0.058	0.059	0.059	0.058	0.062	0.057	0.061	0.062	0.058	0.058	0.058	0.053	0.058	0.058
Other funding		0.211**	0.089	0.207**	0.093	0.211**	0.086	0.216**	0.091	0.216**	0.090	0.208**	0.091	0.209**	0.093	0.213**	0.086
Internal funding		0.163	0.181	0.162	0.193	0.173	0.188	0.192	0.195	0.180	0.185	0.156	0.195	0.159	0.188	0.167	0.194
Constant		-3.338***	0.450	-3.345***	0.514	-3.315***	0.471	-3.275***	0.436	-3.317***	0.476	-3.313***	0.433	-3.329***	0.377	-3.343***	0.451
lnr		12.180**	4.823	12.825**	5.676	12.575**	5.392	11.989**	4.884	12.461**	4.918	13.075**	5.266	12.588***	3.928	13.091***	5.040
lns		19.075***	6.641	19.713**	7.841	19.471***	7.419	18.869***	6.700	19.356***	6.820	19.969***	7.274	19.482***	5.402	19.986***	6.897
Log-likelihood		-2212.68		-2212.07		-2213.16		-2210.32		-2213.11		-2212.07		-2212.40		-2212.92	
Wald X^2 test		65.00		78.76		85.90		70.93		67.23		75.93		97.96		65.14	
LR test		$1.3e^{-4}$		$4e^{-4}$		$2.6e^{-5}$		0.00		0.00		$1.3e^{-4}$		$4.1e^{-4}$		$7.1e^{-4}$	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 766, Groups: 153
(c) References and all ROIs except frpubs and jifauth are scaled at 1/100.
(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-47: Random Effects Negative Binomial model of the amount of funding (in €000) against 3-year moving averages of Research Output Indicators (ROI)-continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		1.975	2.227	0.057	0.044	0.13	0.502	0.308*	0.158	0.202	0.479	0.029	0.061	0.023	0.046	0.017	0.046
References		-0.001	0.001	-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001	0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.043	0.047	-0.041	0.044	-0.046	0.042	-0.042	0.049	-0.046	0.044	-0.047	0.041	0.032	0.271	0.023	0.289
PhD – Top 20		0.321	0.299	0.358	0.309	0.333	0.308	0.364	0.312	0.349	0.305	0.341	0.320	0.311	0.682	0.353	0.550
Degree – Top 20		0.069	0.337	-0.016	0.336	0.061	0.357	-0.006	0.330	0.025	0.342	0.039	0.359	-0.112	1.310	-0.074	0.886
No Master		0.579**	0.261	0.585**	0.283	0.593*	0.308	0.587**	0.264	0.584*	0.315	0.587**	0.291	0.788	1.891	0.702	0.560
Female		0.382	0.483	0.388	0.452	0.365	0.494	0.387	0.517	0.399	0.444	0.369	0.461	0.417	1.491	0.348	0.822
INTNLCOAUTHORS		0.011***	0.004	0.011***	0.004	0.011***	0.004	0.011***	0.004	0.011***	0.004	0.011***	0.004	0.010	0.011	0.009	0.011
LOCALCOAUTHORS		0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.004	0.004	0.012	0.004	0.016
2003		-0.366	0.314	-0.393	0.330	-0.360	0.332	-0.095	0.344	-0.299	0.325	-0.378	0.290	-0.242	0.651	-0.260	0.678
2004		0.070	0.320	0.064	0.286	0.073	0.322	0.333	0.308	0.139	0.331	0.065	0.306	0.414	0.574	0.420	0.592
2005		-0.478	0.313	-0.490	0.319	-0.471	0.358	-0.214	0.323	-0.409	0.322	-0.474	0.314	-0.628	0.689	-0.619	0.700
2006		-0.137	0.251	-0.181	0.266	-0.139	0.252	0.079	0.273	-0.101	0.269	-0.170	0.269	-0.140	0.582	-0.105	0.534
2008		0.505**	0.198	0.434**	0.188	0.496**	0.207	0.655***	0.220	0.524**	0.212	0.484**	0.203	0.717*	0.368	0.625*	0.377
2009		-0.160	0.218	-0.232	0.235	-0.154	0.239	-0.044	0.233	-0.142	0.234	-0.166	0.224	-0.368	0.527	-0.354	0.502
EU funding		0.058	0.057	0.055	0.056	0.059	0.056	0.055	0.054	0.057	0.062	0.061	0.056	0.030	0.116	0.017	0.105
Other funding		0.212**	0.086	0.203**	0.085	0.210**	0.091	0.207**	0.088	0.208**	0.085	0.207**	0.100	0.113	0.217	0.092	0.243
Internal funding		0.163	0.202	0.107	0.202	0.164	0.177	0.129	0.186	0.155	0.191	0.167	0.197	0.087	0.365	0.076	0.339
Constant		-3.361***	0.444	-3.410***	0.406	-3.342***	0.453	-3.574***	0.502	-3.389***	0.494	-3.345***	0.446	-3.631*	2.145	-3.498	3.119
lnr		13.050***	4.682	13.102***	4.049	12.524**	5.402	13.111***	4.546	12.686**	5.067	12.504**	4.949	12.973*	7.123	12.975*	6.974
lns		19.944***	6.443	19.991***	5.575	19.420***	7.420	19.997***	6.229	19.583***	6.982	19.400***	6.805	19.739**	9.830	19.774**	9.724
Log-likelihood		-2212.26		-2210.45		-2212.95		-2209.71		-2212.92		-2212.90		-939.21		-923.21	
Wald X^2 test		87.53		75.34		74.65		95.43		78.39		89.76		22.62		19.19	
LR test		$4.7e^{-4}$		$9.4e^{-4}$		$4e^{-4}$		$6.1e^{-4}$		$5e^{-4}$		$3.2e^{-4}$		$1.3e^{-4}$		$4e^{-4}$	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 766, Groups: 153 except ji2012 where Observations: 275, Groups: 96 and jif5 where Observations: 267, Groups: 94
(c) References and citationspp, jif2012 and jif5 are scaled at 1/100.
(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-48: Multilevel Poisson model with two-level Random Effects of amount of funding (in €000) against 3-year moving average Research Output Indicators (ROI)

Variables	ROI used	citations		jifap		pagescount		authpages		frpubs		jifauth		frcitations		wcitations	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.150***	0.012	-0.137***	0.023	0.578***	0.101	0.126***	0.144	0.112***	0.003	0.030***	0.001	0.301***	0.087	0.012***	0.001
References		0.001***	0.001	0.002***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001
EU funding		0.285***	0.002	0.284***	0.002	0.274***	0.002	0.288***	0.002	0.278***	0.002	0.292***	0.002	0.288***	0.002	0.286***	0.002
Other funding		0.321***	0.005	0.310***	0.006	0.290***	0.006	0.311***	0.005	0.273***	0.005	0.316***	0.005	0.306***	0.005	0.326***	0.006
Internal funding		0.278***	0.007	0.286***	0.006	0.238***	0.007	0.287***	0.006	0.245***	0.006	0.283***	0.007	0.286***	0.007	0.300***	0.007
INTNL COAUTH.		0.014***	0.001	0.014***	0.001	0.013***	0.001	0.014***	0.001	0.013***	0.001	0.014***	0.001	0.014***	0.001	0.014***	0.001
LOCAL COAUTH.		0.012***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001
Degree – Top 20		0.401***	0.015	0.429***	0.015	0.081***	0.012	0.313***	0.017	0.200***	0.012	0.302***	0.012	0.402***	0.012	0.389***	0.013
PhD – Top 20		1.163***	0.017	1.175***	0.012	1.236***	0.011	1.186***	0.015	1.276***	0.011	1.200***	0.010	1.126***	0.015	1.174***	0.012
No Master		1.933***	0.012	1.875***	0.012	1.808***	0.010	1.915***	0.009	1.859***	0.010	1.943***	0.010	1.899***	0.013	1.958***	0.011
2003		-0.318***	0.027	-0.123***	0.028	-0.095***	0.027	-0.145***	0.024	-0.158***	0.026	-0.194***	0.027	-0.243***	0.027	-0.206***	0.028
2004		0.483***	0.020	0.689***	0.021	0.683***	0.019	0.646***	0.021	0.645***	0.019	0.587***	0.020	0.547***	0.021	0.582***	0.023
2005		-0.009	0.021	0.155***	0.021	0.095***	0.019	0.105***	0.022	0.102***	0.024	0.091***	0.021	0.071***	0.021	0.075***	0.022
2006		0.713***	0.016	0.798***	0.016	0.688***	0.016	0.738***	0.015	0.710***	0.015	0.741***	0.017	0.765***	0.016	0.735***	0.017
2009		0.409***	0.015	0.424***	0.016	0.332***	0.016	0.423***	0.015	0.383***	0.013	0.421***	0.017	0.461***	0.014	0.399***	0.017
2011		0.431***	0.014	0.382***	0.015	0.436***	0.013	0.396***	0.015	0.457***	0.012	0.414***	0.015	0.480***	0.017	0.351***	0.016
Bayesian DIC		256,828		258,825		256,249		259,084		258,006		258,929		258,488		256,908	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 761, Groups: 152
(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.
(d) Cluster-robust errors used in all models
(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models
(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

Table 4-49: Multilevel Poisson model with two-level Random Effects of amount of funding (in €000) against 3-year moving average Research Output Indicators (ROI)-continued

Variables	ROI used	wfcitations		publications		citationspp		wpubs		wfpubs		first		jif2012		jif5	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Mov. Av. ROI		0.047***	0.001	0.150***	0.002	0.655***	0.112	0.440***	0.007	0.688***	0.019	0.198***	0.002	0.104***	0.001	0.099***	0.001
References		0.001***	0.001	-0.002***	0.001	0.001***	0.001	-0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001
EU funding		0.286***	0.003	0.266***	0.002	0.289***	0.002	0.279***	0.002	0.278***	0.002	0.301***	0.002	0.307***	0.003	0.279***	0.003
Other funding		0.302***	0.006	0.257***	0.006	0.313***	0.005	0.273***	0.005	0.272***	0.006	0.251***	0.006	0.075***	0.008	-0.001	0.009
Internal funding		0.303***	0.007	0.152***	0.006	0.279***	0.007	0.236***	0.007	0.255***	0.007	0.270***	0.007	0.534***	0.011	0.481***	0.012
INTNL COAUTH.		0.014***	0.001	0.013***	0.001	0.014***	0.001	0.014***	0.001	0.014***	0.001	0.013***	0.001	0.017***	0.001	0.017***	0.001
LOCAL COAUTH.		0.012***	0.001	0.011***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.013***	0.001	0.013***	0.001
Degree – Top 20		0.446***	0.012	0.022	0.015	0.371***	0.015	0.177***	0.014	0.190***	0.012	0.167***	0.015	0.894***	0.024	0.984***	0.021
PhD – Top 20		1.098***	0.011	1.341***	0.014	1.202***	0.013	1.293***	0.011	1.294***	0.013	1.230***	0.012	0.005	0.027	0.088***	0.020
No Master		1.870***	0.015	1.807***	0.012	1.923***	0.011	1.870***	0.011	1.855***	0.013	1.901***	0.013	1.877***	0.014	1.734***	0.013
2003		-0.180***	0.027	-0.236***	0.030	-0.278***	0.028	0.013	0.028	-0.034	0.028	-0.406***	0.025	0.031	0.036	0.140***	0.035
2004		0.591***	0.025	0.633***	0.022	0.516***	0.017	0.811***	0.020	0.753***	0.021	0.414***	0.022	0.768***	0.023	0.913***	0.026
2005		0.099***	0.023	0.119***	0.024	0.014	0.022	0.236***	0.022	0.185***	0.023	-0.076***	0.024	-0.702***	0.034	-0.569***	0.035
2006		0.797***	0.019	0.719***	0.016	0.730***	0.016	0.831***	0.019	0.784***	0.016	0.520***	0.017	-0.284***	0.027	-0.138***	0.030
2009		0.435***	0.017	0.233***	0.016	0.398***	0.014	0.284***	0.016	0.333***	0.016	0.324***	0.017	-0.778***	0.020	-0.718***	0.021
2011		0.469***	0.016	0.466***	0.014	0.392***	0.013	0.064***	0.017	0.238***	0.016	0.363***	0.015	-0.401***	0.020	-0.367***	0.022
Bayesian DIC		257,178		252,213		256,908		256,236		257,497		250,242		77,240		75,556	

Notes:
(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 761, Groups: 152
(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.
(d) Cluster-robust errors used in all models
(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models
(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

Table 4-50: Fixed Effects Poisson model of amount of funding (in €000) against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Average ROI		0.241**	0.116	0.318***	0.001	0.628	2.701	0.024***	0.009	0.013***	0.005	0.046***	0.016	-0.084	0.219	-0.430	0.489	0.915**	0.402	-0.010	0.061
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
INTNLCOAUTHORS		-0.009	0.007	-0.013*	0.008	-0.009	0.009	-0.008	0.007	-0.014**	0.007	-0.014*	0.007	-0.006	0.007	-0.006	0.007	-0.012	0.007	-0.007	0.007
LOCALCOAUTHORS		0.005	0.010	0.003	0.010	0.005	0.009	0.005	0.009	0.002	0.010	0.004	0.010	0.006	0.009	0.006	0.009	0.005	0.010	0.005	0.009
2003		-0.987**	0.486	-1.170**	0.482	-1.315**	0.566	-1.289***	0.485	-1.274**	0.498	-1.219**	0.500	-1.469**	0.613	-1.602***	0.618	-1.163**	0.484	-1.399**	0.571
2004		-0.228	0.433	-0.346	0.426	-0.442	0.480	-0.462	0.428	-0.407	0.428	-0.364	0.436	-0.580	0.538	-0.693	0.526	-0.349	0.433	-0.515	0.482
2005		-1.381***	0.429	-1.498***	0.438	-1.494***	0.462	-1.505***	0.425	-1.527***	0.437	-1.493***	0.443	-1.593***	0.469	-1.674***	0.468	-1.499***	0.440	-1.547***	0.457
2006		-0.733*	0.380	-0.814**	0.397	-0.778*	0.411	-0.782**	0.387	-0.815**	0.396	-0.787**	0.400	-0.858**	0.429	-0.922**	0.424	-0.807**	0.399	-0.819**	0.408
2008		0.458	0.295	0.389	0.307	0.477	0.304	0.461	0.295	0.423	0.303	0.444	0.301	0.433	0.308	0.398	0.305	0.413	0.303	0.454	0.303
2009		-0.623**	0.251	-0.667***	0.259	-0.580**	0.254	-0.594**	0.249	-0.633**	0.256	-0.622**	0.255	-0.613**	0.257	-0.638**	0.254	-0.646**	0.255	-0.597**	0.252
EU funding		-0.027	0.059	-0.017	0.061	-0.015	0.062	-0.023	0.064	-0.012	0.062	-0.018	0.061	-0.012	0.062	-0.011	0.063	-0.019	0.061	-0.015	0.063
Other funding		0.049	0.089	0.065	0.089	0.069	0.089	0.055	0.095	0.067	0.088	0.062	0.089	0.071	0.089	0.074	0.089	0.066	0.089	0.070	0.089
Internal funding		-0.166	0.149	-0.129	0.141	-0.113	0.145	-0.127	0.150	-0.135	0.140	-0.105	0.138	-0.122	0.150	-0.131	0.151	-0.115	0.141	-0.121	0.147
Log-likelihood		-29,917.65		-29,952.68		-30298.15		-30,191.81		-29,889.65		-29,927.04		-30,289.16		-30,231.29		-30,013.91		-30300.40	
Wald X^2 test		70.71		74.26		78.75		127.38		74.35		73.80		82.86		82.87		74.86		80.88	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Localcoauthors, intnlcoauthors, references and publications, pages, frpages and frpubs are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-51: Fixed Effects Negative Binomial model of amount of funding (in €000) against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Average ROI		0.101**	0.043	0.041	0.120	-1.011	1.268	0.048	0.079	0.010**	0.005	0.030*	0.017	-0.059	0.092	-0.233	0.211	0.207	0.199	-0.025	0.026
References		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		0.001	0.005	0.004	0.004	0.008	0.006	0.005	0.005	0.002	0.005	0.001	0.006	0.006	0.005	0.006	0.005	0.003	0.006	0.007	0.006
LOCALCOAUTHORS		-0.004	0.005	-0.002	0.008	0.005	0.005	0.002	0.006	-0.006	0.006	-0.001	0.005	0.004	0.004	0.003	0.004	-0.001	0.005	0.004	0.004
2003		-0.392	0.325	-0.213	0.319	-0.163	0.281	-0.156	0.302	-0.175	0.316	-0.166	0.308	-0.191	0.316	-0.240	0.297	-0.239	0.306	-0.181	0.305
2004		0.104	0.327	0.358	0.336	0.431	0.315	0.424	0.352	0.392	0.351	0.413	0.324	0.407	0.330	0.374	0.302	0.335	0.358	0.417	0.348
2005		-0.639**	0.316	-0.481	0.344	-0.414	0.328	-0.413	0.350	-0.498	0.323	-0.434	0.320	-0.434	0.351	-0.465	0.314	-0.484	0.356	-0.423	0.334
2006		-0.239	0.268	-0.102	0.321	-0.028	0.274	-0.031	0.275	-0.094	0.293	-0.032	0.285	-0.042	0.277	-0.074	0.271	-0.085	0.298	-0.040	0.284
2008		0.319*	0.178	0.432**	0.202	0.486**	0.199	0.479**	0.202	0.401*	0.206	0.447**	0.176	0.478***	0.174	0.459**	0.179	0.431**	0.186	0.475**	0.197
2009		-0.327	0.230	-0.200	0.253	-0.145	0.248	-0.149	0.245	-0.262	0.244	-0.247	0.259	-0.152	0.249	-0.166	0.232	-0.218	0.233	-0.148	0.238
EU funding		-0.032	0.051	-0.052	0.065	-0.058	0.054	-0.055	0.060	-0.041	0.054	-0.030	0.055	-0.053	0.061	-0.052	0.062	-0.039	0.060	-0.058	0.058
Other funding		0.100	0.090	0.091	0.098	0.085	0.103	0.090	0.094	0.087	0.097	0.081	0.095	0.091	0.105	0.084	0.102	0.088	0.101	0.081	0.099
Internal funding		-0.089	0.199	0.035	0.197	0.078	0.168	0.066	0.177	-0.019	0.174	-0.030	0.184	0.092	0.206	0.092	0.178	0.005	0.199	0.075	0.192
Constant		-2.896***	0.350	-2.498***	0.327	-2.472***	0.322	-2.566***	0.298	-2.498***	0.316	-2.639***	0.326	-2.454***	0.336	-2.311***	0.322	-2.582***	0.317	-2.409***	0.320
Log-likelihood		-29917.65		-29952.68		-30298.15		-30191.81		-29889.65		-29927.04		-30289.16		-30231.29		-30013.91		-1350.74	
Wald X^2 test		70.71		74.26		78.75		127.38		74.35		73.80		82.86		82.87		74.86		25.70	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) All ROIs, except h-index, wcitations and frpubs are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-52: Random Effects Poisson model of amount of funding (in €000) against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.238*	0.136	0.312	0.198	0.628	3.323	0.020*	0.011	0.013*	0.007	0.046**	0.023	-0.084	0.222	-0.427	0.544	0.896	0.717	-0.011	0.071
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.016	0.105	0.034	0.134	-0.037	0.127	0.070	0.127	-0.042	0.115	-0.076	0.131	-0.034	0.122	-0.032	0.127	-0.050	0.139	-0.026	0.113
PhD – Top 20		0.049	0.621	0.320	0.588	0.441	0.552	0.248	0.628	0.482	0.502	0.404	0.532	0.552	0.522	0.656	0.490	0.174	0.635	0.544	0.612
Degree – Top 20		0.154	0.684	-0.008	0.628	-0.255	0.588	0.015	0.674	-0.213	0.592	-0.359	0.547	-0.257	0.570	-0.300	0.594	-0.122	0.681	-0.269	0.616
No Master		0.482	0.444	0.292	0.489	0.635	0.560	0.222	0.522	0.586	0.485	0.700	0.555	0.412	0.669	0.231	0.675	0.506	0.485	0.536	0.564
Female		0.325	0.535	0.782	0.545	0.603	0.610	0.744	0.517	0.595	0.579	0.623	0.509	0.527	0.636	0.378	0.628	0.756	0.596	0.536	0.646
INTNLCOAUTHORS		-0.009	0.008	-0.012	0.009	-0.009	0.011	-0.008	0.008	-0.013*	0.008	-0.013	0.008	-0.006	0.008	-0.006	0.008	-0.012	0.009	-0.007	0.008
LOCALCOAUTHORS		0.005	0.012	0.003	0.013	0.005	0.011	0.005	0.010	0.002	0.013	0.004	0.012	0.006	0.012	0.006	0.011	0.005	0.011	0.005	0.012
2003		-0.993**	0.460	-1.172**	0.505	-1.310**	0.599	-1.296***	0.458	-1.270**	0.502	-1.214**	0.481	-1.463**	0.674	-1.595**	0.685	-1.164**	0.509	-1.394**	0.635
2004		-0.232	0.407	-0.347	0.457	-0.437	0.526	-0.464	0.405	-0.403	0.454	-0.360	0.419	-0.574	0.589	-0.686	0.549	-0.349	0.459	-0.510	0.563
2005		-1.384***	0.438	-1.499***	0.464	-1.489***	0.485	-1.507***	0.400	-1.523***	0.468	-1.489***	0.440	-1.588***	0.540	-1.667***	0.482	-1.497***	0.477	-1.541***	0.514
2006		-0.735*	0.376	-0.814*	0.418	-0.773*	0.432	-0.784**	0.376	-0.811**	0.403	-0.782**	0.392	-0.853*	0.455	-0.916**	0.443	-0.806**	0.408	-0.814*	0.453
2008		0.458	0.285	0.390	0.325	0.480	0.315	0.461	0.297	0.425	0.306	0.446	0.291	0.436	0.314	0.402	0.334	0.415	0.314	0.457	0.357
2009		-0.622***	0.240	-0.665**	0.275	-0.578**	0.276	-0.593**	0.242	-0.631**	0.262	-0.620**	0.247	-0.611**	0.265	-0.636**	0.257	-0.644**	0.265	-0.595**	0.287
EU funding		-0.026	0.073	-0.016	0.067	-0.015	0.071	-0.021	0.070	-0.012	0.072	-0.018	0.071	-0.012	0.073	-0.011	0.076	-0.018	0.072	-0.014	0.074
Other funding		0.049	0.101	0.065	0.103	0.069	0.104	0.056	0.099	0.067	0.107	0.062	0.094	0.071	0.103	0.074	0.108	0.066	0.102	0.070	0.104
Internal funding		-0.164	0.170	-0.128	0.163	-0.112	0.166	-0.125	0.171	-0.134	0.165	-0.104	0.160	-0.121	0.157	-0.130	0.163	-0.115	0.155	-0.121	0.173
Constant		3.031***	0.950	3.707***	1.018	4.640***	1.067	3.181***	0.989	4.579***	0.984	4.705***	1.033	4.942***	1.289	5.261***	1.315	4.243***	1.090	4.758***	1.140
$\ln\sigma^2$		1.733***	0.159	1.794***	0.166	1.754***	0.160	1.932***	0.183	1.763***	0.143	1.779***	0.145	1.752***	0.161	1.746***	0.157	1.810***	0.169	1.753***	0.160
Log-likelihood		-30783.81		-30823.60		-31165.87		-31075.39		-30758.08		-30796.73		-31156.71		-31098.43		-30886.04		-31168.09	
Wald X^2 test		61.22		70.62		88.52		105.16		64.01		79.47		77.29		86.81		72.49		82.02	
LR test		$7.6e^4$		$7.8e^4$		$7.9e^4$		$7.7e^4$		$7.8e^4$		$7.6e^4$		$7.7e^4$		$7.6e^4$		$7.4e^4$		$7.7e^4$	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Citations, publications, pages, frpages and frcitations are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-53: Random Effects Negative Binomial model of amount of funding (in €000) against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.091**	0.037	0.042	0.111	-0.533	1.118	0.096	0.142	0.609	0.434	0.020	0.017	-0.116	0.115	-0.372	0.244	0.129	0.512	-0.033	0.022
References		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Department		-0.061	0.040	-0.058	0.041	-0.042	0.045	-0.051	0.043	-0.053	0.044	-0.062	0.050	-0.036	0.043	-0.030	0.040	-0.062	0.043	-0.035	0.041
PhD – Top 20		0.142	0.299	0.342	0.384	0.371	0.297	0.385	0.267	0.299	0.273	0.208	0.346	0.369	0.291	0.338	0.292	0.285	0.324	0.425	0.285
Degree – Top 20		0.048	0.353	0.028	1.199	0.071	0.363	0.032	0.340	0.036	0.358	-0.015	0.368	0.112	0.330	0.140	0.319	-0.009	0.370	0.100	0.340
No Master		0.489	0.302	0.595	1.019	0.593**	0.272	0.580**	0.272	0.595**	0.245	0.611**	0.299	0.565**	0.263	0.584**	0.251	0.580**	0.288	0.609**	0.263
Female		0.531	0.448	0.427	0.481	0.354	0.467	0.418	0.458	0.391	0.526	0.445	0.521	0.315	0.458	0.292	0.392	0.450	0.511	0.309	0.459
INTNLCOAUTHORS		0.006*	0.003	0.009***	0.004	0.012**	0.006	0.009**	0.004	0.009**	0.004	0.008**	0.004	0.013***	0.005	0.012***	0.004	0.010*	0.005	0.013***	0.005
LOCALCOAUTHORS		-0.001	0.004	0.001	0.008	0.004	0.004	0.002	0.005	-0.001	0.004	0.002	0.004	0.004	0.004	0.003	0.004	0.002	0.005	0.004	0.003
2003		-0.536*	0.300	-0.405	0.376	-0.360	0.287	-0.387	0.344	-0.293	0.282	-0.323	0.295	-0.425	0.327	-0.427	0.331	-0.401	0.308	-0.374	0.316
2004		-0.146	0.298	0.040	0.320	0.093	0.300	0.068	0.314	0.153	0.304	0.121	0.304	0.062	0.330	0.089	0.296	0.039	0.306	0.107	0.302
2005		-0.628**	0.293	-0.524	0.333	-0.470	0.287	-0.500	0.330	-0.444	0.302	-0.441	0.328	-0.529	0.332	-0.539*	0.326	-0.489	0.340	-0.494	0.306
2006		-0.287	0.259	-0.210	0.301	-0.154	0.265	-0.195	0.289	-0.115	0.245	-0.106	0.254	-0.209	0.276	-0.221	0.285	-0.163	0.258	-0.182	0.272
2008		0.375**	0.181	0.463**	0.225	0.493***	0.173	0.475**	0.205	0.518**	0.205	0.495**	0.194	0.488**	0.218	0.500**	0.198	0.466**	0.203	0.501**	0.204
2009		-0.312	0.232	-0.203	0.249	-0.145	0.227	-0.166	0.223	-0.163	0.237	-0.200	0.253	-0.149	0.233	-0.143	0.234	-0.202	0.233	-0.127	0.222
EU funding		0.088*	0.048	0.069	0.054	0.055	0.059	0.065	0.059	0.074	0.059	0.085	0.055	0.059	0.062	0.057	0.059	0.076	0.058	0.049	0.061
Other funding		0.199**	0.087	0.207**	0.090	0.212**	0.098	0.209**	0.087	0.205**	0.088	0.213**	0.086	0.210**	0.090	0.200**	0.092	0.210**	0.086	0.208**	0.097
Internal funding		-0.050	0.190	0.055	0.221	0.193	0.207	0.116	0.194	0.040	0.198	0.062	0.198	0.230	0.208	0.218	0.188	0.076	0.203	0.204	0.201
Constant		-3.466***	0.393	-3.234***	0.471	-3.309***	0.419	-3.298***	0.441	-3.332***	0.443	-3.333***	0.510	-3.133***	0.420	-2.990***	0.369	-3.271***	0.606	-3.194***	0.408
lnr		12.607***	3.285	13.110***	4.158	13.107***	5.064	12.707***	4.600	12.455***	4.383	13.128**	5.542	13.074***	4.362	12.870***	3.596	13.049**	5.904	12.010***	4.626
lns		19.455***	4.440	19.993***	5.675	20.001***	6.892	19.595***	6.244	19.316***	5.875	19.990***	7.619	19.954***	5.988	19.721***	4.800	19.932**	8.107	18.883***	6.276
Log-likelihood		-2199.31		-2209.54		-2212.56		-2211.19		-2205.03		-2206.16		-2208.22		-2199.91		-2210.05		-2206.84	
Wald X^2 test		88.45		71.23		68.61		62.50		98.72		73.42		54.96		78.26		63.78		67.22	
LR test		$4e^{-5}$		$6.9e^{-4}$		$8.5e^{-4}$		$2.5e^{-4}$		$2.9e^{-4}$		$5e^{-4}$		$7.9e^{-4}$		$4.9e^{-4}$		$2.9e^{-4}$		n/a	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Citations, publications, pages, frpages and frcitations are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-54: Multilevel Poisson model with two-level Random Effects of the amount of funding (in €000) against cumulative Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulative ROI		0.223***	0.001	0.057***	0.013	1.579***	0.199	0.163***	0.025	0.01***	0.001	0.033***	0.001	0.182***	0.062	-0.25***	0.091	0.258***	0.101	0.026***	0.001
References		0.001***	0.001	0.001***	0.001	0.001***	0.001	0.140***	0.002	0.001***	0.001	0.001***	0.001	0.002***	0.001	-0.001	0.001	0.001***	0.001	0.001***	0.001
EU funding		0.339***	0.002	0.304***	0.002	0.307***	0.002	0.289***	0.002	0.319***	0.002	0.348***	0.002	-	-	-	-	0.330***	0.002	0.300***	0.002
Other funding		0.112***	0.005	0.282***	0.005	0.271***	0.005	0.305***	0.006	0.260***	0.005	0.242***	0.005	-	-	-	-	0.248***	0.005	0.276***	0.005
Internal funding		-0.149***	0.008	0.134***	0.007	0.234***	0.006	0.191***	0.007	0.111***	0.007	0.148***	0.007	-	-	-	-	0.132***	0.007	0.274***	0.007
INTNL COAUTH.		0.006***	0.001	0.013***	0.001	0.011***	0.001	0.011***	0.001	0.012***	0.001	0.012***	0.001	0.012***	0.001	0.011***	0.001	0.013***	0.001	0.013***	0.001
LOCAL COAUTH.		-0.004***	0.001	0.007***	0.001	0.010***	0.001	0.009***	0.001	0.007***	0.001	0.010***	0.001	0.012***	0.001	0.005***	0.001	0.009***	0.001	0.012***	0.001
Degree – Top 20		0.271***	0.014	0.303***	0.015	0.308***	0.013	0.338***	0.012	0.400***	0.013	0.281***	0.012	0.007	0.013	0.183***	0.013	0.179***	0.012	0.311***	0.014
PhD – Top 20		0.339***	0.014	1.175***	0.013	0.912***	0.015	1.311***	0.013	1.050***	0.013	0.752***	0.013	1.133***	0.011	0.320***	0.010	0.949***	0.010	1.006***	0.014
No Master		1.552***	0.010	1.984***	0.011	1.937***	0.010	1.883***	0.010	1.977***	0.011	2.049***	0.013	1.359***	0.010	0.185***	0.008	2.000***	0.011	1.890***	0.013
2003		-0.818***	0.028	-0.142***	0.032	-0.214***	0.026	-0.155***	0.028	-0.050*	0.026	-0.122***	0.031	0.373***	0.025	2.417***	0.025	-0.241***	0.027	-0.194***	0.031
2004		-0.022	0.020	0.658***	0.020	0.575***	0.018	0.654***	0.025	0.743***	0.020	0.674***	0.022	1.444***	0.016	3.553***	0.014	0.558***	0.020	0.592***	0.022
2005		-0.694***	0.022	0.045**	0.022	0.119***	0.020	0.035	0.022	0.057***	0.020	0.029	0.022	0.761***	0.019	2.965***	0.015	0.012	0.022	0.102***	0.022
2006		-0.054***	0.016	0.682***	0.019	0.741***	0.018	0.681***	0.021	0.682***	0.017	0.648***	0.020	1.300***	0.016	3.559***	0.013	0.636***	0.017	0.734***	0.015
2009		-0.046***	0.013	0.410***	0.016	0.358***	0.015	0.413***	0.019	0.332***	0.014	0.243***	0.017	0.737***	0.018	3.607***	0.013	0.325***	0.015	0.357***	0.017
2011		0.181***	0.014	0.469***	0.016	0.305***	0.017	0.489***	0.020	0.253***	0.014	0.122***	0.016	0.580***	0.018	3.906***	0.012	0.327***	0.017	0.308***	0.016
Bayesian DIC		225,598		256,398		256,469		256,390		253,694		249,598		305,597		169,943		252,510		257,647	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 761, Groups: 152
(c) Citations, publications, wcitations, pages, frpages and frcitations are scaled at 1/100.
(d) Cluster-robust errors used in all models
(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models
(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

Table 4-55: Fixed Effects Poisson model of amount of funding (in €000) against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Average ROI		0.082	0.779	0.625	0.701	0.266	0.298	-0.842	1.413	0.103	0.064	0.640**	0.294	0.023	0.035	0.051	0.097	0.059*	0.033	0.547	1.054
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
INTNLCOAUTHORS		-0.008	0.007	-0.008	0.007	-0.011	0.008	-0.008	0.007	-0.010	0.007	-0.013*	0.008	-0.010	0.007	-0.009	0.007	-0.010	0.007	-0.009	0.007
LOCALCOAUTHORS		0.005	0.009	0.007	0.009	0.005	0.009	0.004	0.009	0.006	0.009	0.008	0.009	0.005	0.009	0.006	0.009	0.010	0.009	0.005	0.009
2003		-1.384**	0.582	-1.429***	0.530	-1.417***	0.510	-1.330**	0.529	-1.447***	0.517	-1.515***	0.533	-1.361***	0.504	-1.353***	0.508	-1.589***	0.563	-1.383***	0.511
2004		-0.503	0.496	-0.549	0.457	-0.527	0.435	-0.451	0.459	-0.570	0.447	-0.645	0.457	-0.476	0.435	-0.471	0.437	-0.705	0.481	-0.499	0.437
2005		-1.546***	0.494	-1.625***	0.470	-1.580***	0.437	-1.481***	0.458	-1.677***	0.472	-1.746***	0.477	-1.539***	0.431	-1.522***	0.430	-1.775***	0.488	-1.543***	0.434
2006		-0.819*	0.447	-0.879**	0.429	-0.847**	0.398	-0.768*	0.421	-0.924**	0.423	-0.982**	0.428	-0.812**	0.391	-0.800**	0.392	-0.992**	0.439	-0.817**	0.398
2008		0.453	0.318	0.416	0.313	0.438	0.298	0.485	0.312	0.371	0.319	0.325	0.315	0.455	0.295	0.463	0.295	0.343	0.311	0.455	0.296
2009		-0.597**	0.255	-0.623**	0.260	-0.600**	0.251	-0.576**	0.263	-0.657**	0.268	-0.699***	0.271	-0.588**	0.250	-0.585**	0.250	-0.674**	0.262	-0.591**	0.251
EU funding		-0.015	0.063	-0.020	0.063	-0.019	0.062	-0.010	0.065	-0.022	0.062	-0.023	0.061	-0.018	0.062	-0.016	0.062	-0.019	0.062	-0.015	0.062
Other funding		0.069	0.089	0.072	0.089	0.066	0.088	0.068	0.088	0.070	0.089	0.057	0.091	0.062	0.088	0.063	0.088	0.064	0.090	0.064	0.088
Internal funding		-0.120	0.150	-0.128	0.149	-0.110	0.148	-0.113	0.153	-0.138	0.147	-0.156	0.145	-0.117	0.148	-0.114	0.149	-0.168	0.151	-0.110	0.149
Log-likelihood		-30302.36		-30256.03		-30259.70		-30289.50		-30155.09		-30019.03		-30265.22		-30275.55		-30077.86		-30281.37	
Wald X^2 test		78.36		78.54		78.05		92.35		75.34		75.33		77.63		79.00		80.95		79.47	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index and maxcitations, are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-56: Fixed Effects Negative Binomial Regressions of amount of funding (in €000) against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Average ROI		1.091**	0.482	0.740	0.522	0.226	0.228	0.807	1.521	0.103*	0.058	0.487***	0.186	-0.003	0.016	-0.040	0.032	0.041***	0.014	-0.034	0.450
References		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
INTNLCOAUTHORS		0.003	0.005	0.005	0.004	0.001	0.006	0.004	0.005	0.004	0.005	0.002	0.005	0.005	0.005	0.006	0.005	0.003	0.005	0.005	0.005
LOCALCOAUTHORS		-0.001	0.005	-0.002	0.005	0.002	0.004	0.002	0.005	-0.002	0.005	0.001	0.004	0.003	0.004	0.002	0.004	-0.001	0.004	0.003	0.004
2003		-0.570	0.379	-0.299	0.331	-0.195	0.320	-0.187	0.334	-0.248	0.301	-0.328	0.305	-0.137	0.307	-0.149	0.321	-0.420	0.320	-0.131	0.295
2004		0.001	0.356	0.268	0.348	0.378	0.336	0.393	0.348	0.318	0.302	0.272	0.307	0.445	0.327	0.449	0.332	0.176	0.351	0.447	0.310
2005		-0.906**	0.373	-0.655**	0.332	-0.475	0.353	-0.457	0.345	-0.654**	0.319	-0.651**	0.327	-0.386	0.333	-0.389	0.315	-0.717**	0.331	-0.383	0.303
2006		-0.410	0.316	-0.204	0.318	-0.058	0.287	-0.062	0.302	-0.169	0.280	-0.190	0.284	0.003	0.260	-0.011	0.277	-0.257	0.307	0.006	0.253
2008		0.234	0.191	0.373*	0.212	0.447**	0.203	0.457**	0.212	0.355*	0.190	0.356*	0.184	0.496**	0.202	0.488**	0.205	0.359**	0.183	0.496***	0.189
2009		-0.364	0.226	-0.250	0.243	-0.187	0.243	-0.162	0.241	-0.267	0.260	-0.318	0.248	-0.140	0.238	-0.151	0.224	-0.290	0.243	-0.140	0.204
EU funding		-0.024	0.056	-0.046	0.065	-0.049	0.053	-0.052	0.060	-0.040	0.055	-0.023	0.059	-0.056	0.056	-0.055	0.059	-0.027	0.053	-0.057	0.055
Other funding		0.103	0.099	0.099	0.099	0.093	0.099	0.093	0.103	0.101	0.109	0.080	0.099	0.093	0.095	0.087	0.109	0.083	0.100	0.091	0.104
Internal funding		-0.019	0.193	0.042	0.201	0.054	0.192	0.073	0.180	0.031	0.209	-0.043	0.211	0.076	0.185	0.085	0.187	-0.030	0.208	0.072	0.186
Constant		-2.870***	0.322	-2.500***	0.299	-2.774***	0.357	-2.573***	0.327	-2.556***	0.319	-2.656***	0.297	-2.541***	0.388	-2.263***	0.390	-2.587***	0.312	-2.572***	0.365
Log-likelihood		-1343.06		-1348.81		-1350.81		-1351.79		-1345.53		-1342.04		-1352.43		-1350.25		-1344.20		-1352.48	
Wald X^2 test		37.33		29.77		31.46		29.74		28.75		36.14		31.00		26.83		30.92		32.55	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 495, Groups: 94

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index and maxcitations, are scaled at 1/100.

(d) Cluster-robust errors used in all models

Table 4-57: Random Effects Poisson Regressions of amount of funding (in €000) against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		0.101	0.810	0.632	0.901	0.268	0.338	-0.770	2.123	0.102	0.077	0.635*	0.375	0.022	0.039	0.048	0.109	0.059	0.041	0.537	1.264
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001
Department		-0.027	0.108	-0.020	0.106	-0.025	0.121	-0.035	0.117	-0.026	0.121	-0.065	0.130	-0.014	0.121	-0.021	0.117	-0.042	0.118	-0.026	0.119
PhD – Top 20		0.490	0.527	0.532	0.487	0.471	0.538	0.419	0.616	0.551	0.515	0.570	0.583	0.486	0.548	0.444	0.592	0.501	0.568	0.404	0.628
Degree – Top 20		-0.239	0.588	-0.209	0.581	-0.280	0.571	-0.280	0.614	-0.204	0.558	-0.369	0.610	-0.273	0.564	-0.261	0.600	-0.280	0.627	-0.245	0.595
No Master		0.570	0.528	0.503	0.469	0.675	0.475	0.692	0.686	0.467	0.495	0.526	0.584	0.846	0.639	0.812	0.774	0.482	0.508	0.695	0.608
Female		0.555	0.564	0.648	0.565	0.578	0.569	0.488	0.646	0.539	0.599	0.537	0.565	0.627	0.559	0.688	0.648	0.683	0.527	0.634	0.569
INTNLCOAUTHORS		-0.008	0.008	-0.008	0.008	-0.011	0.009	-0.008	0.008	-0.010	0.008	-0.013	0.009	-0.010	0.008	-0.009	0.008	-0.010	0.009	-0.009	0.009
LOCALCOAUTHORS		0.005	0.010	0.007	0.011	0.005	0.011	0.005	0.012	0.006	0.012	0.008	0.010	0.005	0.011	0.006	0.011	0.010	0.011	0.005	0.011
2003		-1.383**	0.609	-1.426**	0.562	-1.413***	0.527	-1.326**	0.566	-1.442**	0.573	-1.509***	0.570	-1.356***	0.497	-1.347**	0.559	-1.584***	0.570	-1.377**	0.550
2004		-0.502	0.525	-0.546	0.477	-0.522	0.442	-0.448	0.496	-0.565	0.481	-0.639	0.491	-0.471	0.470	-0.466	0.445	-0.700	0.507	-0.493	0.470
2005		-1.546***	0.540	-1.623***	0.504	-1.576***	0.432	-1.478***	0.454	-1.673***	0.500	-1.740***	0.499	-1.533***	0.455	-1.517***	0.439	-1.770***	0.494	-1.537***	0.466
2006		-0.819*	0.463	-0.877**	0.439	-0.843**	0.372	-0.765*	0.437	-0.920**	0.452	-0.977**	0.452	-0.807*	0.416	-0.795*	0.428	-0.988**	0.437	-0.812*	0.428
2008		0.453	0.355	0.417	0.317	0.440	0.304	0.487	0.312	0.374	0.338	0.328	0.324	0.458	0.304	0.466	0.296	0.346	0.316	0.458	0.299
2009		-0.597**	0.277	-0.622**	0.274	-0.598**	0.249	-0.575**	0.276	-0.655**	0.280	-0.696**	0.288	-0.586**	0.262	-0.584**	0.267	-0.672***	0.259	-0.589**	0.266
EU funding		-0.015	0.068	-0.019	0.077	-0.019	0.071	-0.010	0.083	-0.022	0.078	-0.023	0.074	-0.018	0.077	-0.016	0.072	-0.019	0.075	-0.014	0.070
Other funding		0.069	0.096	0.072	0.112	0.066	0.103	0.068	0.120	0.070	0.096	0.057	0.111	0.062	0.094	0.063	0.103	0.064	0.099	0.064	0.096
Internal funding		-0.120	0.161	-0.128	0.189	-0.109	0.167	-0.113	0.161	-0.137	0.157	-0.155	0.163	-0.117	0.187	-0.114	0.167	-0.167	0.172	-0.109	0.177
Constant		4.610***	1.159	4.429***	0.982	4.318***	1.076	4.847***	1.040	4.496***	1.034	4.611***	1.091	4.211***	1.251	4.289***	1.435	4.385***	1.007	4.394***	1.202
$\ln\sigma^2$		1.746***	0.162	1.727***	0.161	1.738***	0.142	1.778***	0.169	1.754***	0.153	1.780***	0.156	1.770***	0.164	1.789***	0.182	1.746***	0.145	1.761***	0.157
Log-likelihood		-31169.57		-31121.66		-31126.20		-31159.21		-31022.82		-30888.75		-31134.17		-31146.05		-30944.95		-31149.64	
Wald X^2 test		70.96		90.83		73.04		85.13		82.68		72.75		84.02		85.56		62.89		73.90	
LR test		$7.2e^{4}$		$7.5e^{-4}$		$7.8e^{-4}$		$7.6e^{-4}$		$7.8e^{-4}$		$7.6e^{-4}$		$7.7e^{-4}$		$7.3e^{-4}$		$7.5e^{-4}$		$7.5e^{4}$	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-58: Random Effects Negative Binomial Regressions of amount of funding (in €000) against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Cumulated ROI		1.32***	0.330	0.879**	0.380	0.252	0.207	0.015	0.011	0.044	0.036	0.297**	0.130	-0.016	0.437	-0.073***	0.034	0.033**	0.017	-0.446	0.482
References		-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.01	0.001	0.001
Department		-0.032	0.038	-0.049	0.043	-0.048	0.042	-0.044	0.046	-0.045	0.039	-0.050	0.040	-0.048	0.043	-0.043	0.041	-0.062	0.044	-0.047	0.040
PhD – Top 20		0.142	0.266	0.291	0.307	0.229	0.343	0.380	0.289	0.307	0.293	0.177	0.301	0.328	0.291	0.264	0.277	0.208	0.316	0.385	0.293
Degree – Top 20		0.188	0.333	0.087	1.257	0.044	0.402	0.052	0.356	0.078	0.365	0.058	0.346	0.083	0.328	0.118	0.324	0.026	0.392	0.072	0.357
No Master		0.544**	0.242	0.576	1.049	0.617**	0.282	0.550**	0.278	0.549**	0.262	0.579**	0.264	0.540**	0.265	0.522**	0.239	0.593**	0.295	0.582**	0.263
Female		0.402	0.383	0.452	1.152	0.402	0.450	0.434	0.458	0.292	0.514	0.376	0.451	0.342	0.454	0.318	0.390	0.494	0.522	0.354	0.528
INTNLCOAUTHORS		0.007***	0.002	0.009**	0.004	0.007	0.005	0.009**	0.004	0.010***	0.003	0.009***	0.004	0.012***	0.004	0.011***	0.004	0.009**	0.004	0.012**	0.005
LOCALCOAUTHORS		0.001	0.003	-0.001	0.004	0.003	0.003	0.002	0.004	0.002	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.002	0.003	0.004	0.003
2003		-0.708**	0.317	-0.480	0.826	-0.404	0.295	-0.425	0.328	-0.273	0.296	-0.327	0.300	-0.354	0.296	-0.305	0.327	-0.520	0.337	-0.306	0.317
2004		-0.222	0.322	-0.028	0.819	0.040	0.306	0.036	0.309	0.174	0.302	0.133	0.318	0.110	0.294	0.186	0.303	-0.054	0.299	0.146	0.298
2005		-0.930***	0.307	-0.720	0.825	-0.523*	0.298	-0.569*	0.328	-0.434	0.334	-0.485	0.333	-0.447	0.297	-0.430	0.308	-0.660*	0.357	-0.413	0.324
2006		-0.498*	0.290	-0.337	0.780	-0.180	0.267	-0.250	0.292	-0.098	0.267	-0.128	0.277	-0.138	0.260	-0.142	0.254	-0.290	0.260	-0.114	0.282
2008		0.291	0.193	0.393	0.388	0.451**	0.196	0.431**	0.206	0.548***	0.190	0.502**	0.202	0.523***	0.200	0.540***	0.189	0.404**	0.188	0.529***	0.191
2009		-0.333	0.245	-0.258	0.726	-0.209	0.216	-0.188	0.240	-0.113	0.225	-0.175	0.256	-0.140	0.244	-0.141	0.204	-0.264	0.243	-0.122	0.228
EU funding		0.104**	0.051	0.076	0.057	0.075	0.054	0.066	0.056	0.067	0.056	0.085	0.053	0.057	0.061	0.049	0.054	0.089	0.056	0.047	0.058
Other funding		0.209***	0.081	0.212**	0.091	0.201**	0.087	0.213**	0.093	0.206**	0.082	0.210**	0.088	0.210**	0.092	0.190*	0.100	0.211**	0.092	0.210**	0.096
Internal funding		0.056	0.195	0.079	0.187	0.137	0.178	0.147	0.183	0.110	0.190	0.094	0.194	0.181	0.206	0.177	0.187	0.072	0.203	0.168	0.190
Constant		-3.784***	0.378	-3.263***	0.783	-3.532***	0.423	-3.332***	0.428	-3.415***	0.425	-3.444***	0.438	-3.048***	0.447	-2.680***	0.368	-3.290***	0.458	-3.120***	0.404
lnr		13.043***	2.427	13.104***	4.674	11.961***	4.188	12.733***	4.311	12.991***	3.903	12.869***	4.952	12.722***	3.977	12.131***	2.574	12.604**	4.907	12.582***	4.438
lns		19.839***	3.084	19.962***	6.340	18.845***	5.736	19.612***	5.931	19.858***	5.337	19.715***	6.769	19.611***	5.438	18.977***	3.464	19.443***	6.618	19.468***	6.107
Log-likelihood		-2188.17		-2202.87		-2209.27		-2209.25		-2205.44		-2201.77		-2210.47		-2196.88		-2201.82		-2210.40	
Wald X^2 test		108.51		68.38		85.87		76.24		92.35		123.52		51.87		75.05		81.24		62.24	
LR test		$1.1e^{-4}$		$9.1e^{-4}$		$8.5e^{-4}$		$5.1e^{-4}$		$1.8e^{-4}$		$5.3e^{-4}$		$3.5e^{-4}$		$1.2e^{-4}$		$4.9e^{-4}$		$4.7e^{-4}$	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1

(b) Observations: 761, Groups: 152

(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.

(d) Cluster-robust errors used in all models (Bootstrap resampling produces cluster-robust errors - 300 iterations)

Table 4-59: Multilevel Poisson model with two-level Random Effects of amount of funding (in €000) against career average Research Output Indicators (ROI)

Variables	ROI used	h-index		citations		publications		maxcitations		wcitations		wfcitations		pages		frpages		frcitations		frpubs	
		coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Average ROI		2.676***	0.010	0.015***	0.001	0.960***	0.005	0.028***	0.001	0.068***	0.001	0.523***	0.003	0.057***	0.001	0.084***	0.001	0.056***	0.001	1.484***	0.009
References		0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001	0.001***	0.001
EU funding		0.300***	0.002	0.310***	0.002	0.319***	0.002	0.278***	0.002	0.299***	0.002	0.335***	0.002	0.264***	0.002	0.279***	0.002	0.339***	0.002	0.311***	0.002
Other funding		0.258***	0.005	0.275***	0.006	0.168***	0.005	0.308***	0.006	0.282***	0.005	0.242***	0.005	0.224***	0.005	0.256***	0.005	0.207***	0.005	0.201***	0.005
Internal funding		0.264***	0.007	0.242***	0.008	0.271***	0.007	0.251***	0.006	0.216***	0.006	0.233***	0.007	0.239***	0.007	0.317***	0.007	0.224***	0.007	0.352***	0.006
INTNL COAUTH.		0.007***	0.001	0.012***	0.001	-0.001***	0.001	0.011***	0.001	0.013***	0.001	0.012***	0.001	0.010***	0.001	0.014***	0.001	0.013***	0.001	0.009***	0.001
LOCAL COAUTH.		0.002***	0.001	0.004***	0.001	0.007***	0.001	0.010***	0.001	0.011***	0.001	0.010***	0.001	0.010***	0.001	0.012***	0.001	0.008***	0.001	0.010***	0.001
Degree – Top 20		0.781***	0.013	0.468***	0.014	0.427***	0.014	0.377***	0.013	0.443***	0.011	0.477***	0.014	0.183***	0.014	0.182***	0.013	0.321***	0.015	0.255***	0.013
PhD – Top 20		0.323***	0.012	1.046***	0.012	0.198***	0.013	1.375***	0.014	1.173***	0.011	0.731***	0.013	0.744***	0.011	0.997***	0.012	0.799***	0.013	0.612***	0.012
No Master		1.424***	0.010	1.895***	0.012	2.028***	0.009	1.690***	0.012	1.813***	0.011	1.859***	0.009	1.964***	0.009	1.888***	0.010	1.955***	0.011	1.908***	0.011
2003		-1.347***	0.026	-0.234***	0.028	-0.863***	0.025	-0.191***	0.029	-0.169***	0.026	-0.239***	0.026	-0.533***	0.024	-0.533***	0.024	-0.412***	0.028	-0.652***	0.027
2004		-0.281***	0.020	0.600***	0.019	0.050***	0.019	0.632***	0.022	0.634***	0.022	0.587***	0.019	0.297***	0.018	0.278***	0.020	0.445***	0.020	0.196***	0.018
2005		-1.643***	0.024	-0.503***	0.024	-0.679***	0.024	-0.182***	0.020	-0.075***	0.021	-0.245***	0.022	-0.480***	0.020	-0.315***	0.022	-0.427***	0.022	-0.367***	0.021
2006		-0.646***	0.019	0.275***	0.017	0.090***	0.015	0.528***	0.016	0.589***	0.017	0.445***	0.018	0.242***	0.014	0.359***	0.015	0.298***	0.017	0.334***	0.015
2009		-0.036**	0.015	0.345***	0.016	-0.062***	0.014	0.382***	0.016	0.290***	0.016	0.164***	0.016	-	-	-	-	0.220***	0.014	0.022*	0.013
2011		0.334***	0.012	0.543***	0.013	0.089***	0.013	0.530***	0.012	0.188***	0.014	0.070***	0.015	-0.053***	0.012	0.004	0.014	0.309***	0.013	0.111***	0.013
Bayesian DIC		204,759		247,289		227,041		25,494		251,190		241,914		238,515		249,030		241,994		243,299	

Notes:

(a) *** p<0.01, ** p<0.05, * p<0.1
(b) Observations: 761, Groups: 152
(c) Localcoauthors, intnlcoauthors and references and all ROIs, except h-index are scaled at 1/100.
(d) Cluster-robust errors used in all models
(e) Markov-chain Monte Carlo (MCMC) simulation is used to estimate all models
(f) Bayesian Deviance Information Criterion (DIC) is used as a measure of goodness of fit

5 THE DETERMINANTS OF APPLICATION AND SUCCESS IN FP7: A COUNTRY-BASED ANALYSIS

Abstract

We examine the potential effect of research output and resources on competitive funding applications and success rates at the country level. To this end, data from the *Seventh Framework Programme of the European Union for Research and Technological Development* (FP7) for the EU28 countries in 2007-2013 were utilised. Accounting for both country- and year-specific effects, the results show that past research output in science and technology matters for FP7 applications while in the social sciences and the humanities it does not. However, the effect of most inputs, such as research intensity and research personnel, on FP7 applications and success is ambiguous. Comparing countries of low or high research capacity (research followers or leaders as defined by the EU[6]), we find that for research followers both scientific publications and international collaboration matter for FP7 applications and success. In contrast, for research leaders, publications matter for FP7 applications and citations matter for FP7 success rates.

5.1 Background

The economics literature on the optimal allocation of research funding is sparse considering the importance of this topic within the framework of endogenous economic growth. The importance of technological change for the improvement of economic growth has been recognised since the 50s when Solow (1956) concluded that the only factor which could boost the efficiency of capital and labour is exogenous technological change. In the late 80s a wave of economists embodied this into what became known as the *endogenous growth model*.

This theoretical development gave rise to a number of economic studies which emphasised the role of scientific research as a driver of technological change (Jones, 1995). This, in turn, linked the advancement of science to better technology and stimulated interest in the economics of science and related policy implications. Funding science as a policy measure for inducing social and economic prosperity is a widely

[6] See http://ec.europa.eu/research/innovation-union/pdf/state-of-the-union/2012/innovation_union_progress _at_country _level_2013.pdf

recognised practice (Stephan, 2008). It was first implemented in 1950 with the establishment of the National Science Foundation (NSF) in the US and subsequently other national funding agencies followed the same rationale.

The EU has also been formulating science policies within the endogenous growth framework. The *Lisbon Strategy* for the EU's socioeconomic growth formed in 2000 set a target of reaching an average R&D intensity of 3% of GDP (European Commission, 2005). This ambitious target is maintained for its current "Europe 2020 strategy for smart, inclusive and sustainable growth" (European Commission, 2010b, p.10).

The Framework Programme of the European Union for Research and Technological Development (EU FP) is the research funding instrument of the EU. It is unique insofar as it is the only R&D instrument where countries contribute to a common pot and then a competitive process is used to reallocate the funds to the research community. This reallocation mechanism has not been adequately studied within economics but how this money is allocated matters for its impact on technological progress (Arora, et al., 1998). In particular we need to understand the application and funding process of the EU FP to understand its impact on economic growth.

A number of studies have addressed specific aspects related to the EU FPs such as national collaboration patterns, the participation of Universities, the impact of R&D funding on subsequent scientific knowledge, and the role of distance for EU FP knowledge spillovers. However, no economics study has analysed the application process and the success rate in securing funding at the country level, let alone their determinants. The EU produces frequent monitoring reports and statistical analyses on EU FP application and success patterns by country, thematic areas, economic

sectors and other dimensions. To the best of our knowledge, no study exists that uses this information to examine the association between country characteristics, the application process and success rate in the EU FPs. The present chapter addresses this topic for the EU28 member states. This is not only important because no other study has addressed this issue but also because we now have a complete picture for the recently terminated Seventh FP (FP7) which ran from 2007 to 2013. Information for the whole FP7 became accessible through the final FP7 Monitoring Report in March 2015.

Our aim is to answer questions such as how the quantity and quality of scientific research output and the related productivity measures contribute in defining the success of FP7. Furthermore, we are interested in how research inputs influence the process. For example, in what direction is the effect, that is, does abundance in national research resources boost application and success in FPs (additionality) or does it work the other way round disincentivising researchers from seeking further funds (substitutability)?

Offering empirical answers to these research questions is the main contribution of this chapter to the literature. To this end, the paper is structured as follows: The next section describes the literature on research funding allocation and provides basic background information for the research funding system in the EU. The third section focuses on the theoretical model for writing research proposals while the fourth section outlines the methodological approach describing the country-level data and specifying the econometric models. The fifth section analyses the findings. A final section concludes.

5.2 Literature Review

The economics literature on competitive research funding allocation is much smaller in magnitude than one would expect (Lepori et al, 2014). The first noticeable finding in the literature is that the exploration of the determinants of application and success in the EU FP at the country level has not attracted the attention of economists so far. This is probably a consequence of the FP being the only instrument that provides EU member states and associated countries with equal opportunities to apply for research funding from a common pot and thus provides sufficient data to carry out studies at the country-level. At the individual and institutional level the field has attracted little interest (Geuna, 1998) as a small number of studies address the factors that determine how funding is secured from different agencies. Before reviewing the relevant scientific work in further depth, the next section reviews the EU FP rationale and history to provide background information to the subsequent literature review.

5.2.1 Background of the Research Funding system in the European Union

The FP is the instrument established, monitored and utilised by the EU member states to fund collaborative Research and Technological Development (RTD) activities. All member states contribute to a common fund according to the size of their economies. Then the European Commission designs a multi-year funding scheme to allocate the funds back to the member states for RTD purposes via a competitive process with submission and evaluation of collaborative research proposals. In the latest FP, called Horizon 2020 (H2020), Innovation is also prominent across areas (priority axes) of the Programme demonstrating the emphasis placed on funding activities that are closest to the market even if not marketable. The overall aim is to contribute to the Europe

2020 agenda which is designed to generate economic growth and social cohesion within the EU. Predominantly, H2020 aims to tackle societal challenges by bridging the gap between R&D and the market through facilitating the development of technological breakthroughs into viable products with actual commercial prospects by innovative firms. This market-driven approach aims to create partnerships to unify the necessary resources for optimal results to occur (European Union, 2012).

The first FP was implemented in 1984 with a budget of €3.75 billion whereas the current FP, Horizon 2020, conveys a total budget of €80 billion. Table 5-1 shows the evolution of the FP budget. When the budget is normalised in 2005 constant prices and in annual averages we see the real increase in the FP budget which reaches its peak in H2020. This illustrates the increasing importance the EU gives to research and innovation activities.

Table 5-1: Chronicle of the EU Framework Programmes for Research and Technological Development

Framework Programme	Period	Budget (current prices - €bln)	Budget (2005 constant prices - €bln)	Average Annual Budget (2005 constant prices - €bln)	Growth Rate of Average Annual Budget
1st	1984–1987	€3.75	€5.98	€1.50	n/a
2nd	1987–1991	€5.40	€7.59	€1.52	2%
3rd	1990–1994	€6.60	€8.57	€1.71	11%
4th	1994–1998	€13.22	€15.91	€3.18	46%
5th	1998–2002	€14.96	€17.03	€3.41	7%
6th	2002–2006	€17.88	€18.42	€3.68	8%
7th	2007–2013	€53.23	€47.23	€6.75	45%
H2020	2014–2020	€80.00	€66.18	€9.45	29%

The ever increasing importance of the EU FPs illustrates the need for better understanding the process of funding allocation. Unfortunately, annual data for reviewing this scheme are available only at the country level. There are more data for FP6 but these are aggregated across the programme and not available annually and

we therefore do not utilise them. For institutions, individuals and thematic areas, there are not sufficient data to carry out an in-depth analysis.

In what follows we explain some important aspects of FP7 to clarify the conditions for applying and then we review some statistics to understand its funding allocation. A general characteristic of FP7 is that funding is awarded to research proposals. These proposals are submitted in regular points in time known as 'calls for proposals deadlines' and the formed consortium bears responsibility for what is submitted. A set of regulations and an electronic system for submitting proposals and managing projects is in place. An important regulation applicable to the vast majority of the FP7 Actions is that it is obligatory to have at least three institutions from three different member states or associated countries in each proposal submitted to be considered eligible for funding. Otherwise, the proposal is not sent for scientific evaluation. The evaluation system is based on the peer review system with consensus committees formed for the final selection.

We see that Germany leads the list with nearly €7bln and UK follows with approximately €6bln. France and Italy are in third and fourth place respectively and their funding varies from 4.6 to 3,5 €bln. In the last places we find mainly small countries along with the member states that acceded to the EU in the last 10 years. What is impressive is that the Netherlands is higher than countries such as Spain which is almost three times bigger in population. This is reflected in Figure 5:2 where funding is normalised by population.

Figure 5:1: Total secured funding from FP7 by EU country (in €mln)

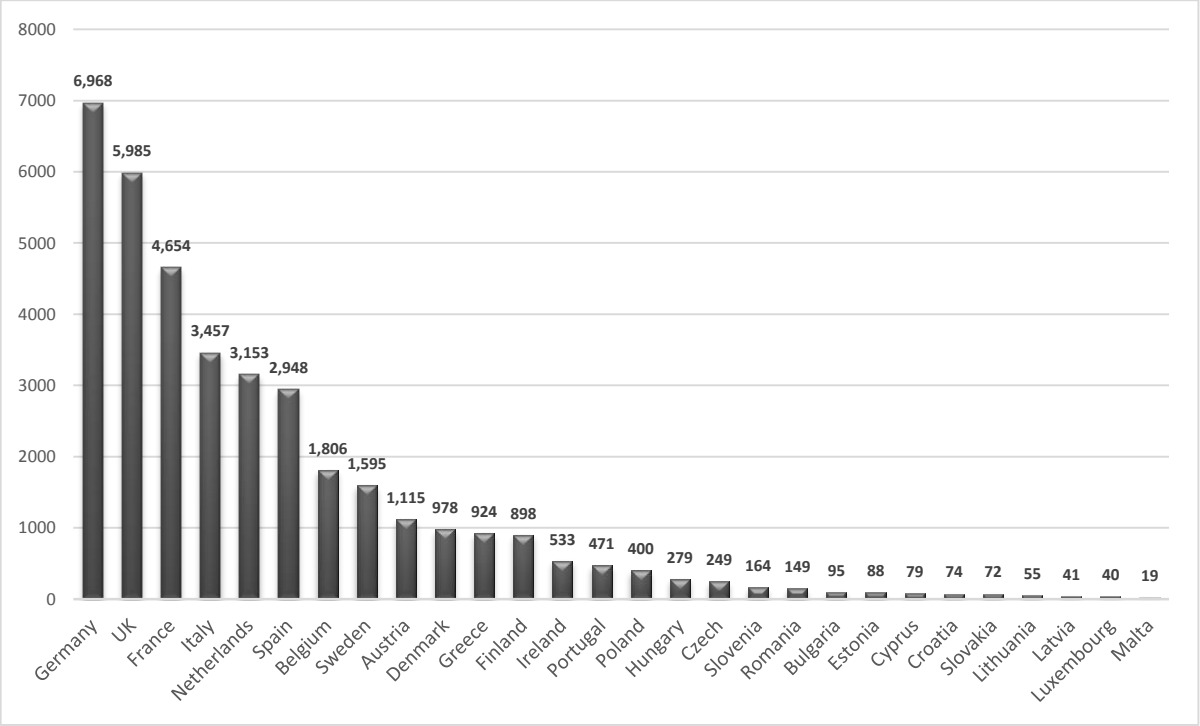
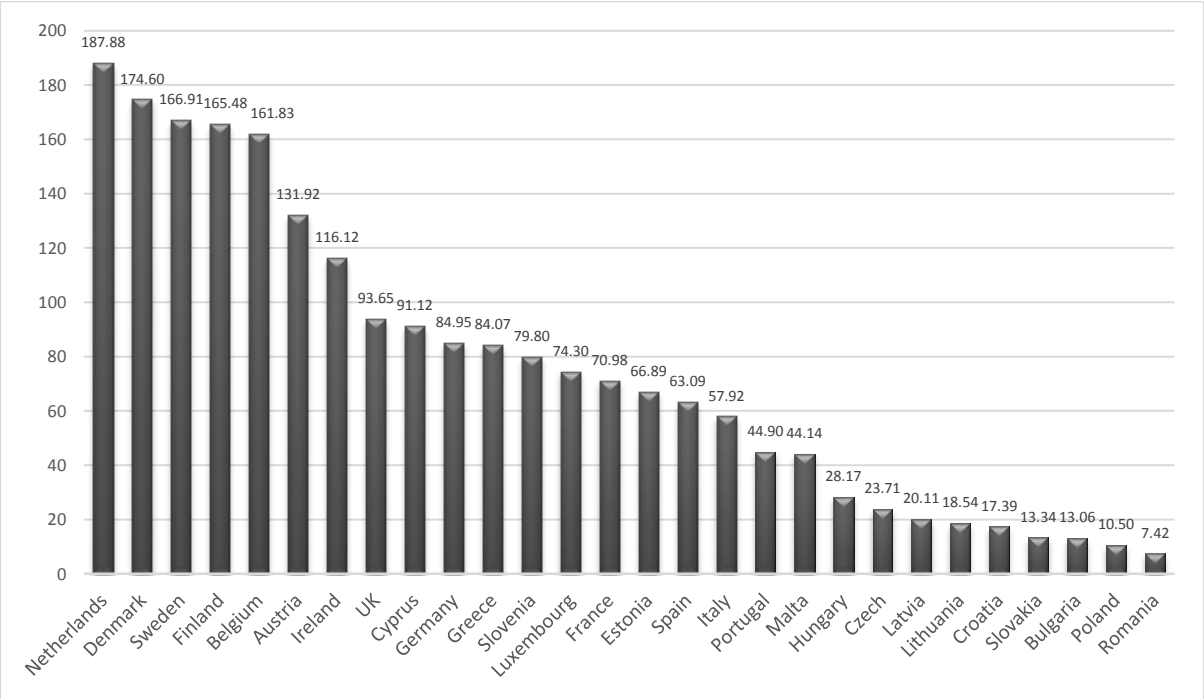


Figure 5:2 illustrates that the Netherlands is ranked first in per capita FP7 funding with €188.000 per resident and the three Nordic EU member states follow with funding around €170.000 per resident. We also observe that the high performers in absolute terms are pushed somewhere in the middle of the list when it comes to per capita values. In the last places we find 9 countries from Eastern Europe which shows that it may take more years for EU newcomers to reach the levels of established EU member states.

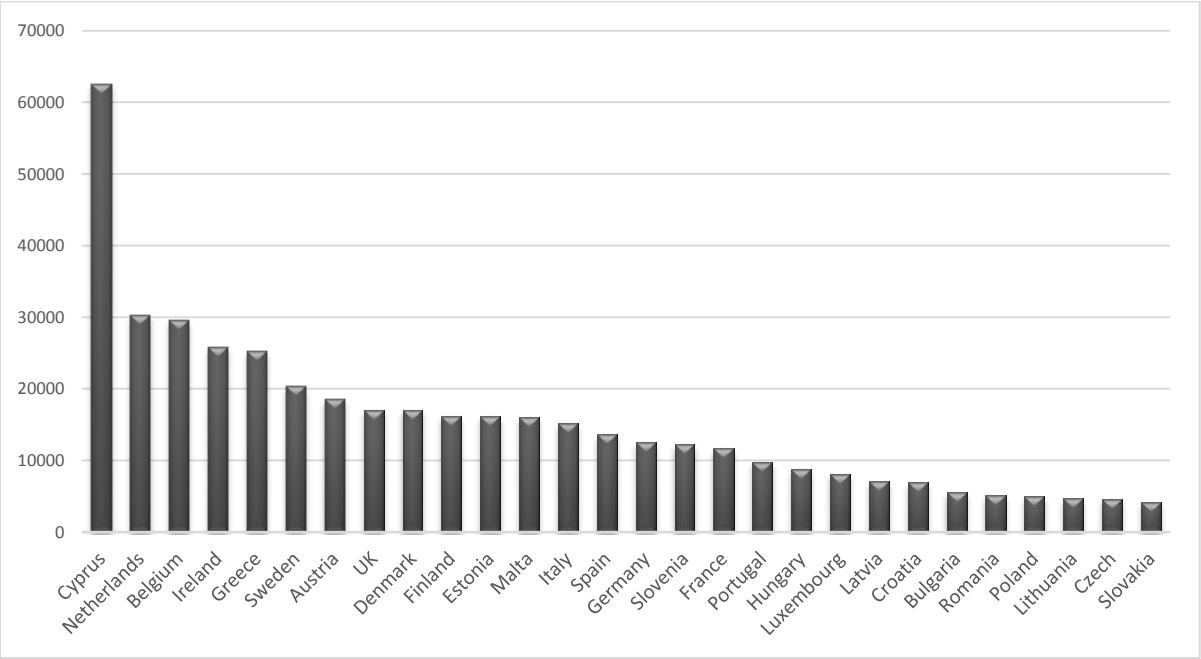
Figure 5:2: Total secured funding from FP7 per capita by EU country (in €)



After taking into account the density of funding across EU28 countries it is interesting to look at the respective performance in productivity terms. Thus, we divide FP7 funding by the five year average of full-time equivalent (FTE) R&D personnel and the results are illustrated in Figure 5:3.

The first striking fact is that a small country which is a relatively new member state (since 2004) has emphatically outperformed all other member states. Cyprus accounts for €62.550 of FP7 funding per FTE R&D personnel whereas the second highest performing country, the Netherlands, secured €30.268 per FTE R&D personnel. Again, the big five are pushed towards the middle of the distribution and at the bottom we encounter 8 countries from Eastern Europe confirming our previous argument that these countries are still in a phase of transition.

Figure 5:3: Total secured funding from FP7 per FTE R&D personnel by EU country (in €)



This variation in FP7 funding allocation when different measures are used is worth exploring in further depth. We endeavour to shed light to the determinants of this variation in the present chapter by framing it in a theoretical background that puts in place a potential mechanism through which applications and success in EU FPs materialise. This theoretical background is presented in a subsequent section right after the review of the relevant literature.

5.3 Previous studies

The first reaction from reviewing the literature is that four major gaps are evident:

a. Limited research work is available concerning the funding allocation mechanisms of EU FPs,
b. The econometric approaches encountered in studies of EU FPs treat important methodological challenges rather lightly,
c. All economics research on EU FPs uses data that are at least 10 years old and

d. To the best of our knowledge no study exists examining the determinants of EU FP applications and success at the country level.

It might be true that the EU FP is the only instrument for which this analysis is applicable and this might limit the generality of our research framework. Though the funding schemes of many countries allow participation of institutions from other countries in funding applications, the difference with the EU FP is that all EU member states contribute to the funding pot and thus its reallocation through competitive processes is characterised by equal opportunities. At the national level though, there are restrictions as to the involvement of foreign partners both in terms of funding asked for and exploitation of research results. These facts along with the lack of data have probably made its study at the macroeconomic level difficult.

In the recent literature on the economics of science, we identified a number of authors that have contributed valuable insights in a number of issues including allocation of research funding (Dasgupta and David, 1995, and Stephan, 1996). These developments were more at the empirical level than the theoretical level. In particular, we found a single study (David and Keely 2003) that constructs a theoretical framework for multiple funding agencies and does so at both national and international level. They emphasise how reputation and past research performance are critical for serving as signals for the outcome of the funding decision and that these are measured at the collaboration network level. The authors refer to the European Research Area (ERA) as a paradigm of a market for funding with different levels of agencies including the EU FP.

Among the empirical studies, we noticed that much is done at the institutional level (universities, firms) while little work was carried out at the regional level. However,

we repeat that no study addresses applications and success in funding schemes at the macroeconomic (country) level. Adams (2010) analysed the research output and collaboration patterns of EU27 countries (before Croatia entered the EU) in order to assess the potential impact of FP7 but he did not approach the determinants of applications and success in FPs. We aim to fill this gap using data from FP7. We firstly review the empirical studies at the institutional level and then proceed to outline the literature by critically reviewing studies undertaken at the individual level. As mentioned before, we aim to address a number of econometric challenges and for this reason, in addition to reviewing the rationale and findings of past research work, we will also comment on methodological caveats and how our study addresses them.

Geuna (1999) studies patterns of university participation in funded projects in the first three EU FPs aiming to unveil the determinants of variation among higher education institutions across Europe. He examines this association drawing data for 1992 and concludes that past research output of universities is the most important determinant of successful applications. He also finds that the country of the institution plays a significant role in defining success, along with the size of the institution expressed by personnel. The results of the study also show that thematic areas are critical for the outcome of the applicants. However, a number of drawbacks were present. Firstly, the author uses publication data for one year (1993) as a proxy of scientific research output. This limits the validity of the findings as research output varies greatly from year to year. In the present chapter, we employ three-year and five year moving averages of research output prior to the year of FP application to tackle this shortcoming. We also include patents and citations in order to reflect the multiple facets of research output. Geuna (1999) avoids addressing potential endogeneity

problems between R&D funding and output, albeit widely evident in the literature. He also uses Probit to model the dichotomous nature of the decision to participate in a project but does not address the existence of either unobserved heterogeneity or incidental parameters. Likewise, his estimation approach includes Tobit for modelling the count of funded projects but again no provision is in place for potential violation of normality and homogeneity. The latter assumptions are critical for the consistency of the estimates. So, although the findings of Geuna are in line with intuition, some econometric issues are not dealt with in his analysis. Conversely, in our present chapter we address such distortions in our estimation process.

In the same vein as Geuna, Nokkala et al (2011) examine the effect of the reputation of universities on their success in securing funding from FP6. They find that only a trivial effect exists from university rankings upon subsequent success in FP6. Another important finding of their study is the positive correlation of the university rank position to the frequency of coordinating an FP funded project, whereas for participation in these projects the same explanatory variable is insignificant or even negative. Nokkala et al (2011) use a standard Poisson process to estimate the counts of either coordinated projects or participations thereof. However, their descriptive statistics demonstrate that the variance far exceeds the mean of the dependent variables. This violation of the Poisson assumption of equidispersion is not treated with cluster-robust errors causing potential upward bias in the statistical significance of the estimated coefficients. Also, unobserved heterogeneity is not accounted for in the estimation process.

In contrast to Nokkala et al (2011), Simmonds et al report that all top ranked UK institutions are active participants in EU FPs from FP4 onwards. Likewise, Lepori et al

(2014) infer the existence of the "Matthew effect in science" (Merton, 1968) at the institutional level whereby 150 European HEIs secure more than 70% of the overall FP funding indicating the existence of a strong reputation effect. In essence, they investigate the determinants of the success of European Higher Education Institutions (HEIs) in the EU FPs for the years 2008-2010. The authors use country dummy variables which are proven to be non-significant in explaining FP success. Although the authors have access to a rich database at the institutional level, their econometric approach falls into two statistical pitfalls. First, the use of negative binomial for cross-sectional data does not control for potential distortions such as unobserved heterogeneity or the incidental parameters problem where institution dummies are used. We attend to this issue using a panel fixed effects approach that handles them adequately. Second, their use of a single year for measuring on-going projects means that a number of these projects preceded the realisation of the explanatory variables. This suggests possible endogeneity due to double causality. We tackle double causality by including predetermined explanatory variables which precede the decision for funding.

Wanzenbock et al (2015) make an enquiry into the structure of EU FPs at the regional level examining the determinants of partnerships of EU regions in research projects funded by the EU FP. Using a mixed-effects panel setting, they found that GDP matters more than the research capacity of regions for explaining participation in FP projects. The authors approach the topic from a purely network-oriented perspective related to social capital without reference to the research capacity of regions. The size of R&D sector is not addressed but instead the stock of human resources at the level of tertiary education is used as proxy. This only partially captures the research size of a region

and is imperfect as a proxy. Personnel employed in R&D activities is more representative of research size and is the variable that serves this purpose in our model. In terms of the econometric methods used, the authors assume random effects for country-specific characteristics that do not vary with time. The obvious caveat of this estimation method is that the random effects are by assumption considered independent of regressors, which is unlikely for largely heterogeneous regions with persistent idiosyncratic effects.

A number of empirical studies have explored the determinants of success in funding schemes other than the EU FP, using data either at the researcher or research group levels. Arora, David and Gambardella (1998) estimate a production function for research output and they model the first step where research funding is allocated using the structural equations approach for the field of Biotechnology in Italy. By analysing research groups they find that past research output is key for defining the selection of researchers to be funded. Similar findings are produced by Arora and Gambardella (2005) who infer statistical significance for the ability of past research performance along with collaboration patterns in explaining secured funding from the National Science Foundation. Contrary results are reported by Van den Besselaar and Leydesdorff (2009) who, in the context of exploring a funding scheme in Netherlands, find that past research productivity does not strongly affect funding decisions.

A number of studies have concentrated in assessing the impact of EU FP funding on the subsequent productivity of research institutions, firms or even countries. Dekker and Kleinknecht (2008) study the effects of EU FPs on the innovation activities of firms in the Netherlands, Germany, France and Greece. Interestingly, their results reveal that no significant effect exists from the participation of firms in EU FPs on their future

turnover of novel products. Arnold et al (2008) investigated the impact of EU FPs on Swedish firms and universities for the FP3-FP6 and have found that for universities the additionality effect holds as the national budget was not reduced due to increased inflows of research funds from FPs. For firms the study concluded that FP funding mattered only where applied research was enhanced (such as the automotive industry) whereas in other industrial sectors the impact seemed moderate to low and came mostly from the participation of Small-Medium Enterprises (SMEs) with universities. Similarly, Simmonds et al (2010) produce an assessment report for the impact of FPs on the UK research capacity and systems. The authors find that FP funding secured by UK organisations accounts for a little more than 10% of the overall UK research budget. They also observe a high degree of alignment in research priorities between the UK and the EU FP, while revealing a more significant effect of EU FPs on the academic sector rather than on the industrial base of the country.

Our feeling is that past research within economics on the determinants of FP7 applications and success is not sufficient to cover all aspects of this important topic. We therefore endeavour to contribute towards filling this gap, at least partially, by investigating the determinants of applications and success of EU28 member states in FP7 at the macro level. The timing is ideal since we recently obtained access to data for the whole duration of FP7. In what follows we outline the theoretical model that drives our subsequent econometric approach.

5.4 Theoretical background

To provide a theoretical background for the applications process and successes in EU FPs funding we specify an aggregate production function for submitting research proposals. The difficulty specifying this function lies in the uncertainty of whether a

proposal will be funded and the two stage process inherent in the funding application schemes. Therefore, we consider application and then success as a two-step process. Moreover, aside from writing research proposals, a researcher has to produce research output and most likely teach as well. However, here we refrain from modelling a multiple output production function and instead specify a reduced form equation that focuses solely on writing research proposals and take other outputs as given. We specify a Cobb-Douglas production function with human and social capital

$$P_{i,t} = A_t K_{i,t}^{a_1} L_{i,t}^{\beta_1} H_{i,t}^{\gamma_1} S_{i,t}^{\delta_1} \quad (1)$$

where P_{it} is the number of applications submitted in EU FP by country i in year t, A_t represents the current level of scientific knowledge, K_{it} are the physical resources used and L_{it} measures the size of the research workforce. and H_{it} is the human capital involved in the preparation of research proposals. S_{it} is a proxy for external social-capital networks that captures past international collaborations. For the parameters we expect that $0 < a_1, \beta_1, \gamma_1, \delta_1 < 1$.

Proceeding to the production function for successful proposals we specify

$$\Phi_{i,t} = A_t K_{i,t}^{a_2} L_{i,t}^{\beta_2} H_{i,t}^{\gamma_2} S_{i,t}^{\delta_2} G_{i,t}^{\theta_2} \quad (2)$$

where Φ_{it} is a measure of success either expressed by the number of successful applicants, the amount of secured funding or the success rates thereof. G_{it}^{θ} represents the qualitative factors that judge whether a proposal is likely to get funding. We now consider each element separately and discuss its relation to quality. A_t is assumed common amongst countries so no quality issues arise. K_{it} represents the infrastructure needed to write proposals. By this definition no particular enhancement due to quality is in place. However, what is more important as capital, is the investment in research,

which is also related to the quality of labour. We consider that R&D intensity should suffice to cover these qualitative aspects of capital. Labour L_{it} is the straight count of person-hours devoted in the proposal writing process which does not convey any fluctuations in quality since this is accommodated by H_{it}. The latter is approximated by the past research performance of the country. In our view, a three- or five-year moving average of past patents and citable publications accompanied by the corresponding citations are the most suitable signal for the quality of human capital in R&D. For the parameters we expect that $0 < a_2, \beta_2, \gamma_2, \delta_2 < 1$, and that $\theta_2 > 0$ as we expect the qualitative factors to exhibit increasing returns.

As the production function applies for a specific funding scheme some key simplifications are in order. Firstly, the budget, as well as other attributes of FPs, become fixed across applicants from EU member states once they are aggregated. What varies is the annual availability of funds which can be incorporated in the econometric model with the use of year dummy variables. The A term is time-dependent with an average annual growth rate of approximately 7% from 1996 to 2013 according to Scimago (2014). This trend is adequately modelled with year dummies.

Taking the natural logs of equation (1) we get

$$\ln P_{i,t} = \ln A_{1,t} + a_1 \ln K_{1i,t} + \beta_1 \ln L_{1i,t} + \gamma_1 \ln H_{1i,t} + \delta_1 \ln S_{1i,t} \quad (3)$$

which can also be expressed in per capita terms yielding the following equation

$$\ln p_{i,t} = \ln A_{1t} + a \ln k_{1i,t} + \beta \ln l_{1i,t} + \gamma \ln h_{1i,t} + \delta \ln s_{1i,t} \quad (4)$$

where small letters denote per capita variables. A_t remains the same as it is a public good that can be used simultaneously by all applicants and $\ln l_{1i,t} = 0$ is integrated out as we assume that the population equals labour.

The corresponding equations for success after the log-transformation are, in aggregate terms

$$\ln \Phi_{i,t} = \ln A_{2t} + a_2 \ln K_{2i,t} + \beta_2 \ln L_{2i,t} + \gamma_2 \ln H_{2i,t} + \delta_2 \ln S_{2i,t} + \theta \ln G_{i,t} \quad (5)$$

and in per capita terms

$$\ln \varphi_{i,t} = \ln A_t + a_2 \ln k_{i,t} + \beta_2 \ln l_{i,t} + \gamma_2 \ln h_{i,t} + \delta_2 \ln s_{i,t} + \theta \ln g_{i,t} \quad (6)$$

In addition to the above equations we also define the probability of success in securing funding as

$$\Pr(\varphi_{i,t} > \bar{\varphi}) = f(P_{i,t}, G_{i,t}) \quad (7)$$

where $\bar{\varphi}$ is the contribution of the country to the common pot of the EU FP. Optimising (5) we get $\max \Pr(\varphi_{i,t} > \bar{\varphi} | P_{i,t}, G_{i,t})$. Therefore, the success rate ω of country i for succeeding in securing funding in period t is

$$\omega_{i,t} = \frac{\varphi_{i,t}}{\Phi_{i,t}} \quad (8)$$

Finally we derive the optimisation objective of countries participating in the EU FP to maximise their success rate and the amount of funding:

$$\max \ \omega_{i,t} \quad (9)$$

subject to the constraints:

$$H_{1i,t} \leq Y_{i,t} + T_{i,t} + C_{i,t} \quad (10)$$

$$L_{1i,t} \leq L_{R\&D,i,t} \tag{11}$$

$$A_{1i,t} \leq \bar{A}_t \tag{12}$$

$$K_{1i,t} \leq \left({}^{m_{R\&D,i,t}}/_{GDP_{i,t}}\right) \tag{13}$$

$$S_{1i,t} \leq R\&D_j \tag{14}$$

where Y and C are publications and citations respectively, T is patent applications, $L_{R\&D}$ is labour employed in the R&D sector, $\bar{A}$ is the scientific knowledge common to all countries, $m_{R\&D}$ is expenditure in R&D, and $m_{R\&D,i,t}/GDP_{i,t}$ is R&D intensity. The term $R\&D_j$ is the number of the total research networks from which a researcher can draw collaborators for writing funding proposals.

Alternatively, we can set up the more intuitively appealing function for secured funding:

$$\max B_{i,t} \tag{13}$$

where *B* is the budget of secured funding or the number of grants, if the budget is similar across grants.

Equations (7) to (13) are added to the theoretical model in order to state the optimisation objectives of countries subject to the relevant constraints. In the estimation process we use the variables to be optimised as dependent variables in the model, such as success rate of equations (8) and (9) and the budget as in equation (13). We do not form the Langrangian to formally compute this optimisation objective and solve the system. Instead, we focus on the econometric estimation of the model and we take these constraints into account in the discussion of the findings.

5.5 Methodology

5.5.1 Data and Rationale

The data used in the present study were extracted from several sources and focuses on the EU28 member states. The raw data for the success and participation indicators of FP7, were obtained from the EU technical and monitoring reports and from EU statistics. These data were available for all years of FP7 (2007-2013). We extracted and used six types of application and success indicators at the country level as dependent variables. All of these variables result from the theoretical model in Section 3 and they are:

1. The straight count of successful applicants (number and rate per pop.)
2. The total secured funding (amount and rate per pop.)
3. The ratio of funding applicants that received funding out of all applicants
4. The ratio of secured funding relative to the total amount applied for
5. The total number of funding applicants (number and rate per pop.)
6. The total amount of funding applied for (amount and rate per pop.)

Indicators 1 to 4 are (six) measures of funding success whilst 5 and 6 are (four) measures of participation.

We have two categories of explanatory variables relating to research outputs and inputs respectively. The first category of variables (indicators 1 to 4) that explain FP7 application and success consists of research output indicators. The effect of these variables is the central point of interest. Geuna (1999) has found research output to be important in explaining success of institutions in the first three EU FPs. To the best

of our knowledge, this association has not been addressed before at the country level and certainly not for FP7. We proxy scientific knowledge using aggregate journal publications by country and year in three broad thematic areas: Science and Technology, Social Sciences and Arts and Humanities. We obtained these data from Scopus-Scimago for 1996-2013. The time span is wider than the one for dependent variables because we wanted to include lagged values and to compute moving averages for research output. To ensure robustness and validity of our data we check the relevance of our metrics with the corresponding total figures of the Institute of Scientific Information Web of Science (WoS). The correlation coefficient is 0.9823 corroborating the validity of our scientific research proxies. As primary measures we used either the three year or the five year moving averages of the years before the grant application. All research output variables are expressed both in absolute and in per capita terms. As a metric of invention activities we used patent applications to the European Patent Office.

The other category of explanatory variables (indicators 5 and 6) consists of research input indicators. The first of these is the most frequently used macroeconomic measure of R&D investment, R&D intensity, which is the ratio of total R&D expenditure to the GDP. We also used R&D Personnel represented by the Full Time Equivalent (FTE) personnel employed in the R&D sector either absolute or per capita. We extracted these three variables from the relevant Eurostat database with additional information for a few missing cases obtained from the estimates of the respective national statistical bureaus. GDP per capita in 2005 purchasing power parity (PPP) prices along with the corresponding total measure were obtained from the Penn World Tables of Summers and Heston (2012). As the data were available until 2011, we

extrapolated for 2012 values based on corresponding growth estimates available from Eurostat. Tables 5-2 and 5-3 provide detailed information for the variables and data.

Table 5-2: Descriptive statistics of dependent variables

Variable	Mean	Variance	St. Dev.	Min	Max
Participation:					
Applicants, number of	2683.77	10,521,006	3243.61	88.00	13324
Applicants per million of pop.	200.02	14,828	121.77	27.56	696.05
Money asked for, € million	1005.74	1,815,352	1347.35	17.28	7127.71
Money asked for, per capita of pop.	65.21	1964.26	44.32	7.19	244.98
Success:					
Applicants in retained proposals, number of	573.41	527	725.89	17.00	3036
Applicant rate in retained proposals, per capita of pop.	40.18	613	24.76	3.60	121.93
Secured funding, € million	190.24	74,868	273.62	1.40	1209.3
Secured funding rate, per capita of pop.	10.89	74.65	8.64	0.70	40.01
Successful applicant rate, out of total applicants*	0.20	0.002	0.04	0.11	0.28
Secured funding rate, out of total € applied for*	0.16	0.004	0.06	0.05	0.28

Notes: 196 observations
* These two variables are modelled using the Quasi Conditional Maximum Likelihood Estimation (QCMLE) process rather than OLS

Table 5-2 is revealing in several ways. First, it shows that the mean 'success rates of applicants' in the calls for proposals was 20%, varying from 11% up to 28%, whereas the mean success rate in terms of money secured to money asked for was lower at 16%. Essentially, this means that on average one out of five participants from the EU member states received funding throughout the duration of the programmes.

Table 5-3: Descriptive statistics of explanatory variables

3-year moving averages (280 observations):				
Variable	**Mean**	**St. Dev.**	**Min**	**Max**
Science and Technology Publications	19863.24	27,843.39	64	121,739.7
- per thousand residents	1.05	0.605	0.11	2.73
Social Sciences Publications	2417.11	4,440.47	13.67	29,646.33
- per thousand residents	0.14	0.11	0.005	0.50
Arts and Humanities Publications	746.77	1,376.62	3.33	9,627.33
- per thousand residents	40.53	32.47	1.85	152.87
Patents	2001.04	4,552.73	2.5	24,155.32
- per thousand residents	83.4	94.32	0.58	302.99
Citations	335,845.2	508.494	1,518	2,396,667
- per thousand residents	18.00	15.56	1.03	63.67
FTE R&D personnel	83233.64	124,234.4	426.67	571,694.3
- per thousand residents	4510.85	2519.95	854.6	11,105.1
Research Intensity (%)	1.4	0.88	0.24	3.71
International collaboration (%)	43.97	9.67	22.32	75.20
GPD per capita in PPP 2005 prices	26,085.98	13,058.78	6,595.96	78,647.84

5-year moving averages (224 observations):				
Variable	**Mean**	**St. Dev.**	**Min**	**Max**
Science and Technology Publications	19,976.28	27850	71.8	117,602
- per thousand residents	1.06	0.59	0.14	2.56
Social Sciences Publications	2,388.87	4,339.35	19.2	27,247.8
- per thousand residents	0.14	0.11	0.01	0.45
Arts and Humanities Publications	732	1,328.23	8631	8631
- per thousand residents	0.04	0.03	0.00	0.14
Patents	2,012.21	4,578.57	4.16	23,774.85
- per mln residents	83.85	94.58	0.824	301.12
Citations	343,372	513,441	1,760	2,324,000
- per thousand residents	18.39	15.58	1.20	61.53
FTE R&D personnel	83,218.25	123,889.6	564.4,	554,712.6
- per thousand residents	4.51	2.51	0.95	11.01
Research Intensity (%)	1.39	0.87	0.31	3.62
International collaboration (%)	44.29	9.4	23.86	74.19
GPD per capita in PPP 2005 prices	26,254.15	13,108.64	7,130.43	77,112.84

In the sample there are countries with R&D intensity ranging from 0.22% to 4.76% of GDP and the respective 3-year moving average values range from 0.24% to 3.71%. The average R&D intensity is 1.4%. As regards the research output indices of countries, the mean number of patent applications to the European Patent Office,

considered in per thousand residents, was 95. The average of Publications per thousand residents was 1.05 whereas the corresponding figures for Social Sciences and Arts and Humanities are 0.14 and 0.04 respectively. Average citations per thousand residents were found to be 18.

5.5.2 Econometric Model

Based on the theoretical background and the data, we consider two econometric models. The first concerns both applications and success in FP7 and involves applicants, funding asked for, successful applicants and secured funding. The dependent variables are log-transformed according to the theoretical model and separate estimates are carried out with the dependent variables in absolute and per capita values. We did not log-transform any explanatory variables that were expressed as percentages. All explanatory variables are either 3-year or 5-year moving averages. The general form of the estimated model is:

$$\ln succ_{it} = \beta_0 + \beta_1 \ln y_{i,t-k} + \beta_2 rd_{i,t-k} + \beta_3 hr_{it-k} + \beta_4 pat_{i,t-k} + \beta_5 sp_{i,t-k} + \beta_6 ss_{i,t-k} + \beta_7 ah_{i,t-k} + \beta_8 c_{i,t-k} + \beta_9 s_{i,t-k} + \beta_{10} \sum_{t=1}^{6} \tau_t + \sum_{i=1}^{27} \alpha_i + \varepsilon_{it} \qquad (14)$$

where $succ_{it}$ is any one of the first eight of the ten measures of participation or success in FP7 listed in Table 5-2.

$y_{i,t-k}$ is GDP per capita of the three previous years in PPP 2005 prices

$rd_{i,t-k}$ = R&D intensity

$hr_{i,t-k}$ = FTE R&D personnel

$pat_{i,t-k}$= applications in the European Patent Office

$sp_{i,t-k}$ = Publications in Science and Technology

$ss_{i,t-k}$ = Publications in Social Sciences

$hu_{i,t-k}$ = Publications in Arts and Humanities

$c_{i,t-k}$ = citations (excl. self-citations)

$s_{i,t-k}$= international collaboration as a % of all publications

a_i= the country-specific fixed effect

τ_t= the time-specific effect which is invariant across countries

$\varepsilon_{it}$is the stochastic error of the model where it is assumed that $E(\varepsilon_i x_i) = 0$, $E(a_i x_{it}) \neq 0$, $E(x_{it} x_{jt})$=0

We estimate the models in equation (14) using fixed effects to control for unobserved heterogeneity between countries. We obtain cluster-robust errors by using White's formula to deal with potential heteroskedasticity and we assume that endogeneity exists only in the form of simultaneity and double causality which are treated sufficiently with the fixed effects and the predetermined explanatory variables respectively. The estimated coefficients are interpreted as elasticities.

The last two of the ten dependent variables in Table 5-2 are ratios and therefore in theory bounded between 0 and 1 but in practice have even tighter bounds. This means we cannot apply standard OLS-type estimators such as fixed effects because these assume a full spectrum of values. We therefore estimate the models on the two ratio variables using Quasi Conditional Maximum Likelihood Estimation (QCMLE) where the success rates are treated as Poisson but only with respect to the mean, that is,

$$E(y_{it}) = \exp(\beta X_{it})$$

Another possible estimator could have been the log-odds ratio transformation but the bounds for our two dependent were much tighter than from 0 to 1 and the log-odds transformation would provide estimated parameters based on too wide a distribution.

Wooldridge highlighted the robustness of QCMLE to consistently estimate models on data that are neither Poisson distributed nor in the form of counts (Wooldridge, 2002). Although success rates can be easily transformed into counts by multiplying by 100, it is unnecessary to do so as the QCMLE estimated coefficients represent semi-elasticities and their magnitude remains the same regardless of scaling. To ensure the estimated coefficients on the level variables can be interpreted as elasticities these variables were logged. Also, in QCMLE it is critical to infer based on robust errors when overdispersion is present, that is, when the variance is greater than the mean. This is the case in our data as seen in Table 5-30. In all cases of the dependent variables, variance exceeds the mean rejecting the assumption of equidispersion.

$$\boldsymbol{succ_{it} = exp(\beta_0 + \beta_1 \ln y_{i,t-k} + \beta_2 rd_{i,t-k} + \beta_3 hr_{it-k} + \beta_4 pat_{i,t-k} + \beta_5 sp_{i,t-k} + \beta_6 ss_{i,t-k} + \beta_7 ah_{i,t-k} + \beta_8 c_{i,t-k} + \beta_9 s_{i,t-k} + \beta_{10} \sum_{t=1}^{6} \tau_t + \sum_{i=1}^{27} \alpha_i + \varepsilon_{it})} \quad (15)$$

where the variables are already denoted in equation (14). In estimating the model we make use of panel data econometric techniques. We prefer a static over a dynamic panel data estimator since we consider that the country and year-specific effects capture potential serial correlation.

We favour the Fixed Effects over the Random effects since regressors can be associated with the country's idiosyncratic effects thereby capturing unobserved heterogeneity. This advantage also allows to capture initial values which are difficult to observe otherwise, such as R&D capacity at the starting point of the study. It also facilitates treatment of other important time-invariant characteristics such as physical distance from key R&D centres and cultural connections to other countries.

Despite our preference, we ran the Hausman test to obtain a formal result for the trade-off between consistency and efficiency. The fixed effects estimator is always consistent but might lack efficiency. Conversely, the random effects estimator exhibits increased efficiency but it might be inconsistent if the regressors are not orthogonal to the individual effects. The Hausman test favoured Fixed Effects over Random effects in all but two settings (see Tables 5-4 to 5-7) when the null hypothesis of no substantial differences between the FE and RE estimated coefficients could not be rejected. The two cases where random effects were preferred are probably because the Hausman test cannot be performed when cluster-robust errors are obtained, which is the case in all our regressions where we use country as the cluster indicator. We instead performed the test with default errors which is not strictly representative unless the robust errors do not differ from the default, a highly unlikely case.

We recognise the shortcomings of implementing the within-transformation that the fixed effects dictate, such as loss in efficiency caused by not estimating time-constant variables and the between variation in the time-variant variables. Nonetheless, we argue that choosing fixed effects is optimal since it accounts for unobserved heterogeneity across countries and endogeneity caused by time-invariant characteristics. The other fact acting in favour of fixed effects is the absence of time-invariant variables in our dataset. This limits the consistency-efficiency trade-off only to the loss of the between variation of the variables of interest, albeit not negligible. Table 5-30 in the Appendix shows that the between variation is greater than within variation, and in some instances by a great deal. This is logical as country-specific variation is likely to be more uniform than variation among largely heterogeneous countries. However, endogeneity is very likely to exist in the model and especially with

the country-specific characteristics that are constant over time. Such complexity cancels the assumption of orthogonality of the regressors with the errors, which is a basic ingredient for the consistency of the random errors model. The Hausman test did not converge for the QCMLE process and therefore we implemented the preferable fixed effects estimator.

The multicollinearity tests show that there is a problem for some of the explanatory variables (See Tables 5-26 & 5-27). Some of the independent variables are strongly correlated possibly rendering the estimates unstable and enlarging the standard errors. This may be due to two reasons: the first is the simultaneous inclusion of final products of research such as publications, citations and patents with input variables such as R&D intensity, GDP per capita and human resources devoted to R&D. A latent variable, such as research capacity of a country, can simultaneously cause these variables or there might be double causality between them. In order to address this type of complexity we estimate the models again without the inclusion of the science-input variables. The relevant results reported in the findings section are supportive of no significant effect on the estimates in all cases. The second reason is that there are persistent country-specific effects and time-trends present in the model which induce multicollinearity. We handle this persistence by including both these effects in the model to be estimated. It is expected that they will absorb the largest part of the correlation among the explanatory variables.

The most critical issue in our estimation process concerns possible endogeneity of the model variables. The model is complicated as many research input and output variables are included representing different proxies of the research capacity of countries. We have discussed that these interact with each other but may also interact

with the dependent variable and in a way that hinders consistency of the estimators. These interactions can lead to the endogeneity of these variables. For example, patent applications are likely to strengthen the ability of a country to acquire funding but funding is likely to help the country to invent more, resulting in more patent applications. The same applies with publications. Also, human resources devoted in research and R&D intensity could be endogenously determined. As human resources may help in writing more successful research proposals, success may induce countries to invest further human resources into research.

As with R&D intensity, the association with gaining funding is rather ambiguous. It could be that countries with high R&D intensity have the potential to compete for EU funding with better chances than other countries that do not earmark a high share of their GDP to R&D. Alternatively, devoting a high share of GDP to R&D, may limit the incentives of researchers to invest time and resources to write a proposal for EU funding since they are more likely to secure funding from national sources. If these two effects co-exist and offset each other, it could be that human resources devoted to research could end up having an ambiguous effect on participation and success in FPs. To treat the possibility of double causality we use 3-year and 5-year lagged moving averages of all the explanatory variables so that we direct the effect from independent variables towards application and success in FPs. Not only does this treatment handle double causality but it is also intuitively appealing as in reality the realisation of these variables precedes the evaluation process.

We also address endogeneity caused by simultaneity of the dependent and the independent variables. Latent variables that have a causal effect on both funding success and research capacity of a country are responsible for the existence of

simultaneity. An example discussed before is the "stock" of research capacity or, put differently, the critical mass of R&D resources and output. At the starting point of our dataset these variables are fixed. We control for their flow through the explanatory variables but the stock is unobserved. It can thus be argued that this stock variable may play a pivotal role in both producing more knowledge and securing FP funding. Given such simultaneity, the pure effect from knowledge flow to funding success cannot be isolated. This type of endogeneity is accounted for by the use of fixed effects which are allowed to relate to the explanatory variables without affecting consistency of the estimates. This enables the model to accommodate all important time-invariant latent variables that cause simultaneity. The other desirable property of fixed effects is their exclusion from estimation through the within-transformation.

5.6 Findings

We begin the analysis with dependent variables related to applications in FP7. As observed, there are eight different specifications of the model for each dependent variable aside from success rates where the per capita normalisation is not applicable and specifications are reduced to four. In specifications I and II, we consider the natural logarithm of applicants and in III and IV the corresponding log-transformation of applicants per capita. The explanatory variables are lagged 3-year moving averages or 5-year moving averages interchangeably and again we use logs of values or logs of per capita ratios.

Table 5-4: Research input and output effect on applicants in FP7 by EU28 member states, fixed effects estimates for 2007-2013

Model (see footnote):	**I**		**II**		**III**		**IV**	
Dependent variable:	**Log-applicants**				**Log-applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	0.922***	(0.314)	0.388	(0.374)	0.950**	(0.376)	0.402	(0.455)
Arts and Humanities Publications	-0.014	(0.086)	-0.018	(0.146)	0.023	(0.097)	0.018	(0.173)
Social Sciences Publications	0.023	(0.092)	-0.020	(0.19)	-0.013	(0.104)	-0.072	(0.234)
Citations	-0.326*	(0.188)	0.041	(0.314)	-0.277	(0.202)	0.100	(0.362)
International Collaboration (% of total)	0.035***	(0.008)	0.013	(0.013)	0.034***	(0.011)	0.009	(0.017)
Research Intensity (%)	-0.012	(0.101)	0.052	(0.165)	-0.065	(0.103)	0.029	(0.152)
R&D personnel (1000 residents)	-0.128	(0.259)	-0.213	(0.256)	-0.086	(0.269)	-0.308	(0.26)
Patents	0.075	(0.079)	0.060	(0.104)	0.114	(0.081)	0.097	(0.11)
GPD per capita in PPP 2005 prices	-0.846*	(0.443)	-1.610*	(0.64)	-0.838*	(0.458)	-1.637**	(0.644)
y2008	-0.512***	(0.042)	-0.458**	(0.079)	-0.518***	(0.047)	-0.450***	(0.093)
y2009	-0.363***	(0.083)	-0.228	(0.149)	-0.372***	(0.091)	-0.214	(0.172)
y2010	-0.633***	(0.112)	-0.416*	(0.203)	-0.642***	(0.123)	-0.399	(0.232)
y2011	-0.508***	(0.135)	-0.209	(0.243)	-0.506***	(0.15)	-0.174	(0.28)
y2012	-0.465***	(0.172)	-0.072	(0.315)	-0.463**	(0.187)	-0.030	(0.36)
y2013	-1.000***	(0.235)	-0.505	(0.398)	-0.992***	(0.256)	-0.453	(0.452)
Constant	10.999*	(4.899)	21.158***	(6.641)	8.929	(5.539)	20.186***	(7.165)
R-squared (within)	0.7874		0.7719		0.7653		0.7496	
R-squared (between)	0.7513		0.0556		0.2626		0.2644	
R-squared (overall)	0.7474		0.0704		0.3114		0.1331	
F test	85.52		172.10		85.35		206.15	
Hausman Test	73.23(FE)		49.88 (FE)		84.91 (FE)		33.91 (FE)	

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: OLS of log of applicants against logs of 3-year moving average variables, II: OLS of log of applicants against logs of 5-year moving average variables, III: OLS of log of applicants per capita against logs of 3-year moving average per capita variables, IV: OLS of log of applicants per capita against logs of 5-year moving average per capita variables.
(c) Cluster-robust errors used in all models (in parentheses)
(d) Research Intensity and International Collaboration are expressed as a percentage
(e) Observations: 196

Table 5-4 reports the results from the regressions of FP7 applicants. The R-squared correlation coefficient for the within dimension of the data shows that the independent

variables explain around 75%-79% of the variation. Although the fixed effect method generates a loss in efficiency in the estimation process it is formally selected by the Hausman test in seven out of eight model specifications. The F test of significance always rejects the null hypothesis of no joint statistical significance of the explanatory variables. The country and year specific effects are consistent and statistically significant.

The findings are informative and somewhat unexpected. Firstly, we notice statistical significance for only three explanatory variables of interest and not in all model specifications: Science and Technology Publications, international collaboration and citations, with the latter variable affecting FP7 applicants negatively. These findings are robust for both per capita and absolute number of applicants.

For Science and Technology Publications, the observed positive association is normal since capacity in R&D should bring increased participation in calls for high scale research projects such as the ones funded by FP7. This is also in line with the findings of Geuna (1999) but we note that, unlike our study which focuses on the country-level, he obtained estimates at the institution level. No association or statistical significance is found in the estimates for Social Sciences and Arts and Humanities publications but this is perhaps accords with the proportion of funds allocated to these research areas in FP7. Indeed, the money earmarked to these two broad fields accounts for around 5% of the total FP7 budget.

Citations found to be statistically significant in only three of the eight models and at the 10% level of significance. This result is surprising. It is plausible if highly-cited researchers are not allowed to receive additional compensation for their participation in FP7 and either shift their time to claiming funds from alternative sources of funding

or to utilising their already existing resources. Despite not being significant, citations are expected to play a critical role to the overall ability of a country to compete for funding and may be more important for success than for applicants. The more competent the population of a country in terms of producing research worth citing, the more likely it is that research proposals submitted in the EU FP will be of analogous quality. Also, aside from top researchers, citations are deemed to represent the number of Universities with high reputation in a country, an intuitively important variable for attracting funding grants (Geuna, 1999; Nokkala et al, 2001).

With international collaborations, the matter is straightforward even though we lack information on its quality. As collaboration between countries is in the majority of the calls mandatory we expect to see a positive association, as in our findings. It would be interesting to see if international collaboration enhances success as well since opposing forces are at play. One such force is that countries with high success in EU FPs tend to keep their number of proposals low, their consortia concise and have partners of high calibre. In absolute terms, this is valid since the countries with the highest participation are the ones with the highest research output and most probably the leaders in research proposals. Leaders tend to follow this pattern whereas followers try to achieve the maximum result by participating in many consortia. The latter situation represents the opposing force discussed above. However, concrete conclusions can be drawn only if this analysis takes place at the institution level which goes beyond the scope of this research. From the existing studies, it is clear that this possibility has not yet been explored.

Other research output variables, such as publications in Social Sciences and Arts and Humanities and patent applications, do not seem to affect FP applicants in a

statistically significant manner. This may be because the EU FP is oriented more toward the 'hard' rather than 'soft' sciences. Also, these variables along with S&T publications represent the quality of the country's human capital in R&D and thus are essential for success but probably do not define the number of applicants. One could claim that they affect the production function for writing proposals as better human capital is connected to fast-written and better proposals. However, the number of proposals submitted is a matter of choice of researchers and institutions. Therefore it could be the case that in countries with high research output, researchers and institutions may opt to submit a few proposals of high quality or even not submit at all. For patents the findings can be attributed to the nature of the calls for proposals in the FP which may be biased towards less technology-oriented scientific fields. Should this be the case, the inventing ability of countries is unlikely to determine either the applicants or success in FP7. This is also supported by the existence of the EU Innovation framework programme for Competitiveness and Innovation (CIP) which ran in the same period with FP7 and may have absorbed most applicants aiming at technology and innovation.

In general, we observe that 3-year moving averages are more able to explain participation in FP7 than the 5-year averages. For the former, we observe statistical significance most of the time, but not for the latter. This pattern seemingly owes to less variation among 5-year periods rather than 3-year periods within a country. In any case, we maintain both measures in our findings at this stage to secure consistent inference.

Table 5-5: Research input and output effect on money applied for in FP7 for EU28 member states, fixed effects estimates of 2007-2013

Model (see footnote):	**I**		**II**		**III**		**IV**	
Dependent variable:	**Log-money applied for**				**Log- money applied for per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	1.044**	(0.406)	0.353	(0.487)	1.153**	(0.481)	0.370	(0.573)
Arts and Humanities Publications	0.047	(0.131)	-0.053	(0.212)	0.072	(0.14)	0.083	(0.242)
Social Sciences Publications	0.082	(0.151)	0.046	(0.241)	0.046	(0.162)	-0.116	(0.285)
Citations	-0.619**	(0.252)	-0.032	(0.46)	-0.601**	(0.251)	0.025	(0.514)
International Collaboration (% of total)	0.039***	(0.014)	0.011	(0.017)	0.040**	(0.016)	0.005	(0.02)
Research Intensity (%)	-0.100	(0.123)	0.122	(0.209)	-0.197	(0.157)	0.089	(0.227)
R&D personnel (1000 residents)	-0.096	(0.324)	-0.216	(0.374)	0.033	(0.347)	-0.303	(0.401)
Patents	0.018	(0.12)	-0.123	(0.148)	0.114	(0.118)	-0.055	(0.154)
GPD per capita in PPP 2005 prices	-0.250	(0.612)	-0.789	(0.671)	-0.312	(0.614)	-0.842	(0.683)
y2008	-0.419***	(0.054)	-0.327***	(0.1)	-0.435***	(0.06)	-0.318***	(0.113)
y2009	-0.344***	(0.108)	-0.135	(0.181)	-0.368***	(0.116)	-0.120	(0.201)
y2010	-0.543***	(0.15)	-0.225	(0.251)	-0.574***	(0.16)	-0.206	(0.277)
y2011	-0.554***	(0.208)	-0.131	(0.333)	-0.579***	(0.222)	-0.091	(0.369)
y2012	-0.327	(0.247)	0.232	(0.42)	-0.359	(0.255)	0.280	(0.462)
y2013	-0.997***	(0.339)	-0.265	(0.527)	-1.036***	(0.349)	-0.207	(0.58)
Constant	5.179	(6.91)	13.607*	(7.552)	2.519	(7.734)	12.317	(7.954)
R-squared (within)	0.6137		0.5855		0.5919		0.5616	
R-squared (between)	0.7325		0.2487		0.4805		0.4392	
R-squared (overall)	0.7083		0.1601		0.4777		0.2261	
F test	39.99		33.75		39.42		47.26	
Hausman Test	42.47 (FE)		385.12 (FE)		19.64 (FE)		33.56 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of money applied for against logs of 3-year moving average variables, II: OLS of log of money applied for against logs of 5-year moving average variables, III: OLS of log of per capita money applied for against logs of 3-year moving average per capita variables, IV: OLS of log of per capita money applied for against logs of 5-year moving average per capita variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

A similar situation is observed when the dependent variable is the amount of money asked for through the application process. As seen in Table 5-5, Publications in Science and Technology are highly significant in all model variations when 3-year moving average explanatory variables are used. International collaboration is related directly with money asked for and a negative association of citations is also sporadically observed to be significant. The rest of the variables remain insignificant but their sign is not always in line with intuition. We assume that the factors shaping these findings are similar to the ones discussed for the number of applicants. The only difference is that the amount is differentiated from applicants if a number of institutions or researchers aim systematically for either high or low amounts of money. Should this hold, then we would observe an asymmetric association of applicants to money in some cases. Overall, the main result is that there is nearly perfect correlation between the two values as shown in Tables 5-26 and 5-27 in the Appendix. For both absolute and per capita values the coefficients are 0.975 and 0.99 respectively.

Table 5-6: Research input and output effect on successful applicants in FP7 by EU28 member states, fixed effects estimates 2007-2013

Model (see footnote):	**I**		**II**		**III**		**IV**	
Dependent variable:	**Log-successful applicants**				**Log- successful applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	0.555**	(0.271)	0.183	(0.32)	0.651**	(0.307)	0.221	(0.411)
Arts and Humanities Publications	0.085	(0.114)	0.003	(0.129)	-0.045	(0.129)	-0.038	(0.158)
Social Sciences Publications	-0.046	(0.155)	-0.069	(0.184)	0.075	(0.173)	-0.036	(0.213)
Citations	-0.145	(0.203)	0.206	(0.298)	-0.113	(0.216)	0.252	(0.345)
International Collaboration (% of total)	0.023**	(0.011)	0.002	(0.013)	0.023*	(0.013)	-0.002	(0.017)
Research Intensity (%)	-0.055	(0.11)	-0.033	(0.166)	-0.126	(0.103)	-0.108	(0.166)
R&D personnel (1000 residents)	0.051	(0.248)	-0.042	(0.226)	0.166	(0.222)	-0.048	(0.22)
Patents	-0.096	(0.09)	-0.093	(0.123)	-0.030	(0.106)	-0.018	(0.133)
GPD per capita in PPP 2005 prices	-0.743	(0.456)	-1.559***	(0.6)	-0.785*	(0.472)	-1.651***	(0.608)
y2008	-0.510***	(0.06)	-0.440***	(0.078)	-0.525***	(0.061)	-0.440***	(0.092)
y2009	-0.267***	(0.101)	-0.115	(0.136)	-0.291***	(0.107)	-0.116	(0.161)
y2010	-0.429***	(0.138)	-0.198	(0.192)	-0.457***	(0.146)	-0.200	(0.222)
y2011	-0.387**	(0.169)	-0.076	(0.236)	-0.404**	(0.184)	-0.062	(0.272)
y2012	-0.366*	(0.217)	0.033	(0.305)	-0.389	(0.238)	0.049	(0.354)
y2013	-0.877***	(0.287)	-0.389	(0.381)	-0.903***	(0.311)	-0.369	(0.438)
Constant	8.819*	(5.327)	18.676***	(6.000)	6.042	(5.457)	17.363***	(6.532)
R-squared (within)	0.7339		0.7266		0.7232		0.7164	
R-squared (between)	0.4006		0.0022		0.0063		0.4467	
R-squared (overall)	0.4033		0.0001		0.0595		0.2843	
F test	152.96		171.59		119.00		154.39	
Hausman Test	88.85 (FE)		14.67(RE)		69.63 (FE)		61.04 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of applicants in retained proposals against logs of 3-year moving average variables, II: OLS of log of applicants in retained proposals against logs of 5-year moving average variables, III: OLS of log of per capita applicants in retained proposals against logs of 3-year moving average per capita variables, IV: OLS of log of per capita applicants in retained proposals against logs of 5-year moving average per capita variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

Turning our attention to the estimates for success, we identify a number of associations for the number of successful applicants: Firstly, the number of publications in Science and Technology remains significant in most cases. International collaboration presents the same picture although its quality is not measured by this variable. However, here we spot a negative association of patents with successful participations. This can be perceived as either limited availability of FP7 calls for proposals related to technological scientific fields or unwillingness of countries with high invention rates to invest time in writing proposals under FP7. GDP per capita also appears to be significant and this can be explained when we take a closer look at Figures 5:1 and 5:3 where Eastern European countries with low GDP per capita feature in the bottom of the list with the highest FP7 secured funding. To be clear, this association does not necessarily mean that low GDP per capita is the reason for not succeeding in securing funding. Low GDP per capita is a common characteristic amongst countries with low success. This is probably a proxy for the weak research culture of these countries over the last decades.

Table 5-7: Research input and output effect on secured funding in FP7 for EU28 member states, fixed effects estimates 2007-2013

Model (see footnote):	**I**		**II**		**III**		**V**	
Dependent variable:	**Log-secured funding**				**Log-secured funding per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	0.435	(0.39)	0.241	(0.46)	0.544	(0.469)	0.249	(0.539)
Arts and Humanities Publications	-0.018	(0.137)	-0.102	(0.186)	0.025	(0.155)	-0.051	(0.203)
Social Sciences Publications	-0.004	(0.25)	-0.087	(0.339)	-0.054	(0.274)	-0.157	(0.361)
Citations	0.377	(0.302)	0.599	(0.527)	0.381	(0.317)	0.677	(0.552)
International Collaboration (% of total)	0.013	(0.017)	-0.009	(0.025)	0.012	(0.021)	-0.016	(0.028)
Research Intensity (%)	0.092	(0.22)	0.118	(0.353)	0.075	(0.221)	0.090	(0.359)
R&D personnel (1000 residents)	0.060	(0.493)	-0.040	(0.509)	0.074	(0.461)	-0.086	(0.473)
Patents	-0.276**	(0.109)	-0.268	(0.178)	-0.242	(0.147)	-0.228	(0.196)
GPD per capita in PPP 2005 prices	-0.780	(0.536)	-1.527*	(0.834)	-0.850	(0.525)	-1.648**	(0.796)
y2008	-0.466***	(0.088)	-0.397***	(0.125)	-0.475***	(0.094)	-0.383***	(0.131)
y2009	-0.198	(0.126)	-0.059	(0.214)	-0.216	(0.149)	-0.039	(0.227)
y2010	-0.316	(0.197)	-0.114	(0.341)	-0.338	(0.231)	-0.086	(0.357)
y2011	-0.177	(0.223)	0.089	(0.413)	-0.186	(0.271)	0.141	(0.435)
y2012	0.011	(0.297)	0.335	(0.52)	-0.007	(0.359)	0.395	(0.551)
y2013	-0.293	(0.38)	0.069	(0.654)	-0.320	(0.457)	0.140	(0.689)
Constant	4.216	(7.691)	13.719	(10.76)	3.226	(6.223)	13.464	(9.189)
R-squared (within)	0.5195		0.4944		0.5133		0.4915	
R-squared (between)	0.5799		0.0664		0.0219		0.3313	
R-squared (overall)	0.5753		0.0734		0.0479		0.2428	
F test	62.85		42.70		71.42		48.22	
Hausman Test	61.90 (FE)		43.40 (FE)		52.75 (FE)		42.69 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of EC funding secured against logs of 3-year moving average variables, II: OLS of log of EC funding secured against logs of 5-year moving average variables, III: OLS of log of per capita EC funding secured against logs of 3-year moving average per capita variables, IV: OLS of log of per capita EC funding secured against logs of 5-year moving average per capita variables,

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

As we saw in previous tables, publications in Science and Technology are positively associated with applications and funding success in FP7. However, this is not the case for the amount of secured funding. In the case where EU FP funding is a substitute for national funding then Table 5-7 reveals another pattern. David et al (1995) discuss this possibility of substitution along with the opposite trend, that of additionality. The latter term refers to the exploitation of EU FP funding for carrying out additional research activities, not pursued in case only national funding was available. If the substitution effect is at play then we have two scenarios: a. either researchers have access to adequate national resources and they invest less or no time and effort in writing proposals in FPs or b. in countries with low research capacity researchers aim at FP7 money to cover for the lack of national funds or as a substitute for private funding. Also, this tendency is likely to be thematically-driven. Hard sciences need large scale funding and thus match the definition of the additionality effect. They are willing to invest time and resources to acquire such funding and this may explain our findings for the significance of S&T for FP7 applications. In contrast, a theoretical researcher may carry out research with only basic capital and labour and only the substitution effect may serve as a potential explanation for variation in success in these fields.

Another possible explanation for this propensity could be that in countries with high total publications the best researchers are reluctant to devote more time to write research proposals, unless acting within the additionality context. This also stands if these researchers secured national or other funding which they used to produce significant research output the year before. This hypothesis implies that researchers could still be in the phase of exploiting that funding.

When the success rate is the dependent variable of the model, then the effects are negative for most explanatory variables including S&T publications and statistically insignificant for research input variables such as R&D intensity, R&D personnel and GDP per capita. Essentially, for S&T publications all estimation results of the coefficient have a negative sign and the elasticity varies from -0.634 up to -0.059. Other publications remain insignificant. International collaboration also appears to have a negative impact on success and this can be rationalised when the opportunistic participation pattern is taken into account. The latter term refers to the phenomenon of participating in research proposals assigning from very little or no resources in the preparation process. Coordinating the preparation of research proposals for EU FP demands time and resources and countries with weak research culture encountered difficulties in assimilating the FP requirements. Driven by this difficulty, participants from small countries have used the opportunistic approach to become acquainted with the FP with view to progressively engage in preparing their own proposals after they acquire experience.

For citations per capita, a positive association is found for the success rates of FP7 funding for 3-year moving averages. This finding corroborates our theoretical model and the notion that quality of research is important for determining success in securing funding. Patents are negatively associated with success rates and are significant across all but two specifications of the model. This robustness shows that countries with inventive activity have a special formula of application and success in FP7. We speculate that this negative association is due to factors such as passive applicants of these countries in proposals or lack of knowledge of the FP7 regulations due to the emphasis placed on technological orientation. We can also extend this argument by

assuming that in these countries business enterprises are heavily involved in patenting activity, which would justify the lack of expertise in FP7 regulations and norms. However, our findings do not reveal if any of these arguments hold for the effect of patenting activity on FP application and success.

Table 5-8: Research input and output effect on success rates in applicants of EU28 member states FP7, fixed effects estimates 2007-2013

Model (see footnote):	**I**		**II**		**III**		**V**	
Dependent variable:	**Success rate of applicants**							
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	-0.295	(0.197)	-0.188	(0.131)	-0.363*	(0.199)	-0.210	(0.14)
Arts and Humanities Publications	-0.085	(0.082)	-0.081	(0.06)	0.132	(0.082)	0.051	(0.063)
Social Sciences Publications	0.121	(0.129)	0.065	(0.097)	-0.087	(0.122)	-0.075	(0.091)
Citations	0.153	(0.188)	0.157	(0.146)	0.174	(0.176)	0.170	(0.155)
International Collaboration (% of total)	-0.011	(0.008)	-0.011*	(0.007)	-0.011*	(0.007)	-0.011*	(0.007)
Research Intensity (%)	-0.061	(0.078)	-0.122	(0.119)	-0.041	(0.075)	-0.074	(0.124)
R&D personnel (1000 residents)	0.247	(0.2)	0.257	(0.198)	0.177	(0.201)	0.175	(0.205)
Patents	-0.147***	(0.051)	-0.134**	(0.064)	-0.174***	(0.058)	-0.169**	(0.07)
GPD per capita in PPP 2005 prices	0.115	(0.291)	0.083	(0.416)	0.168	(0.283)	0.149	(0.398)
y2008	-0.013	(0.053)	0.006	(0.045)	-0.006	(0.052)	0.012	(0.048)
y2009	0.072	(0.084)	0.092	(0.071)	0.087	(0.079)	0.105	(0.075)
y2010	0.168	(0.103)	0.186**	(0.087)	0.186**	(0.094)	0.202**	(0.09)
y2011	0.088	(0.139)	0.105	(0.113)	0.107	(0.126)	0.122	(0.117)
y2012	0.063	(0.17)	0.079	(0.14)	0.089	(0.153)	0.100	(0.141)
y2013	0.067	(0.231)	0.077	(0.175)	0.101	(0.21)	0.104	(0.177)
Wald chi2 test	506.25		427.26		1164.81		624.12	
Log-pseudolikelihood	-53.249		-53.252		-53.247		-53.251	

Notes:

*(a) *** p<0.01, ** p<0.05, *p<0.1*

(b) I: Poisson of success rate of applicants against logs of 3-year moving average per capita variables, II: Poisson of success rate of applicants against logs of 5-year moving average per capita variables, III: Poisson of success rate of applicants against logs of 3-year moving average variables, IV: Poisson of log of success rate of applicants against logs of 5-year moving average variables,

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

Table 5-9: Research input and output effect on success rates in secured funding of EU28 member states FP7, fixed effects estimates 2007-2013

Model (see footnote):	**I**		**II**		**III**		**V**	
Dependent variable:	**Success rate of secured funding**							
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	-0.602*	(0.319)	-0.059	(0.349)	-0.634**	(0.312)	-0.064	(0.14)
Arts and Humanities Publications	-0.069	(0.104)	-0.135	(0.182)	-0.068	(0.108)	-0.109	(0.063)
Social Sciences Publications	-0.108	(0.229)	-0.092	(0.32)	-0.099	(0.219)	-0.136	(0.091)
Citations	0.952***	(0.268)	0.570	(0.452)	0.960***	(0.28)	0.563	(0.155)
International Collaboration (% of total)	-0.034**	(0.014)	-0.027	(0.02)	-0.030**	(0.012)	-0.027	(0.007)
Research Intensity (%)	0.308	(0.327)	0.083	(0.45)	0.267	(0.301)	0.108	(0.124)
R&D personnel (1000 residents)	0.057	(0.633)	0.186	(0.65)	0.080	(0.627)	0.092	(0.205)
Patents	-0.383***	(0.142)	-0.185	(0.166)	-0.358**	(0.145)	-0.175	(0.07)
GPD per capita in PPP 2005 prices	-0.342	(0.514)	-0.700	(0.694)	-0.317	(0.51)	-0.650	(0.398)
y2008	-0.004	(0.069)	-0.016	(0.103)	-0.005	(0.061)	-0.013	(0.048)
y2009	0.184*	(0.096)	0.124	(0.165)	0.185**	(0.073)	0.132	(0.075)
y2010	0.253*	(0.148)	0.148	(0.248)	0.251**	(0.121)	0.158	(0.09)
y2011	0.432**	(0.191)	0.281	(0.315)	0.425***	(0.164)	0.291	(0.117)
y2012	0.400*	(0.234)	0.166	(0.386)	0.393*	(0.201)	0.179	(0.141)
y2013	0.751**	(0.325)	0.375	(0.513)	0.747**	(0.293)	0.392	(0.177)
Wald chi2 test	217.17		124.35		244.48		117.35	
Log-pseudolikelihood	-44.139		-44.182		-44.140		-44.184	

Notes:
*(a) *** p<0.01, ** p<0.05, *p<0.1,*
(b) I: Poisson of success rate of applicants against logs of 3-year moving average per capita variables, II: Poisson of success rate of applicants against logs of 5-year moving average per capita variables, III: Poisson of success rate of applicants against logs of 3-year moving average variables, IV: Poisson of log of success rate of applicants against logs of 5-year moving average variables,
(c) Cluster-robust errors used in all models (in parentheses)
(d) Research Intensity and International Collaboration are expressed as a percentage
(e) Observations: 196

Having reviewed all the main findings we now focus on the idiosyncratic results of the estimated models. This is necessary as there are gaps which can be explained when

our model undergoes some adjustments. One of these concerns the high correlation between explanatory variables corroborated by the coefficients observed in the correlation Tables 5-31 and 5-32 in the Appendix. According to our theoretical model, the explanatory variables proxy different components of the production function or some of them may jointly proxy a specific component. However, the correlation seen in the data may say that most explanatory variables are different reflections of the research capacity of a country. If this is so, then the estimates may be distorted. For example, R&D intensity is correlated with R&D personnel since expenditure in R&D largely concerns the salaries of the R&D personnel. Other forms of interaction are also present in the model. We thus run the models again by excluding different variables each time. The variables of interest are left intact and we exclude the research input variables interchangeably and in combinations. We did not want to do so before, since we consider that the theoretical premises should be maintained for the model to have intuitive meaning. But our dataset dictates otherwise. Multicollinearity is a problem that cannot be overlooked, especially when some correlation coefficients approach unity. Table 5-10 shows the impact of excluding R&D intensity, R&D personnel, GDP per capita and combinations thereof on the non-excluded variables and on the model as a whole. Table 5-10 reveals that results only change when R&D personnel and GDP per capita are excluded, where R&D intensity becomes statistically significant at the 10% level and only for success rates. No other variable from the three research input variables is affected. For the overall model, the values of the F-test and R-squared are reduced considerably but the coefficients of the remaining variables change only slightly and their statistical significance is largely unchanged. These results confirm the importance of the country- and time-specific effects in capturing much of the high

association between explanatory variables. Since no significant impact is observed and for reasons pertaining to the theoretical background of the model we maintain all variables in the model.

Table 5-10: Treatment of multicollinearity by excluding research input variables and combinations thereof from the model

Overall Impact on Variables /Variables excluded	(a)	(b)	(c)	(a), (b)	(a), (c)	(b), (c)	(a), (b) & (c)
R&D intensity (a)	-	Null	Null	-	-	Succ. Rate	-
R&D personnel (b)	Null	-	Null	-	Null	-	-
GDP per capita (c)	Null	Null	-	Null	-	-	-
Other model coefficients	Trivial	Trivial	Trivial	Trivial	Trivial	Trivial	Trivial

Another pattern we have detected is that, although the EU28 are members of a union implementing collective R&D policies, they seem largely heterogeneous in R&D performance. Going back to Figure 5:1 we can separate the EU28 into two groups; high performers and low performers. The EU has done so officially through an assessment exercise undertaken for this purpose (European Commission, 2013) which matches this rationale. The EU is keen on creating a fertile environment for convergence of weak R&D countries to the levels of their strong counterparts. Overall, the aim of this initiative is to enable the EU to compete with the USA and Japan in research excellence and innovation in the long-term (Pavitt, 1998). This motivation gave rise to this assessment which has separated the strong R&D countries (EU13) from the weak R&D countries (EU15) and has formulated policies targeted to improve the R&D capacity of weak countries. Di Cagno et al (2014) examined the impact of EU FP participation on knowledge generation and economic growth. They applied a similar separation in EU countries and found that countries which are leaders in R&D observe a positive effect whereas countries with low R&D capacity are followers. In this light, we consider our model separately for these two groups of countries expecting a higher

level of between homogeneity due to common characteristics. We estimate the model again for all dependent variables and we report the most important findings in this section. We include the full set of estimates in the Appendix.

We modify the explanatory variables since the F-test cannot perform adequately due to the size of clusters which is smaller than the explanatory variables. We retain the year and country effects but we unify S&T publications with the corresponding in Social Sciences and Arts and Humanities. We do so as the latter two variables appear to be statistically insignificant in all settings of the model and they are also very highly correlated with S&T publications as seen in Tables 5-31 and 5-32. We also exclude GDP per capita, the variable least relevant to R&D, since from our previous attempt to tackle multicollinearity we concluded that only a slight impact of that variable was evident.

Table 5-11: Research input and output effect on participation of EU13 member states in FP7, 2007-2013

	I	II	III	IV	V	VI	VII	VIII
Explanatory variables				**Coefficients**				
Total Publications	2.508*	2.519**	2.479*	2.414**	1.393	1.224	1.364	1.118
Citations	-1.131	-1.094	-1.163	-1.087	-0.811	-0.551	-0.843	-0.544
International Collaboration (% of total)	0.009	0.016	0.005	0.011	0.009	0.014	0.004	0.009
Research Intensity (%)	0.079	0.002	0.076	0.010	0.047	-0.120	0.043	-0.113
R&D personnel (1000 residents)	-0.788**	-0.522	-0.695**	-0.444	-0.864**	-0.483	-0.771*	-0.406
Patents	0.377	0.342	0.373	0.331	0.675	0.803*	0.671	0.792*
y2008	-0.592***	-0.614***	-0.595***	-0.608***	-0.337	-0.346*	-0.339	-0.341*
y2009	-0.446	-0.490*	-0.450	-0.479*	-0.253	-0.263	-0.257	-0.252
y2010	-0.855*	-0.912**	-0.860*	-0.894**	-0.424	-0.416	-0.429	-0.399
y2011	-0.810	-0.873	-0.828	-0.860	-0.431	-0.387	-0.449	-0.374
y2012	-1.025	-1.091	-1.049	-1.074	-0.282	-0.190	-0.306	-0.173
y2013	-1.823	-1.898*	-1.854	-1.874*	-0.937	-0.791	-0.969	-0.768
Constant	6.148	-0.164	3.231	-2.629	9.256	1.173	6.340	-1.292
Observations	91	91	91	91	91	91	91	91
R-squared (within)	0.8828	0.8916	0.8813	0.8880	0.7408	0.7542	0.7259	0.7382
R-squared (between)	0.1099	0.8543	0.0738	0.7703	0.0004	0.6914	0.0317	0.3662
R-squared (overall)	0.0370	0.8454	0.1628	0.4889	0.0078	0.6844	0.0745	0.2219
F test	264.98	1450.67	409.18	2755.40	916.43	2050.42	5384.56	115,158

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: Fixed Effects OLS of log of applicants against logs of 3-year moving average per capita variables, II: Fixed Effects OLS of log of applicants against logs of 3-year moving average variables, III: Fixed Effects OLS of log of applicants per capita against logs of 3-year moving average per capita variables, IV: Fixed Effects OLS of log of applicants per capita against logs of 3-year moving average variables V: Fixed Effects OLS of log of money applied for against logs of 3-year moving average per capita variables VI: Fixed Effects OLS of log of money applied for against logs of 3-year moving average variables, VII: Fixed Effects OLS of log of per capita money applied for against logs of 3-year moving average per capita variables, VIII: Fixed Effects OLS of log of per capita money applied for against logs of 3-year moving average variables
(c) Cluster-robust errors used in all models (reported in detailed tables 5-25 & 5-26 in the Appendix)
(d) Research Intensity and International Collaboration are expressed as a percentage
(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

We start with the analysis of the strong R&D countries, henceforth EU13. Applicants in FP7 seem to be modelled satisfactorily by previous research output measured by lagged total publications. The coefficient states that a 1% increase in the average total publications would increase the number of participants by 2.5%, giving an elasticity of 2.5. A similar magnitude is found whether we consider absolute of per capita applicants. This stands for the number of applicants but not for money asked in the proposals submitted. For the latter perhaps it is the choice of specific action or call for proposals that determines the amount of money so it is not fully captured by total publications.

R&D personnel seems to be negatively related to participation mostly in per capita settings of the model with impact in the range of 0.7%-0.9%. This is probably a result of the inverse impact of having reached a critical mass of researchers funded by national sources who do not strive to secure additional funding and do not participate as in countries where the opposite applies. Total publications is a better measure in the sense that it shows the density of the output that the R&D personnel has produced. All other variables are statistically insignificant for determining participation in FP7, which may indicate homogeneity in research capacity among the EU13. As these countries are competent in R&D and probably leaders in research proposals, the size of international collaboration is not a critical factor for their participation. They are likely to choose high quality partners irrespective of the consortia size which is less concise. As expected the year of application plays a significant role as it captures important features like the FP7 annual budget and the importance placed on thematic and other policy priorities.

Table 5-12: Research input and output effect on FP7 participation of EU15 member states, 2007-2013

	I	II	III	IV	V	VI	VII	VIII
Explanatory variables				**Coefficients**				
Total Publications	1.138***	1.044***	1.104***	0.985***	1.309***	1.200***	1.276***	1.141**
Citations	-0.492	-0.407	-0.367	-0.324	-0.756**	-0.761**	-0.632*	-0.678*
International Collaboration (% of total)	0.037***	0.033***	0.033***	0.030***	0.043***	0.042***	0.039**	0.038**
Research Intensity (%)	-0.081	-0.072	-0.141	-0.054	-0.220	-0.109	-0.280*	-0.092
R&D personnel (1000 residents)	0.158	0.132	0.213	-0.037	0.213	-0.155	0.268	-0.324
Patents	0.050	0.056	0.107	0.055	0.041	-0.035	0.098	-0.036
y2008	-0.621***	-0.615***	-0.629***	-0.605***	-0.520***	-0.487***	-0.528***	-0.477***
y2009	-0.614***	-0.600***	-0.625***	-0.579***	-0.448***	-0.385***	-0.458***	-0.364***
y2010	-0.895***	-0.870***	-0.906***	-0.839***	-0.676***	-0.592***	-0.687***	-0.561***
y2011	-0.857***	-0.820***	-0.837***	-0.749***	-0.709***	-0.605***	-0.688***	-0.533***
y2012	-0.827***	-0.763***	-0.794***	-0.675***	-0.487***	-0.358*	-0.454***	-0.271
y2013	-1.407***	-1.316***	-1.354***	-1.208***	-1.235***	-1.085***	-1.181***	-0.977***
Constant	0.661	-0.240	-1.905	-0.275	-0.273	3.156	-2.839	3.121
Observations	105	105	105	105	105	105	105	105
R-squared (within)	0.7274	0.7954	0.7687	0.7537	0.6023	0.5920	0.5773	0.5611
R-squared (between)	0.3564	0.7842	0.5184	0.2815	0.0695	0.3096	0.5597	0.0206
R-squared (overall)	0.2507	0.7828	0.5415	0.1688	0.0171	0.3295	0.5618	0.0698
F test	170.34	84.48	81.05	116.14	90.67	60.59	61.80	47.58

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Fixed Effects OLS of log of applicants against logs of 3-year moving average per capita variables, II: Fixed Effects OLS of log of applicants against logs of 3-year moving average variables, III: Fixed Effects OLS of log of applicants per capita against logs of 3-year moving average per capita variables, IV: Fixed Effects OLS of log of applicants per capita against logs of 3-year moving average variables V: Fixed Effects OLS of log of money applied for against logs of 3-year moving average per capita variables VI: Fixed Effects OLS of log of money applied for against logs of 3-year moving average variables, VII: Fixed Effects OLS of log of per capita money applied for against logs of 3-year moving average per capita variables, VIII: Fixed Effects OLS of log of per capita money applied for against logs of 3-year moving average variables
(c) Cluster-robust errors used in all models (reported in detailed tables 5-20 & 5-21 in the Appendix)
(d) Research Intensity and International Collaboration are expressed as a percentage
(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

For the weak R&D countries, henceforth EU15, the landscape seems somewhat different. Total publications still play a significant role in defining participation, with a nearly unitary elastic effect. Now international collaboration is important in all settings representing the dependence of weaker countries in research networks, especially with linkages to strong R&D countries. Here the North-South paradigm in R&D (Coe et al, 1995) is evident, where EU13 is in the North and EU15 is in the South. We also observe that for the amount of funding applied, citations are inversely related with an effect of approximately 0.7%. This finding is hard to put in a theoretical context but we can merely assume that countries whose research is more impactful have a critical

mass of research infrastructure and thus ask for less money from their proposals. It is implicit that the opposite applies for countries that are below a threshold of prerequisite research capacity within the EU15 whereby they ask for more money to converge to the levels of their counterparts. However, we should note that this explanation is not confirmed by either R&D intensity or R&D personnel. Again, the year of participation is highly significant for explaining the dependent variables showing that participation in the first year, 2007, was higher than any other year of the FP7.

Table 5-13: Research input and output effect on success in FP7 for EU13 member states, 2007-2013

	I	II	III	IV	V	VI	VII	VIII
Explanatory variables				**Coefficients**				
Total Publications	1.869	1.888	1.711	2.523	1.840	1.859	1.606	2.418
Citations	-0.508	-0.546	-0.521	-0.990	-0.540	-0.578	-0.514	-0.983
International Collaboration (% of total)	0.001	-0.018	0.007	0.004	-0.003	-0.022	0.001	-0.002
Research Intensity (%)	-0.131	-0.358	-0.174	-0.430*	-0.134	-0.361	-0.167	-0.422*
R&D personnel (1000 residents)	0.177	0.473	0.426	0.847	0.270	0.566	0.503*	0.924
Patents	0.167	0.412	0.161	0.203	0.163	0.408	0.149	0.192
y2008	-0.599***	-0.477***	-0.610***	-0.569***	-0.601***	-0.480***	-0.605***	-0.564***
y2009	-0.315	-0.307	-0.344	-0.505	-0.319	-0.311	-0.333	-0.494
y2010	-0.621	-0.508	-0.660	-0.806	-0.626	-0.513	-0.642*	-0.788
y2011	-0.586	-0.459	-0.630	-0.861	-0.604	-0.476	-0.617	-0.849
y2012	-0.690	-0.498	-0.741	-1.025	-0.714	-0.522	-0.724	-1.009
y2013	-1.396	-1.142	-1.464	-1.840	-1.428	-1.173	-1.440	-1.816
Constant	-3.676	-7.024	-9.714*	-17.482**	-6.593	-9.941	-12.179**	-19.95***
Observations	91	91	91	91	91	91	91	91
R-squared (within)	0.9104	0.6883	0.9216	0.7223	0.9127	0.6955	0.9216	0.7265
R-squared (between)	0.1348	0.0000	0.9657	0.9453	0.5049	0.5630	0.6552	0.4245
R-squared (overall)	0.0385	0.0044	0.9385	0.9103	0.5867	0.5785	0.4151	0.3106
F test	2072.91	2206.16	$1.98e^{10}$	$1.13e^{6}$	22211.74	1477.62	20130.51	11177.12

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: Fixed Effects OLS of log of applicants in retained proposals against logs of 3-year moving average per capita variables, II: Fixed Effects OLS of log of applicants in retained proposals against logs of 3-year moving average variables, III: Fixed Effects OLS of log of per capita applicants in retained proposals against logs of 3-year moving average per capita variables, IV: Fixed Effects OLS of log of per capita applicants in retained proposals against logs of 3-year moving average variables, V: Fixed Effects OLS of log of EC funding secured against logs of 3-year moving average per capita variables, VI: Fixed Effects OLS of log of EC funding secured against logs of 3-year moving average variables, VII: Fixed Effects OLS of log of per capita EC funding secured against logs of 3-year moving average per capita variables, VIII: Fixed Effects OLS of log of per capita EC funding secured against logs of 3-year moving average variables.
(c) Cluster-robust errors used in all models (reported in detailed tables 5-27 & 5-28 in the Appendix)
(d) Research Intensity and International Collaboration are expressed as a percentage
(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

The findings in Table 5-13 seem somewhat peculiar. None of the explanatory variables seem to play any role in determining success in FP7 when measured by either the number of successful applicants or the amount of secured funding. We suspected that multicollinearity may be responsible for this paradox and we ran the models again excluding different groups of variables. Still, the findings remained the same in all model specifications. Therefore, the question of what factors define success in R&D advanced countries is left unanswered based on the setting of our model. A probable cause is that after the R&D capacity minimum threshold is reached then micro-factors play a more significant role and there are not any common trends that serve as explanatory variables at the aggregate level. Attempting to explain this behaviour, we go back to our theoretical model and seek answers by reviewing the process of succeeding in EU FPs. Ultimately, it seems that success in FP7 is a matter of right choices rather than research capacity when the countries are homogeneous in the latter characteristic. Choices such as the partners in research proposals, the individuals that actually contribute in writing a proposal and the evaluators' perspective when assessing proposals may be catalytic. When evaluators have to select research projects worth funding they have to follow their intuition if proposals are of similar quality. This is not captured in our model. We capture the probability of writing good proposals by proxying this ability of doing so with previous research output. But if research output is similar among EU13 countries then the effect is not isolated and the model exhibits insignificant coefficients.

For EU15 things are different. They continue to exhibit a positive association with success that resembles unitary elasticity for total publications. For international collaboration, albeit of lesser magnitude, a statistically significant effect of around

0.03% on successful applicants is present, along with a less significant effect of the same magnitude on secured funding. Also, for secured funding, we detect a positive effect within the range of 0.3%-0,4% which is most of the times statistically significant. All years have explanatory power over success for EU15 and this is in line with the negative trend present throughout the duration of FP7 when the base year used is 2007.

Table 5-14: Research input and output effect on success in FP7 for EU15 member states, 2007-2013

	I	II	III	IV	V	VI	VII	VIII
Explanatory variables	**Coefficients**							
Total Publications	0.991***	0.886***	0.958***	0.827***	0.940**	0.819*	0.907	0.759
Citations	-0.487***	-0.455**	-0.363**	-0.372	-0.263	-0.160	-0.138	-0.077
International Collaboration (% of total)	0.033***	0.032***	0.029**	0.029**	0.033*	0.033*	0.029	0.029
Research Intensity (%)	-0.066	-0.028	-0.126	-0.011	0.396**	0.312	0.336**	0.329*
R&D personnel (1000 residents)	-0.014	-0.203	0.041	-0.372	-0.733	-0.650	-0.678	-0.819
Patents	-0.113	-0.146	-0.056	-0.147	-0.448***	-0.419***	-0.391**	-0.420***
y2008	-0.591***	-0.569***	-0.599***	-0.559***	-0.610***	-0.600***	-0.619***	-0.591***
y2009	-0.512***	-0.467***	-0.523***	-0.445***	-0.389***	-0.361***	-0.399***	-0.339***
y2010	-0.647***	-0.588***	-0.658***	-0.557***	-0.535***	-0.505***	-0.545***	-0.473***
y2011	-0.697***	-0.629***	-0.677***	-0.557***	-0.444**	-0.419**	-0.423*	-0.347*
y2012	-0.741***	-0.650***	-0.708***	-0.562**	-0.337	-0.293	-0.304	-0.205
y2013	-1.292***	-1.179***	-1.239***	-1.071***	-0.724**	-0.652**	-0.671*	-0.543
Constant	1.729	3.577	-0.837	3.542	4.248	4.014	1.682	3.979
Observations	105	105	105	105	105	105	105	105
R-squared (within)	0.6954	0.6925	0.6730	0.6678	0.5179	0.5155	0.5120	0.5169
R-squared (between)	0.0639	0.0287	0.3953	0.1023	0.0544	0.3248	0.0030	0.3419
R-squared (overall)	0.0012	0.0810	0.4107	0.1566	0.0907	0.1824	0.0079	0.3556
F test	188.79	102.90	302.83	1306.90	254.53	149.56	177.15	214.49

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: Fixed Effects OLS of log of applicants in retained proposals against logs of 3-year moving average per capita variables, II: Fixed Effects OLS of log of applicants in retained proposals against logs of 3-year moving average variables, III: Fixed Effects OLS of log of per capita applicants in retained proposals against logs of 3-year moving average per capita variables, IV: Fixed Effects OLS of log of per capita applicants in retained proposals against logs of 3-year moving average variables, V: Fixed Effects OLS of log of EC funding secured against logs of 3-year moving average per capita variables, VI: Fixed Effects OLS of log of EC funding secured against logs of 3-year moving average variables, VII: Fixed Effects OLS of log of per capita EC funding secured against logs of 3-year moving average per capita variables, VIII: Fixed Effects OLS of log of per capita EC funding secured against logs of 3-year moving average variables.
(c) Cluster-robust errors used in all models (reported in detailed tables 5-22 & 5-23 in the Appendix)
(d) Research Intensity and International Collaboration are expressed as a percentage.
(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

When success rates are the dependent variables of concern we compare the findings for EU13 and EU15 to obtain a side-by-side view of the differences. We see that for EU13 there exists a very interesting pattern: for the success rate of applicants,

citations and FTE R&D personnel matter positively and a negative trend is detected for patents. The former finding is in accord with our theoretical model where the quality of proposals is what shapes success and citations form the best way to proxy this quality. This finding is also in line with our assertion that researchers from EU13 are likely to focus on submitting a few and high quality proposals. Furthermore, the fact that citations are jointly statistically significant with R&D personnel, documents our theoretical approach. On the other hand, EU15 present a different pattern whereby R&D intensity seems to play a role in determining the success rate in the amount of money granted from FP7, to which both R&D personnel and patents are negatively associated. We can explain this difference by stating that the primary role in research proposals is played by countries in EU13 and institutions from EU15 are most of the times participating as followers. This is substantiated by the relevant final monitoring report of FP7 (European Commission, 2015).

Table 5-15: Research input and output effect on success rates of EU15 and EU13 member states in FP7, 2007-2013

	I	II	III	IV	V	VI	VII	VIII
Explanatory variables	**Coefficients (EU15)**				**Coefficients (EU13)**			
Total Publications	-0.144	-0.157	-0.427	-0.424	-0.549	-0.739*	0.780	1.266
Citations	-0.019	-0.070	0.466	0.502	0.544**	0.509**	0.011	-0.511
International Collaboration (% of total)	-0.003	0.000	-0.017	-0.013	-0.007	-0.009	-0.022	-0.010
Research Intensity (%)	0.024	0.052	0.689***	0.556**	-0.204**	-0.172**	-0.393	-0.317
R&D personnel (1000 residents)	-0.265**	-0.424**	-1.027**	-0.771	0.941***	0.926***	1.306*	1.342*
Patents	-0.178***	-0.220***	-0.535***	-0.474***	-0.211**	-0.178**	-0.226	-0.505
y2008	0.039	0.057	-0.030	-0.043	-0.015	-0.004	-0.149	-0.206*
y2009	0.122	0.155	0.129	0.112	0.112	0.129	-0.105	-0.239
y2010	0.264**	0.299***	0.184	0.147	0.208	0.230	-0.168	-0.388
y2011	0.190	0.224	0.348	0.287	0.185	0.210	-0.153	-0.476
y2012	0.121	0.149	0.231	0.157	0.280	0.305	-0.392	-0.840
y2013	0.140	0.163	0.585*	0.512	0.348	0.370	-0.449	-1.063
Observations	105	105	105	105	91	91	91	91
Wald Chi2 test	179.05	819.39	187.66	507.98	8045.63	529,338	508.93	1257.08
Log Pseudolikelihood	-26.737	-26.732	-19.896	-19.906	-26.500	-26.501	-24.192	-24.190

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: Fixed Effects Poisson of success rate of applicants against logs of 3-year moving average per capita variables, II: Fixed Effects Poisson of success rate of applicants against logs of 3-year moving average variables, III: Fixed Effects Poisson of success rate in secured funding against logs of 3-year moving average per capita variables, IV: Fixed Effects Poisson of success rate in secured funding against logs of 3-year moving average variables, V: Fixed Effects Poisson of success rate of applicants against logs of 3-year moving average per capita variables, VI: Fixed Effects Poisson of success rate of applicants against logs of 3-year moving average variables, VII: Fixed Effects Poisson of success rate in secured funding against logs of 3-year moving average variables, VIII: Fixed Effects Poisson of success rate in secured funding against logs of 3-year moving average per capita variables.
(c) Cluster-robust errors used in all models (reported in detailed tables 5-24 & 5-29 in the Appendix).
(d) Research Intensity and International Collaboration are expressed as a percentage.
(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.
(f) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

5.7 Conclusions

The present chapter has contributed to the existing literature on research funding applications and success by investigating this process in FP7 through an empirical study at the country level for the EU28 member states. The foundations of this analysis relied heavily upon the emerging field of the economics of science and its importance to the process of economic growth.

No previous study had explored the dynamics of research funding allocation at the country (macroeconomic) level. Only a few studies have dealt with FP7 at the

institution level, or in other related directions, along with a number of technical reports prepared by European Union authorities. No economic study exists with respect to the potential determinants of applications and success of EU countries in securing FP funds, FP7 or otherwise.

The methodology for approaching these gaps traced in the literature relied on econometric methods that accounted for potential forms of endogeneity of the explanatory variables, such as double causality and simultaneity. We used lagged independent variables to handle double causality and the fixed effects method to treat simultaneity.

Past research output in Science and Technology, both in absolute and per capita terms, seems to have a noticeable effect upon applicants of countries in FP7. The magnitude of this effect seems to be in line with the general notion since a change of 1% in total publications produces a positive effect of around 1% on the number of participants or money asked from FP7. This proportional association shows that FP7 applications are unit elastic to changes in research output. Research output in Social Sciences and Arts and Humanities does not appear to be significant in any setting of the model. Moreover, research input variables exhibit zero statistical significance in all findings on FP7 applications of the EU28.

For FP7 success the results are the same when the dependent variable is the number of successful applicants. When the amount of funding secured is analysed instead, all explanatory variables are insignificant. A potential reason for this peculiarity may be that secured funding depends on the budget claimed in each successful proposal which may be exogenous to the evaluation decision and to the competence of the applicant. Countries that lack research capacity may still secure higher funding than their

stronger counterparts if they select successful consortia and negotiate with the coordinators of proposals for more money. The choice of budget size is not represented by the explanatory variables of our model and inverse effects are possible if applicants with low research capacity apply for larger budgets and vice-versa. Such opposing forces may be responsible for the low statistical insignificance of some of the explanatory variables on the dependent variable. This budget choice effect is likely to hold for both FP7 applications and success.

When it comes to success rates the results are quite different. Science and technology publications demonstrate a slight tendency to affect the success rate negatively whereas citations play a decisive positive role when the dependent variable is the success rate in money applied for. The latter finding is aligned with intuition and our theoretical model where it suggests that the quality of the applicants should be prominent in shaping the success rate of a country in the FP7 process.

However, the fact that many explanatory variables were not important for determining participation and success in FP7 led us to further extend the analysis. We separated countries into strong and weak based on their R&D capacity as previously done by the EC and we re-estimated our models for each of the groups. This revealed new trends responsible for the overall results discussed above. The findings for weak countries maintain the importance of the determinants for participation whereas for strong countries they do not apply to the same extent. Specifically, total publications are still important for the number of applicants whereas international collaboration does not matter for strong countries. This finding is not unexpected. The collaboration factor is more important for weak R&D countries that seek for strategic partnerships with

stronger counterparts to maximise the chances of getting funded. On the other hand, strong R&D countries are already leaders and need not behave this way.

A profoundly interesting finding is that citations play a crucial role for the success rates of the applicants from strong countries in FP7. This perhaps constitutes evidence that quality of research at the aggregate level matters for the FP success of countries. For the weak countries we observe the paradox of R&D personnel and R&D intensity to have a negative effect on success rates. This can be explained only in the context of leaders and followers, that is, the quality of research personnel of research leading countries matters as expressed by citations but not the quantity.

In addition, R&D personnel appear to be insignificant in the vast majority of the findings for both strong and weak countries. A reason could be the proportion of time allocated to writing proposals. We use the FTE R&D personnel as proxy of the time devoted to writing research proposals assuming that in all countries researchers dedicate the same proportion of their time to this activity. The variance in this proportion is not captured by the model. R&D intensity could serve as a supplementary measure to account for its magnitude. The rationale is that the higher the R&D intensity the higher the commitment to R&D and the greater the national resources devoted to it. Unfortunately, this would cause an ambiguous effect on applicants and success in FPs. The R&D intensity of the (research strong) EU13 indicates that the critical mass of resources is secured and that participation in FP7 is mostly due to the need for large scale research projects or in other words due to an additionality effect. But this is more a matter of choice for the researchers not a necessity. Indeed, we see that R&D intensity affects the FP7 success rate of EU13 negatively and in almost all findings the sign of the coefficient is negative albeit non-significant. Therefore, it

can be argued that the choice of not applying or applying without devoting much effort may prevail over the choice of engaging in large scale research projects.

For the (research weak) EU15 the results are different as their R&D intensity is representative of the need to supplement resources from FP7 funding in order to eventually reach the critical mass. Here a substitution effect may be in place where the lack of national funding, either public or private is substituted with FP7 funding. This tendency seems to play a positive role in their success rates as the coefficient of the R&D intensity is both positive and statistically significant. This difference in motivation among the two groups of countries can explain a significant portion of the non-significance or ambiguity of certain explanatory variables such as R&D personnel and R&D intensity.

In conclusion, the present chapter shows that there are trends for application and success in FP7 across EU countries, albeit complicated to comprehend. Distinguishing between strong and weak countries in research provides a somewhat clearer framework for the association of research output and input with the particulars of FP7 at the country level. It is of paramount importance for the EU to trace these associations and embody essential elements in its strategy to ensure optimisation of research funding allocation. The first step was done with the new "Spreading Excellence and Widening Participation" Action within the new EU FP, which aims to bridge the gap between strong and weak countries in R&D. But there is always room for further improvement and the empirical analysis of FP7 carried out in the present study can be of substantial help to that end.

Our approach reveals a number of limitations. Primarily, we lack data for the quality of international collaboration. Especially for weak R&D countries this factor may be

critical as collaborating with institutions coming from advanced R&D countries could form in many cases the only significant factor that shapes success. Data were not available annually but there were totals for FP7. Including the total would be pointless as time-invariant variables are dropped from estimation in the fixed effects setting.

Drawing on this last remark, not exploiting the between variance in our data is a shortcoming as well. The use of fixed effects has advantages which are nonetheless coupled with the trade-off of losing efficiency in estimation. An alternative solution would be to estimate both fixed and random effects but in our study we abstained from doing so for two reasons: firstly, the Hausman test showed clearly that fixed effects were preferable and secondly because the country effects appear persistent and are shown to be strongly correlated to the explanatory variables. As the random effects approach assumes away this correlation, ignoring this would lead to having a voluminous analysis of questionable findings.

Our study offers fertile ground for further research. We are the first to engage in explaining the effects of R&D inputs and outputs on applications and success in FP7 at the country level. This study could easily be extended to previous FPs as our data concern only the latest programme. For this to be feasible, the EU should be more willing to provide access to the E-Corda database to interested researchers. This would be beneficial for both research community and the EU as very useful conclusions could be extracted for the efficiency of the FPs. This is not the case at present but a number of EU funded projects are currently underway to construct databases for providing information for higher education institutions and funded projects[7]. The information we

[7] For more information see http://risis.eu/

used for the study, although publicly available, had to be extracted from EU documents rather than taken as a ready dataset.

Another possible direction for extending our research could be to undertake our analysis at the institution, or even individual, level. The richness of such datasets would facilitate robustness of potential findings and the interest of involved stakeholders would be immense. These suggestions will become feasible once the appropriate databases become accessible.

5.8 Appendix of Chapter 5

Table 5-16: Research input and output effect on applicants in FP7 by EU28 member states, fixed effects estimates for 2007-2013

Model (see footnote):	**I**		**II**		**III**		**IV**	
Dependent variable:	**Log-applicants**				**Log-applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	0.989***	(0.299)	0.445	(0.382)	0.818**	(0.381)	0.295	(0.442)
Arts and Humanities Publications	0.037	(0.084)	-0.007	(0.142)	-0.031	(0.107)	-0.077	(0.177)
Social Sciences Publications	-0.002	(0.086)	-0.033	(0.186)	0.021	(0.123)	0.008	(0.244)
Citations	-0.398**	(0.182)	-0.013	(0.331)	-0.182	(0.226)	0.203	(0.367)
International Collaboration (% of total)	0.038***	(0.008)	0.015	(0.014)	0.029***	(0.011)	0.005	(0.016)
Research Intensity (%)	-0.029	(0.104)	0.061	(0.156)	-0.001	(0.101)	0.066	(0.154)
R&D personnel (1000 residents)	-0.105	(0.258)	-0.274	(0.245)	-0.205	(0.276)	-0.310	(0.279)
Patents	0.071	(0.066)	0.073	(0.095)	0.072	(0.088)	0.053	(0.113)
GPD per capita in PPP 2005 prices	-0.940**	(0.437)	-1.650**	(0.644)	-0.698	(0.501)	-1.593**	(0.652)
y2008	-0.515***	(0.043)	-0.462***	(0.083)	-0.506***	(0.046)	-0.433***	(0.089)
y2009	-0.374***	(0.086)	-0.233	(0.157)	-0.345***	(0.091)	-0.183	(0.166)
y2010	-0.656***	(0.114)	-0.424**	(0.213)	-0.597***	(0.125)	-0.355	(0.226)
y2011	-0.546***	(0.137)	-0.222	(0.256)	-0.441***	(0.157)	-0.117	(0.275)
y2012	-0.523***	(0.171)	-0.093	(0.332)	-0.370	(0.2)	0.046	(0.354)
y2013	-1.079***	(0.233)	-0.535	(0.419)	-0.869***	(0.271)	-0.356	(0.447)
Constant	12.901***	(4.686)	22.568***	(6.67)	7.862	(6.008)	19.475***	(7.246)
R-squared (within)	0.7908		0.7723		0.7573		0.7479	
R-squared (between)	0.0808		0.0927		0.0633		0.3942	
R-squared (overall)	0.0189		0.0559		0.0247		0.2373	
F test	84.74		170.04		85.42		214.38	
Hausman Test	23.38(FE)		19.86 (FE)		104.76 (FE)		86.64 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of applicants against logs of 3-year moving average per capita variables, II: OLS of log of applicants against logs of 5-year moving average per capita variables, III: OLS of log of applicants per capita against logs of 3-year moving average variables, IV: OLS of log of applicants per capita against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

Table 5-17: Research input and output effect on money applied for in FP7 for EU28 member states, fixed effects estimates of 2007-2013

Model (see footnote):	**I**		**II**		**III**		**IV**	
Dependent variable:	**Log-money applied for**				**Log- money applied for per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	1.192***	(0.398)	0.414	(0.507)	0.939*	(0.468)	0.260	(0.552)
Arts and Humanities Publications	0.086	(0.125)	0.057	(0.211)	0.030	(0.153)	-0.113	(0.243)
Social Sciences Publications	0.056	(0.135)	-0.077	(0.236)	0.080	(0.19)	0.074	(0.298)
Citations	-0.722**	(0.226)	-0.089	(0.471)	-0.475	(0.292)	0.131	(0.523)
International Collaboration (% of total)	0.044**	(0.013)	0.011	(0.019)	0.033*	(0.016)	0.003	(0.018)
Research Intensity (%)	-0.162	(0.136)	0.121	(0.211)	-0.089	(0.14)	0.136	(0.219)
R&D personnel (1000 residents)	0.013	(0.331)	-0.269	(0.377)	-0.173	(0.347)	-0.314	(0.408)
Patents	0.071	(0.1)	-0.079	(0.146)	0.015	(0.13)	-0.130	(0.149)
GPD per capita in PPP 2005 prices	-0.414	(0.568)	-0.855	(0.672)	-0.101	(0.684)	-0.772	(0.682)
y2008	-0.432**	(0.055)	-0.329**	(0.108)	-0.413**	(0.059)	-0.302**	(0.106)
y2009	-0.371**	(0.106)	-0.139	(0.191)	-0.326**	(0.119)	-0.090	(0.193)
y2010	-0.588**	(0.146)	-0.231	(0.264)	-0.508**	(0.166)	-0.164	(0.269)
y2011	-0.619**	(0.199)	-0.139	(0.348)	-0.486*	(0.239)	-0.039	(0.363)
y2012	-0.419*	(0.23)	0.218	(0.438)	-0.232	(0.281)	0.350	(0.456)
y2013	-1.122**	(0.317)	-0.288	(0.549)	-0.866*	(0.382)	-0.116	(0.575)
Constant	6.491	(6.567)	14.700**	(7.393)	2.043	(8.248)	11.924	(8.151)
R-squared (within)	0.6201		0.5844		0.5809		0.5630	
R-squared (between)	0.0668		0.1708		0.0074		0.3581	
R-squared (overall)	0.0201		0.1062		0.0238		0.1919	
F test	45.82		41.50		34.42		34.69	
Hausman Test	n/a		47.14 (FE)		56.25 (FE)		47.14 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of money applied for against logs of 3-year moving average per capita variables, II: OLS of log of money applied for against logs of 5-year moving average per capita variables, III: OLS of log of per capita money applied for against logs of 3-year moving average variables, IV: OLS of log of per capita money applied for against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

Table 5-18: Research input and output effect on successful applicants in FP7 by EU28 member states, fixed effects estimates of 2007-2013

Model (see footnote):	**I**		**II**		**III**		**IV**	
Dependent variable:	**Log-successful applicants**				**Log- successful applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	0.690***	(0.256)	0.264	(0.339)	0.451	(0.321)	0.090	(0.391)
Arts and Humanities Publications	-0.032	(0.112)	-0.063	(0.128)	0.068	(0.139)	-0.057	(0.159)
Social Sciences Publications	0.086	(0.151)	0.004	(0.182)	-0.048	(0.188)	-0.042	(0.223)
Citations	-0.235	(0.198)	0.138	(0.327)	-0.0001	(0.235)	0.368	(0.333)
International Collaboration (% of total)	0.027**	(0.011)	0.004	(0.015)	0.017	(0.013)	-0.007	(0.016)
Research Intensity (%)	-0.090	(0.107)	-0.077	(0.169)	-0.043	(0.103)	-0.020	(0.154)
R&D personnel (1000 residents)	0.147	(0.223)	-0.014	(0.224)	-0.026	(0.261)	-0.140	(0.239)
Patents	-0.073	(0.091)	-0.042	(0.12)	-0.099	(0.096)	-0.100	(0.129)
GPD per capita in PPP 2005 prices	-0.887*	(0.453)	-1.664***	(0.594)	-0.595	(0.503)	-1.542**	(0.627)
y2008	-0.522***	(0.057)	-0.451***	(0.08)	-0.504***	(0.065)	-0.414***	(0.089)
y2009	-0.293***	(0.098)	-0.135	(0.145)	-0.249**	(0.114)	-0.070	(0.153)
y2010	-0.471***	(0.134)	-0.225	(0.203)	-0.394**	(0.155)	-0.137	(0.213)
y2011	-0.444***	(0.167)	-0.110	(0.251)	-0.319	(0.196)	0.016	(0.262)
y2012	-0.449**	(0.212)	-0.013	(0.326)	-0.271	(0.256)	0.151	(0.343)
y2013	-0.989***	(0.281)	-0.450	(0.409)	-0.746**	(0.33)	-0.240	(0.424)
Constant	10.014**	(4.686)	19.746***	(5.86)	5.682	(6.168)	16.993**	(6.698)
R-squared (within)	0.7381		0.7258		0.7164		0.7170	
R-squared (between)	0.3206		0.1422		0.2029		0.5249	
R-squared (overall)	0.1329		0.1011		0.0853		0.3590	
F test	154.77		156.53		120.42		162.47	
Hausman Test	20.08 (FE)		243.76 (FE)		146.71 (FE)		92.65 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of applicants in retained proposals against logs of 3-year moving average per capita variables, II: OLS of log of applicants in retained proposals against logs of 5-year moving average per capita variables, III: OLS of log of per capita applicants in retained proposals against logs of 3-year moving average variables, IV: OLS of log of per capita applicants in retained proposals against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

Table 5-19: Research input and output effect on secured funding in FP7 for EU28 member states, fixed effects estimates of 2007-2013

Model (see footnote):	**I**		**II**		**III**		**V**	
Dependent variable:	**Log-secured funding**				**Log-secured funding per capita**			
Explanatory variables	**Coefficients/standard errors**							
Science and Technology Publications	0.583	(0.41)	0.292	(0.487)	0.330	(0.451)	0.149	(0.502)
Arts and Humanities Publications	0.038	(0.143)	-0.076	(0.184)	-0.035	(0.153)	-0.162	(0.201)
Social Sciences Publications	-0.043	(0.259)	-0.118	(0.337)	-0.006	(0.272)	-0.060	(0.362)
Citations	0.259	(0.319)	0.563	(0.573)	0.521*	(0.304)	0.761	(0.507)
International Collaboration (%)	0.016	(0.019)	-0.010	(0.026)	0.007	(0.019)	-0.018	(0.026)
Research Intensity (%)	0.111	(0.242)	0.122	(0.378)	0.103	(0.203)	0.131	(0.336)
R&D personnel (1000 residents)	0.054	(0.471)	-0.052	(0.492)	-0.016	(0.494)	-0.138	(0.5)
Patents	-0.285***	(0.137)	-0.252	(0.183)	-0.279***	(0.11)	-0.276	(0.182)
GPD per capita in PPP 2005 prices	-0.952*	(0.554)	-1.660***	(0.796)	-0.631	(0.52)	-1.510*	(0.848)
y2008	-0.472***	(0.094)	-0.394***	(0.125)	-0.460***	(0.09)	-0.371***	(0.129)
y2009	-0.218	(0.143)	-0.058	(0.217)	-0.179	(0.136)	-0.015	(0.223)
y2010	-0.351	(0.221)	-0.111	(0.345)	-0.281	(0.212)	-0.053	(0.351)
y2011	-0.226	(0.256)	0.093	(0.421)	-0.110	(0.244)	0.181	(0.425)
y2012	-0.067	(0.339)	0.333	(0.536)	0.106	(0.325)	0.452	(0.535)
y2013	-0.406	(0.435)	0.059	(0.678)	-0.162	(0.41)	0.217	(0.664)
Constant	7.198	(6.251)	15.846*	(8.826)	1.080	(8.015)	12.036	(11.226)
R-squared (within)	0.5180		0.4919		0.5148		0.4945	
R-squared (between)	0.0197		0.0492		0.0055		0.2231	
R-squared (overall)	0.0052		0.0351		0.0128		0.1666	
F test	63.27		34.24		59.59		53.56	
Hausman Test	26.59 (FE)		6.78 (RE)		66.06 (FE)		55.21 (FE)	

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: OLS of log of EC funding secured against logs of 3-year moving average per capita variables, II: OLS of log of EC funding secured against logs of 5-year moving average per capita variables, III: OLS of log of per capita EC funding secured against logs of 3-year moving average variables, IV: OLS of log of per capita EC funding secured against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) Observations: 196

Table 5-20: Research input and output effect on applicants of EU15 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of applicants**				**Log of applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	1.138***	0.835*	1.044***	0.641	1.104***	0.769	0.985***	0.519
	(0.325)	(0.469)	(0.295)	(0.478)	(0.324)	(0.568)	(0.316)	(0.581)
Citations	-0.492	-0.272	-0.407	-0.074	-0.367	-0.108	-0.324	0.112
	(0.335)	(0.483)	(0.327)	(0.517)	(0.332)	(0.538)	(0.337)	(0.585)
International Collaboration (%)	0.037***	0.028*	0.033***	0.02	0.033***	0.021	0.030***	0.011
	(0.009)	(0.016)	(0.008)	(0.018)	(0.009)	(0.021)	(0.009)	(0.022)
Research Intensity (%)	-0.081	0.011	-0.072	0.032	-0.141	-0.066	-0.054	0.027
	(0.124)	(0.221)	(0.11)	(0.238)	(0.108)	(0.22)	(0.105)	(0.223)
R&D personnel (1000 residents)	0.158	0.209	0.132	0.236	0.213	0.252	-0.037	0.175
	(0.361)	(0.404)	(0.397)	(0.492)	(0.393)	(0.452)	(0.45)	(0.521)
Patents	0.05	0.043	0.056	0.023	0.107	0.087	0.055	0.024
	(0.077)	(0.13)	(0.09)	(0.139)	(0.086)	(0.146)	(0.099)	(0.147)
y2008	-0.621***	-0.654***	-0.615***	-0.628***	-0.629***	-0.650***	-0.605***	-0.608***
	(0.054)	(0.084)	(0.051)	(0.08)	(0.051)	(0.095)	(0.05)	(0.091)
y2009	-0.614***	-0.640***	-0.600***	-0.597***	-0.625***	-0.639***	-0.579***	-0.567***
	(0.106)	(0.147)	(0.099)	(0.143)	(0.1)	(0.168)	(0.1)	(0.164)
y2010	-0.895***	-0.894***	-0.870***	-0.836***	-0.906***	-0.895***	-0.839***	-0.798***
	(0.147)	(0.193)	(0.135)	(0.185)	(0.14)	(0.219)	(0.136)	(0.213)
y2011	-0.857***	-0.830***	-0.820***	-0.754***	-0.837***	-0.797***	-0.749***	-0.674***
	(0.193)	(0.235)	(0.175)	(0.223)	(0.182)	(0.259)	(0.182)	(0.257)
y2012	-0.827***	-0.755**	-0.763***	-0.645**	-0.794***	-0.709**	-0.675***	-0.543
	(0.234)	(0.311)	(0.211)	(0.296)	(0.223)	(0.349)	(0.221)	(0.343)
y2013	-1.407***	-1.261***	-1.316***	-1.116***	-1.354***	-1.198***	-1.208***	-0.987**
	(0.302)	(0.414)	(0.274)	(0.401)	(0.291)	(0.463)	(0.289)	(0.462)
Constant	0.661	0.772	-0.24	-0.679	-1.905	-1.67	-0.275	-2.045
	(3.337)	(3.878)	(4.473)	(5.583)	(3.793)	(4.227)	(5.198)	(5.767)
R-squared (within)	0.7980	0.7621	0.7954	0.7633	0.7687	0.7321	0.7537	0.7274
R-squared (between)	0.0691	0.0455	0.7842	0.8039	0.5184	0.4760	0.2815	0.3564
R-squared (overall)	0.0189	0.0077	0.7828	0.7976	0.5415	0.5004	0.1688	0.2507
F test	76.00	103.13	84.48	143.32	81.05	102.55	116.14	170.39

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of applicants against logs of 3-year moving average per capita variables, II: Log of applicants against logs of 5-year moving average per capita variables, III: Log of applicants against logs of 3-year moving average variables, IV: Log of applicants against logs of 5-year moving average variables, V: Log of applicants per capita against logs of 3-year moving average per capita variables, VI: Log of applicants per capita against logs of 5-year moving average per capita variables, VII: Log of applicants per capita against logs of 3-year moving average variables, VIII: Log of applicants per capita against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

(f) Observations: 105

Table 5-21: Research input and output effect on money applied for by EU15 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of money applied for**				**Log of money applied for per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	1.309***	0.445	1.200***	0.259	1.276***	0.379	1.141**	0.137
	(0.352)	(0.645)	(0.41)	(0.624)	(0.426)	(0.72)	(0.49)	(0.71)
Citations	-0.756**	0.022	-0.761**	0.174	-0.632*	0.186	-0.678*	0.36
	(0.327)	(0.638)	(0.354)	(0.65)	(0.365)	(0.703)	(0.387)	(0.729)
International Collaboration (%)	0.043***	0.011	0.042***	0.006	0.039**	0.004	0.038**	-0.003
	(0.014)	(0.022)	(0.016)	(0.022)	(0.017)	(0.025)	(0.018)	(0.024)
Research Intensity (%)	-0.22	0.143	-0.109	0.227	-0.280*	0.066	-0.092	0.222
	(0.136)	(0.317)	(0.122)	(0.291)	(0.167)	(0.361)	(0.162)	(0.31)
R&D personnel (1000 residents)	0.213	0.173	-0.155	0.058	0.268	0.216	-0.324	-0.003
	(0.544)	(0.548)	(0.551)	(0.536)	(0.581)	(0.609)	(0.595)	(0.563)
Patents	0.041	-0.141	-0.035	-0.214	0.098	-0.097	-0.036	-0.213
	(0.099)	(0.204)	(0.124)	(0.206)	(0.115)	(0.218)	(0.135)	(0.209)
y2008	-0.520***	-0.466***	-0.487***	-0.431***	-0.528***	-0.462***	-0.477***	-0.411***
	(0.064)	(0.127)	(0.064)	(0.113)	(0.063)	(0.136)	(0.061)	(0.119)
y2009	-0.448***	-0.32	-0.385***	-0.255	-0.458***	-0.319	-0.364***	-0.224
	(0.105)	(0.218)	(0.113)	(0.199)	(0.106)	(0.234)	(0.113)	(0.212)
y2010	-0.676***	-0.458*	-0.592***	-0.373	-0.687***	-0.459	-0.561***	-0.335
	(0.107)	(0.276)	(0.121)	(0.246)	(0.109)	(0.297)	(0.128)	(0.266)
y2011	-0.709***	-0.409	-0.605***	-0.308	-0.688***	-0.375	-0.533***	-0.227
	(0.129)	(0.348)	(0.165)	(0.315)	(0.135)	(0.37)	(0.203)	(0.352)
y2012	-0.487***	-0.055	-0.358*	0.081	-0.454***	-0.009	-0.271	0.183
	(0.168)	(0.462)	(0.215)	(0.422)	(0.169)	(0.49)	(0.249)	(0.462)
y2013	-1.235***	-0.628	-1.085***	-0.459	-1.181***	-0.565	-0.977***	-0.331
	(0.2)	(0.574)	(0.28)	(0.534)	(0.211)	(0.613)	(0.332)	(0.593)
Constant	-0.273	0.359	3.156	1.039	-2.839	-2.083	3.121	-0.327
	(5.033)	(5.632)	(5.835)	(6.338)	(5.669)	(6.43)	(6.38)	(6.759)
R-squared (within)	0.6023	0.5477	0.5920	0.5510	0.5773	0.5294	0.5611	0.5312
R-squared (between)	0.0695	0.0330	0.3096	0.8311	0.5597	0.3289	0.0206	0.2155
R-squared (overall)	0.0171	0.0762	0.3295	0.7733	0.5618	0.3500	0.0698	0.0847
F test	90.67	144.86	60.59	107.83	61.80	340.57	47.58	137.77

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of money applied for against logs of 3-year moving average per capita variables, II: Log of money applied for against logs of 5-year moving average per capita variables, III: Log of money applied for against logs of 3-year moving average variables, IV: Log of money applied for against logs of 5-year moving average variables, V: Log of per capita money applied for against logs of 3-year moving average per capita variables, VI: Log of per capita money applied for against logs of 5-year moving average per capita variables, VII: Log of per capita money applied for against logs of 3-year moving average variables, VIII: Log of per capita money applied for against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

(f) Observations: 105

Table 5-22: Research input and output effect on successful applicants for EU15 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of successful applicants**				**Log of successful applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	0.991***	0.757	0.886***	0.601	0.958***	0.691	0.827***	0.479
	(0.203)	(0.476)	(0.228)	(0.469)	(0.218)	(0.562)	(0.277)	(0.563)
Citations	-0.487***	-0.313	-0.455**	-0.195	-0.363**	-0.149	-0.372	-0.009
	(0.164)	(0.508)	(0.195)	(0.531)	(0.183)	(0.555)	(0.23)	(0.576)
International Collaboration (%)	0.033***	0.022	0.032***	0.017	0.029**	0.015	0.029**	0.009
	(0.01)	(0.017)	(0.011)	(0.018)	(0.011)	(0.021)	(0.012)	(0.021)
Research Intensity (%)	-0.066	-0.051	-0.028	0.048	-0.126	-0.128	-0.011	0.043
	(0.127)	(0.217)	(0.144)	(0.232)	(0.123)	(0.227)	(0.128)	(0.214)
R&D personnel (1000 residents)	-0.014	0.141	-0.203	0.001	0.041	0.185	-0.372	-0.06
	(0.386)	(0.411)	(0.457)	(0.476)	(0.424)	(0.462)	(0.506)	(0.503)
Patents	-0.113	-0.1	-0.146	-0.18	-0.056	-0.056	-0.147	-0.179
	(0.096)	(0.145)	(0.104)	(0.15)	(0.111)	(0.165)	(0.108)	(0.16)
y2008	-0.591***	-0.619***	-0.569***	-0.585***	-0.599***	-0.615***	-0.559***	-0.566***
	(0.058)	(0.082)	(0.066)	(0.079)	(0.056)	(0.089)	(0.067)	(0.091)
y2009	-0.512***	-0.535***	-0.467***	-0.473***	-0.523***	-0.534***	-0.445***	-0.442***
	(0.08)	(0.145)	(0.09)	(0.138)	(0.077)	(0.164)	(0.098)	(0.162)
y2010	-0.647***	-0.650***	-0.588***	-0.569***	-0.658***	-0.651***	-0.557***	-0.531**
	(0.136)	(0.216)	(0.141)	(0.2)	(0.132)	(0.238)	(0.148)	(0.227)
y2011	-0.697***	-0.688***	-0.629***	-0.594**	-0.677***	-0.655**	-0.557***	-0.513**
	(0.153)	(0.25)	(0.159)	(0.231)	(0.15)	(0.271)	(0.172)	(0.261)
y2012	-0.741***	-0.699**	-0.650***	-0.574*	-0.708***	-0.653*	-0.562**	-0.472
	(0.189)	(0.354)	(0.194)	(0.332)	(0.192)	(0.391)	(0.229)	(0.383)
y2013	-1.292***	-1.186***	-1.179***	-1.033**	-1.239***	-1.122**	-1.071***	-0.905*
	(0.226)	(0.437)	(0.23)	(0.408)	(0.227)	(0.484)	(0.265)	(0.469)
Constant	1.729	1.044	3.577	2.08	-0.837	-1.398	3.542	0.714
	(3.728)	(4.294)	(5.191)	(5.952)	(4.157)	(4.661)	(5.713)	(6.007)
R-squared (within)	0.6954	0.6567	0.6925	0.6594	0.6730	0.6400	0.6678	0.6398
R-squared (between)	0.0639	0.0159	0.0287	0.6933	0.3953	0.3425	0.1023	0.4360
R-squared (overall)	0.0012	0.0081	0.0810	0.6482	0.4107	0.3503	0.1566	0.1862
F test	188.79	637.44	102.90	696.83	302.83	154.44	1306.90	242.85

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of applicants in retained proposals against logs of 3-year moving average per capita variables, II: Log of applicants in retained proposals against logs of 5-year moving average per capita variables, III: Log of applicants in retained proposals against logs of 3-year moving average variables, IV: Log of applicants in retained proposals against logs of 5-year moving average variables, V: Log of per capita applicants in retained proposals against logs of 3-year moving average per capita variables, VI: Log of per capita applicants in retained proposals against logs of 5-year moving average per capita variables, VII: Log of per capita applicants in retained proposals against logs of 3-year moving average variables, VIII: Log of per capita applicants in retained proposals against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

(f) Observations: 105

Table 5-23: Research input and output effect on secured funding for EU15 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of secured funding**				**Log of secured funding per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	0.940**	1.096	0.819*	1.097	0.907	1.03	0.759	0.975
	(0.476)	(0.78)	(0.446)	(0.768)	(0.554)	(0.874)	(0.544)	(0.848)
Citations	-0.263	-0.644	-0.16	-0.63	-0.138	-0.48	-0.077	-0.443
	(0.434)	(0.805)	(0.506)	(0.833)	(0.443)	(0.822)	(0.514)	(0.828)
International Collaboration (%)	0.033*	0.031	0.033*	0.036	0.029	0.024	0.029	0.027
	(0.019)	(0.028)	(0.019)	(0.027)	(0.022)	(0.031)	(0.022)	(0.03)
Research Intensity (%)	0.396**	0.658**	0.312	0.627**	0.336**	0.580*	0.329*	0.623**
	(0.19)	(0.332)	(0.222)	(0.304)	(0.156)	(0.314)	(0.185)	(0.28)
R&D personnel (1000 residents)	-0.733	-0.735	-0.65	-0.779	-0.678	-0.691	-0.819	-0.839
	(0.638)	(0.604)	(0.775)	(0.633)	(0.659)	(0.603)	(0.777)	(0.643)
Patents	-0.448***	-0.495**	-0.419***	-0.521***	-0.391**	-0.451*	-0.420***	-0.520**
	(0.147)	(0.227)	(0.149)	(0.199)	(0.153)	(0.247)	(0.144)	(0.213)
y2008	-0.610***	-0.661***	-0.600***	-0.661***	-0.619***	-0.658***	-0.591***	-0.642***
	(0.14)	(0.129)	(0.138)	(0.109)	(0.133)	(0.128)	(0.131)	(0.109)
y2009	-0.389***	-0.452**	-0.361***	-0.439***	-0.399***	-0.450**	-0.339***	-0.409**
	(0.133)	(0.188)	(0.114)	(0.158)	(0.126)	(0.205)	(0.113)	(0.178)
y2010	-0.535***	-0.610**	-0.505***	-0.601**	-0.545***	-0.611*	-0.473***	-0.562**
	(0.189)	(0.292)	(0.164)	(0.258)	(0.19)	(0.32)	(0.17)	(0.283)
y2011	-0.444**	-0.563	-0.419**	-0.562*	-0.423*	-0.53	-0.347*	-0.481
	(0.216)	(0.377)	(0.177)	(0.333)	(0.223)	(0.406)	(0.193)	(0.359)
y2012	-0.337	-0.499	-0.293	-0.488	-0.304	-0.453	-0.205	-0.386
	(0.302)	(0.501)	(0.248)	(0.44)	(0.317)	(0.543)	(0.282)	(0.481)
y2013	-0.724**	-0.905	-0.652**	-0.892	-0.671*	-0.842	-0.543	-0.763
	(0.366)	(0.647)	(0.321)	(0.592)	(0.383)	(0.694)	(0.354)	(0.63)
Constant	4.248	6.667	4.014	7.867	1.682	4.225	3.979	6.501
	(6.315)	(5.978)	(8.886)	(7.564)	(6.096)	(5.651)	(8.56)	(7.355)
R-squared (within)	0.5179	0.4787	0.5155	0.4808	0.5120	0.4743	0.5169	0.4797
R-squared (between)	0.0544	0.0690	0.3248	0.5976	0.0030	0.2708	0.3419	0.2796
R-squared (overall)	0.0907	0.0989	0.1824	0.4424	0.0079	0.1079	0.3556	0.2881
F test	254.53	52.61	149.56	61.29	177.15	27.63	214.49	35.71

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: Log of EC funding secured against logs of 3-year moving average per capita variables, II: Log of EC funding secured against logs of 5-year moving average per capita variables, III: Log of EC funding secured against logs of 3-year moving average variables, IV: Log of EC funding secured against logs of 5-year moving average variables, V: Log of per capita EC funding secured against logs of 3-year moving average per capita variables, VI: Log of per capita EC funding secured against logs of 5-year moving average per capita variables, VII: Log of per capita EC funding secured against logs of 3-year moving average variables, VIII: Log of per capita EC funding secured against logs of 5-year moving average variables.
(c) Cluster-robust errors used in all models (in parentheses)
(d) Research Intensity and International Collaboration are expressed as a percentage
(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.
(f) Observations: 105

Table 5-24: Research input and output effect on success rates of EU15 member states in FP7, fixed effects Poisson estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Success rate of applicants**				**Success rate of secured funding**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	-0.144	-0.107	-0.157	-0.061	-0.427	0.61	-0.424	0.832
	(0.319)	(0.133)	(0.305)	(0.164)	(0.383)	(0.416)	(0.329)	(0.532)
Citations	-0.019	-0.035	-0.07	-0.121	0.466	-0.704	0.502	-0.904
	(0.339)	(0.187)	(0.341)	(0.216)	(0.392)	(0.61)	(0.415)	(0.716)
International Collaboration (%)	-0.003	-0.007	0.0001	-0.002	-0.017	0.012	-0.013	0.025
	(0.012)	(0.007)	(0.012)	(0.007)	(0.014)	(0.022)	(0.011)	(0.024)
Research Intensity (%)	0.024	-0.037	0.052	0.038	0.689***	0.612	0.556**	0.538
	(0.054)	(0.141)	(0.061)	(0.134)	(0.219)	(0.436)	(0.234)	(0.379)
R&D personnel (1000 residents)	-0.265**	-0.164	-0.424**	-0.325**	-1.027**	-0.965	-0.771	-0.981*
	(0.125)	(0.168)	(0.182)	(0.155)	(0.479)	(0.623)	(0.525)	(0.552)
Patents	-0.178***	-0.169**	-0.220***	-0.231***	-0.535***	-0.379*	-0.474***	-0.353*
	(0.05)	(0.076)	(0.052)	(0.082)	(0.137)	(0.212)	(0.16)	(0.21)
y2008	0.039	0.049	0.057	0.054	-0.03	-0.127	-0.043	-0.162*
	(0.072)	(0.054)	(0.073)	(0.059)	(0.134)	(0.111)	(0.131)	(0.09)
y2009	0.122	0.132**	0.155	0.150**	0.129	-0.063	0.112	-0.112
	(0.101)	(0.059)	(0.099)	(0.07)	(0.148)	(0.128)	(0.139)	(0.126)
y2010	0.264**	0.273***	0.299***	0.292***	0.184	-0.111	0.147	-0.183
	(0.118)	(0.044)	(0.109)	(0.043)	(0.176)	(0.153)	(0.156)	(0.166)
y2011	0.19	0.187***	0.224	0.203***	0.348	-0.074	0.287	-0.173
	(0.159)	(0.052)	(0.15)	(0.068)	(0.215)	(0.193)	(0.204)	(0.227)
y2012	0.121	0.112	0.149	0.121	0.231	-0.369	0.157	-0.499*
	(0.2)	(0.104)	(0.187)	(0.12)	(0.288)	(0.241)	(0.248)	(0.263)
y2013	0.14	0.128	0.163	0.128	0.585*	-0.211	0.512	-0.379
	(0.273)	(0.098)	(0.262)	(0.123)	(0.323)	(0.34)	(0.317)	(0.413)
Wald Chi2 test	179.05	1211.60	819.39	554.85	187.66	211.56	507.98	199.54
Log Pseudolikelihood	-26.737	-26.737	-26.732	-26.734	-19.896	-19.932	-19.906	-19.934

Notes:
*(a) *** p<0.01, ** p<0.05, * p<0.1*
(b) I: Success rate of applicants against logs of 3-year moving average per capita variables, II: Success rate of applicants against logs of 5-year moving average per capita variables, III: Success rate of applicants against logs of 3-year moving average variables, IV: Success rate of applicants against logs of 5-year moving average variables, V: Success rate in secured funding against logs of 3-year moving average per capita variables, VI: Success rate in secured funding against logs of 5-year moving average per capita variables, VII: Success rate in secured funding against logs of 3-year moving average variables, VIII: Success rate in secured funding against logs of 5-year moving average variables.
(c) Cluster-robust errors used in all models (in parentheses)
(d) Research Intensity and International Collaboration are expressed as a percentage and not in per capita terms
(e) EU15 are the following countries with low investment in RTDI according to European Commission (2013): Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.
(f) Observations: 105

Table 5-25: Research input and output effect on applicants of EU13 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of applicants**				**Log of applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	2.508*	4.342***	2.519**	4.831***	2.479*	4.232***	2.414**	4.630***
	(1.451)	(1.608)	(1.271)	(1.676)	(1.38)	(1.641)	(1.217)	(1.717)
Citations	-1.131	-2.542**	-1.094	-2.780**	-1.163	-2.565**	-1.087	-2.735**
	(1.235)	(1.12)	(1.128)	(1.236)	(1.164)	(1.086)	(1.064)	(1.227)
International Collaboration (%)	0.009	0.015	0.016	0.033	0.005	0.005	0.011	0.023
	(0.035)	(0.045)	(0.032)	(0.053)	(0.035)	(0.045)	(0.032)	(0.053)
Research Intensity (%)	0.079	0.14	0.002	0.008	0.076	0.153	0.01	0.026
	(0.155)	(0.194)	(0.146)	(0.159)	(0.178)	(0.216)	(0.167)	(0.183)
R&D personnel (1000 residents)	-0.788**	-0.981**	-0.522	-0.672	-0.695**	-0.874**	-0.444	-0.57
	(0.32)	(0.402)	(0.366)	(0.425)	(0.322)	(0.391)	(0.369)	(0.423)
Patents	0.377	0.276	0.342	0.12	0.373	0.264	0.331	0.108
	(0.3)	(0.336)	(0.255)	(0.374)	(0.305)	(0.343)	(0.265)	(0.388)
y2008	-0.592***	-0.748***	-0.614***	-0.842***	-0.595***	-0.723***	-0.608***	-0.809***
	(0.137)	(0.188)	(0.119)	(0.225)	(0.13)	(0.193)	(0.116)	(0.232)
y2009	-0.446	-0.794**	-0.490*	-0.960**	-0.45	-0.759**	-0.479*	-0.907**
	(0.302)	(0.352)	(0.264)	(0.414)	(0.287)	(0.361)	(0.254)	(0.427)
y2010	-0.855*	-1.384***	-0.912**	-1.611***	-0.860*	-1.342***	-0.894**	-1.543**
	(0.462)	(0.503)	(0.408)	(0.595)	(0.439)	(0.513)	(0.392)	(0.613)
y2011	-0.81	-1.507**	-0.873	-1.801**	-0.828	-1.469**	-0.86	-1.727**
	(0.666)	(0.673)	(0.592)	(0.795)	(0.63)	(0.683)	(0.565)	(0.815)
y2012	-1.025	-1.897**	-1.091	-2.269**	-1.049	-1.855**	-1.074	-2.177**
	(0.919)	(0.878)	(0.824)	(1.036)	(0.867)	(0.887)	(0.783)	(1.06)
y2013	-1.823	-2.931***	-1.898*	-3.388**	-1.854	-2.886**	-1.874*	-3.278**
	(1.273)	(1.127)	(1.143)	(1.323)	(1.199)	(1.132)	(1.083)	(1.348)
Constant	6.148	9.403	-0.164	1.633	3.231	7.076	-2.629	-0.503
	(7.473)	(7.46)	(7.389)	(7.66)	(7.423)	(7.309)	(7.374)	(7.641)
R-squared (within)	0.8828	0.8782	0.8916	0.8923	0.8813	0.8755	0.8880	0.8874
R-squared (between)	0.1099	0.0523	0.8543	0.9481	0.0738	0.0006	0.7703	0.8456
R-squared (overall)	0.0370	0.0023	0.8454	0.9285	0.1628	0.0757	0.4889	0.5627
F test	264.98	2656.07	1450.67	49347.55	409.18	3162.77	2755.40	18970.55

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of applicants against logs of 3-year moving average per capita variables, II: Log of applicants against logs of 5-year moving average per capita variables, III: Log of applicants against logs of 3-year moving average variables, IV: Log of applicants against logs of 5-year moving average variables, V: Log of applicants per capita against logs of 3-year moving average per capita variables, VI: Log of applicants per capita against logs of 5-year moving average per capita variables, VII: Log of applicants per capita against logs of 3-year moving average variables, VIII: Log of applicants per capita against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

(f) Observations: 91

Table 5-26: Research input and output effect on money applied for by EU13 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of money applied for**				**Log of money applied for per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	1.393	4.531**	1.224	5.598**	1.364	4.421*	1.118	5.397**
	(2.405)	(2.229)	(1.912)	(2.175)	(2.323)	(2.267)	(1.806)	(2.213)
Citations	-0.811	-3.028*	-0.551	-3.535**	-0.843	-3.052*	-0.544	-3.491**
	(1.789)	(1.576)	(1.53)	(1.682)	(1.719)	(1.569)	(1.45)	(1.689)
International Collaboration (%)	0.009	0.023	0.014	0.047	0.004	0.014	0.009	0.037
	(0.049)	(0.054)	(0.046)	(0.065)	(0.049)	(0.054)	(0.045)	(0.065)
Research Intensity (%)	0.047	0.112	-0.12	-0.094	0.043	0.125	-0.113	-0.075
	(0.233)	(0.245)	(0.227)	(0.206)	(0.256)	(0.267)	(0.245)	(0.231)
R&D personnel (1000 residents)	-0.864**	-1.249***	-0.483	-0.886	-0.771*	-1.143***	-0.406	-0.783
	(0.441)	(0.437)	(0.546)	(0.545)	(0.45)	(0.435)	(0.551)	(0.552)
Patents	0.675	0.294	0.803*	0.157	0.671	0.282	0.792*	0.145
	(0.487)	(0.379)	(0.412)	(0.453)	(0.498)	(0.39)	(0.423)	(0.466)
y2008	-0.337	-0.594**	-0.346*	-0.748**	-0.339	-0.569**	-0.341*	-0.715**
	(0.233)	(0.283)	(0.184)	(0.307)	(0.225)	(0.287)	(0.174)	(0.311)
y2009	-0.253	-0.801	-0.263	-1.077**	-0.257	-0.766	-0.252	-1.025*
	(0.476)	(0.493)	(0.383)	(0.532)	(0.459)	(0.501)	(0.363)	(0.542)
y2010	-0.424	-1.270*	-0.416	-1.657**	-0.429	-1.228*	-0.399	-1.589**
	(0.743)	(0.73)	(0.604)	(0.796)	(0.717)	(0.739)	(0.574)	(0.81)
y2011	-0.431	-1.587	-0.387	-2.093**	-0.449	-1.55	-0.374	-2.018*
	(1.053)	(0.977)	(0.864)	(1.067)	(1.016)	(0.987)	(0.82)	(1.084)
y2012	-0.282	-1.782	-0.19	-2.425*	-0.306	-1.74	-0.173	-2.333*
	(1.418)	(1.261)	(1.166)	(1.389)	(1.365)	(1.271)	(1.102)	(1.408)
y2013	-0.937	-2.880*	-0.791	-3.679**	-0.969	-2.834*	-0.768	-3.568**
	(1.982)	(1.638)	(1.645)	(1.794)	(1.908)	(1.647)	(1.556)	(1.815)
Constant	9.256	13.888	1.173	4.514	6.34	11.562	-1.292	2.378
	(10.116)	(9.607)	(10.508)	(10.043)	(10.112)	(9.54)	(10.505)	(10.073)
R-squared (within)	0.7408	0.7413	0.7542	0.7546	0.7259	0.7252	0.7382	0.7367
R-squared (between)	0.0004	0.0504	0.6914	0.9225	0.0317	0.2043	0.3662	0.7823
R-squared (overall)	0.0078	0.0967	0.6844	0.8994	0.0745	0.0087	0.2219	0.5268
F test	916.43	5343.13	2050.42	189.41	5384.56	398.77	115,158	204.26

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of money applied for against logs of 3-year moving average per capita variables, II: Log of money applied for against logs of 5-year moving average per capita variables, III: Log of money applied for against logs of 3-year moving average variables, IV: Log of money applied for against logs of 5-year moving average variables, V: Log of per capita money applied for against logs of 3-year moving average per capita variables, VI: Log of per capita money applied for against logs of 5-year moving average per capita variables, VII: Log of per capita money applied for against logs of 3-year moving average variables, VIII: Log of per capita money applied for against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

(f) Observations: 91

Table 5-27: Research input and output effect on successful applicants for EU13 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of successful applicants**				**Log of successful applicants per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	1.869	3.216**	1.711	3.197*	1.84	3.106**	1.606	2.996
	(1.345)	(1.512)	(1.342)	(1.762)	(1.278)	(1.568)	(1.288)	(1.825)
Citations	-0.508	-1.609	-0.521	-1.662	-0.54	-1.633	-0.514	-1.618
	(1.18)	(1.092)	(1.066)	(1.196)	(1.108)	(1.063)	(1.003)	(1.194)
International Collaboration (%)	0.001	0.009	0.007	0.023	-0.003	0.001	0.001	0.013
	(0.028)	(0.034)	(0.027)	(0.04)	(0.028)	(0.035)	(0.027)	(0.041)
Research Intensity (%)	-0.131	-0.089	-0.174	-0.156	-0.134	-0.076	-0.167	-0.138
	(0.142)	(0.218)	(0.134)	(0.183)	(0.151)	(0.233)	(0.145)	(0.199)
R&D personnel (1000 residents)	0.177	0.061	0.426	0.316	0.27	0.167	0.503*	0.418
	(0.291)	(0.442)	(0.296)	(0.4)	(0.263)	(0.413)	(0.274)	(0.374)
Patents	0.167	0.127	0.161	-0.008	0.163	0.115	0.149	-0.02
	(0.302)	(0.344)	(0.277)	(0.388)	(0.299)	(0.349)	(0.278)	(0.407)
y2008	-0.599***	-0.725***	-0.610***	-0.768***	-0.601***	-0.699***	-0.605***	-0.734***
	(0.117)	(0.141)	(0.114)	(0.194)	(0.111)	(0.151)	(0.11)	(0.205)
y2009	-0.315	-0.598**	-0.344	-0.670*	-0.319	-0.563*	-0.333	-0.618
	(0.274)	(0.285)	(0.261)	(0.372)	(0.259)	(0.301)	(0.251)	(0.392)
y2010	-0.621	-1.056***	-0.66	-1.151**	-0.626	-1.015**	-0.642*	-1.083*
	(0.421)	(0.409)	(0.403)	(0.537)	(0.396)	(0.43)	(0.386)	(0.563)
y2011	-0.586	-1.166**	-0.63	-1.287*	-0.604	-1.128*	-0.617	-1.213
	(0.617)	(0.576)	(0.586)	(0.736)	(0.582)	(0.597)	(0.56)	(0.767)
y2012	-0.69	-1.428*	-0.741	-1.581*	-0.714	-1.386*	-0.724	-1.49
	(0.861)	(0.754)	(0.82)	(0.961)	(0.81)	(0.776)	(0.78)	(0.998)
y2013	-1.396	-2.342**	-1.464	-2.527**	-1.428	-2.297**	-1.44	-2.416*
	(1.204)	(0.988)	(1.137)	(1.24)	(1.131)	(1.01)	(1.079)	(1.282)
Constant	-3.676	-1.131	-9.714*	-7.664	-6.593	-3.457	-12.179**	-9.8
	(6.181)	(6.16)	(5.653)	(6.048)	(6.034)	(5.973)	(5.604)	(6.043)
R-squared (within)	0.9104	0.9046	0.9216	0.9181	0.9127	0.9059	0.9216	0.9176
R-squared (between)	0.1348	0.1321	0.9657	0.9632	0.5049	0.3228	0.6552	0.7320
R-squared (overall)	0.0385	0.0235	0.9385	0.9345	0.5867	0.4538	0.4151	0.4714
F test	2072.91	2069.08	1.98e[10]	2062.70	22211.74	3373.74	20130.51	2791.03

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of applicants in retained proposals against logs of 3-year moving average per capita variables, II: Log of applicants in retained proposals against logs of 5-year moving average per capita variables, III: Log of applicants in retained proposals against logs of 3-year moving average variables, IV: Log of applicants in retained proposals against logs of 5-year moving average variables, V: Log of per capita applicants in retained proposals against logs of 3-year moving average per capita variables, VI: Log of per capita applicants in retained proposals against logs of 5-year moving average per capita variables, VII: Log of per capita applicants in retained proposals against logs of 3-year moving average variables, VIII: Log of per capita applicants in retained proposals against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

(f) Observations: 91

Table 5-28: Research input and output effect on secured funding for EU13 member states in FP7, fixed effects estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Log of secured funding**				**Log of secured funding per capita**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	1.888	3.552*	2.523	4.339*	1.859	3.442*	2.418	4.138*
	(1.868)	(2.028)	(1.801)	(2.384)	(1.757)	(2.085)	(1.676)	(2.453)
Citations	-0.546	-1.644	-0.990	-2.209	-0.578	-1.668	-0.983	-2.165
	(1.481)	(1.291)	(1.347)	(1.358)	(1.393)	(1.26)	(1.253)	(1.378)
International Collaboration (%)	-0.018	0.009	0.004	0.040	-0.022	-0.001	-0.002	0.030
	(0.039)	(0.047)	(0.036)	(0.058)	(0.038)	(0.047)	(0.035)	(0.058)
Research Intensity (%)	-0.358	-0.506	-0.430*	-0.610*	-0.361	-0.493	-0.422*	-0.592*
	(0.307)	(0.414)	(0.232)	(0.346)	(0.291)	(0.414)	(0.217)	(0.345)
R&D personnel (1000 residents)	0.473	0.419	0.847	0.809	0.566	0.525	0.924	0.911
	(0.714)	(0.946)	(0.67)	(0.912)	(0.669)	(0.91)	(0.63)	(0.877)
Patents	0.412	0.401	0.203	-0.046	0.408	0.388	0.192	-0.058
	(0.392)	(0.458)	(0.359)	(0.525)	(0.372)	(0.45)	(0.339)	(0.526)
y2008	-0.477***	-0.647***	-0.569***	-0.794**	-0.480***	-0.622***	-0.564***	-0.761**
	(0.155)	(0.234)	(0.154)	(0.315)	(0.144)	(0.24)	(0.144)	(0.321)
y2009	-0.307	-0.686*	-0.505	-0.953*	-0.311	-0.651	-0.494	-0.901*
	(0.387)	(0.404)	(0.363)	(0.532)	(0.364)	(0.418)	(0.339)	(0.547)
y2010	-0.508	-1.078*	-0.806	-1.458*	-0.513	-1.037*	-0.788	-1.391*
	(0.582)	(0.581)	(0.556)	(0.77)	(0.546)	(0.599)	(0.518)	(0.791)
y2011	-0.459	-1.199	-0.861	-1.707*	-0.476	-1.161	-0.849	-1.633
	(0.843)	(0.795)	(0.797)	(1.027)	(0.792)	(0.814)	(0.744)	(1.054)
y2012	-0.498	-1.405	-1.025	-2.064	-0.522	-1.363	-1.009	-1.972
	(1.145)	(1.025)	(1.086)	(1.322)	(1.073)	(1.044)	(1.009)	(1.356)
y2013	-1.142	-2.268*	-1.840	-3.097*	-1.173	-2.223	-1.816	-2.987*
	(1.588)	(1.336)	(1.496)	(1.678)	(1.49)	(1.355)	(1.392)	(1.72)
Constant	-7.024	-7.879	-17.482**	-18.338*	-9.941	-10.205	-19.947***	-20.474**
	(7.95)	(9.683)	(7.355)	(10.302)	(7.779)	(9.414)	(7.227)	(10.145)
R-squared (within)	0.6883	0.6823	0.7223	0.7176	0.6955	0.6865	0.7265	0.7196
R-squared (between)	0.0000	0.0103	0.9453	0.9093	0.5630	0.6477	0.4245	0.5022
R-squared (overall)	0.0044	0.0003	0.9103	0.8742	0.5785	0.6529	0.3106	0.3735
F test	2206.16	5300.79	$1.13e^{6}$	1850.09	1477.62	3098.42	11177.12	1262.23

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Log of EC funding secured against logs of 3-year moving average per capita variables, II: Log of EC funding secured against logs of 5-year moving average per capita variables, III: Log of EC funding secured against logs of 3-year moving average variables, IV: Log of EC funding secured against logs of 5-year moving average variables, V: Log of per capita EC funding secured against logs of 3-year moving average per capita variables, VI: Log of per capita EC funding secured against logs of 5-year moving average per capita variables, VII: Log of per capita EC funding secured against logs of 3-year moving average variables, VIII: Log of per capita EC funding secured against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage

(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

(f) Observations: 91

Table 5-29: Research input and output effect on success rates of EU13 member states in FP7, fixed effects Poisson estimates of 2007-2013

Model (see footnote)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Dependent Variable	**Success rate of applicants**				**Success rate of secured funding**			
Explanatory variables	**Coefficients/standard errors**							
Total Publications	-0.549	-1.020	-0.739*	-1.514**	0.780	-0.921	1.266	-1.295
	(0.421)	(0.676)	(0.439)	(0.595)	(1.046)	(1.314)	(1.214)	(1.317)
Citations	0.544**	0.834**	0.509**	1.016***	0.011	1.304	-0.511	1.298
	(0.221)	(0.344)	(0.238)	(0.331)	(0.714)	(0.83)	(0.803)	(0.84)
International Collaboration (% of total)	-0.007	-0.005	-0.009	-0.008	-0.022	-0.011	-0.010	-0.003
	(0.013)	(0.015)	(0.014)	(0.019)	(0.024)	(0.022)	(0.025)	(0.028)
Research Intensity (%)	-0.204**	-0.232**	-0.172**	-0.167*	-0.393	-0.596*	-0.317	-0.493
	(0.079)	(0.099)	(0.068)	(0.1)	(0.334)	(0.359)	(0.292)	(0.375)
R&D personnel (1000 residents)	0.941***	1.063***	0.926***	1.013***	1.306*	1.721**	1.342*	1.758*
	(0.202)	(0.228)	(0.208)	(0.264)	(0.709)	(0.812)	(0.714)	(0.931)
Patents	-0.211**	-0.170*	-0.178**	-0.154	-0.226	0.028	-0.505	-0.242
	(0.09)	(0.098)	(0.074)	(0.123)	(0.33)	(0.264)	(0.31)	(0.314)
y2008	-0.015	0.014	-0.004	0.060	-0.149	-0.043	-0.206*	-0.035
	(0.047)	(0.085)	(0.049)	(0.089)	(0.098)	(0.135)	(0.118)	(0.163)
y2009	0.112	0.173	0.129	0.259*	-0.105	0.101	-0.239	0.118
	(0.089)	(0.15)	(0.095)	(0.157)	(0.187)	(0.241)	(0.223)	(0.28)
y2010	0.208	0.295	0.230	0.419*	-0.168	0.168	-0.388	0.191
	(0.134)	(0.216)	(0.144)	(0.221)	(0.307)	(0.365)	(0.362)	(0.416)
y2011	0.185	0.295	0.210	0.457	-0.153	0.352	-0.476	0.373
	(0.181)	(0.274)	(0.194)	(0.28)	(0.417)	(0.486)	(0.488)	(0.543)
y2012	0.280	0.408	0.305	0.614*	-0.392	0.331	-0.840	0.349
	(0.236)	(0.359)	(0.254)	(0.363)	(0.582)	(0.632)	(0.678)	(0.704)
y2013	0.348	0.507	0.370	0.764*	-0.449	0.557	-1.063	0.572
	(0.315)	(0.45)	(0.341)	(0.457)	(0.792)	(0.84)	(0.914)	(0.912)
Wald Chi2 test	8045.63	4014.18	529,338	25733.84	508.93	1246.91	1257.08	271.21
Log Pseudolikelihood	-26.500	-26.501	-26.501	-26.502	-24.192	-24.189	-24.190	-24.192

Notes:

*(a) *** p<0.01, ** p<0.05, * p<0.1*

(b) I: Success rate of applicants against logs of 3-year moving average per capita variables, II: Success rate of applicants against logs of 5-year moving average per capita variables, III: Success rate of applicants against logs of 3-year moving average variables, IV: Success rate of applicants against logs of 5-year moving average variables, V: Success rate in secured funding against logs of 3-year moving average per capita variables, VI: Success rate in secured funding against logs of 5-year moving average per capita variables, VII: Success rate in secured funding against logs of 3-year moving average variables, VIII: Success rate in secured funding against logs of 5-year moving average variables.

(c) Cluster-robust errors used in all models (in parentheses)

(d) Research Intensity and International Collaboration are expressed as a percentage and not in per capita terms

(e) EU13 are countries with high investment in RTDI according to European Commission (2013): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Spain, Sweden and UK.

(f) Observations: 91

Table 5-30: Detailed descriptive statistics of dependent variables

Dependent Variables		Mean	Variance	Std. Dev.	Min	Max	Obs.
Applicants	overall	2683.77	1.05E+07	3243.61	88.00	13324.00	N = 196
	between		1.03E+07	3205.51	136.71	10498.86	n = 28
	within		561921.60	749.61	-106.94	5508.91	T = 7
Applicants per mln residents	overall	200.02	14828.59	121.77	27.56	696.05	N = 196
	between		12620.10	112.34	44.15	433.70	n = 28
	within		2596.81	50.96	42.84	462.36	T = 7
Money asked (in €mln)	overall	1005.74	1.82E+06	1347.35	17.28	7127.71	N = 196
	between		1.72E+06	1311.30	26.86	4397.81	n = 28
	within		148771.97	385.71	-333.50	3735.64	T = 7
Money asked pc	overall	65.21	1963.88	44.32	7.19	244.98	N = 196
	between		1672.89	40.90	12.14	152.67	n = 28
	within		342.47	18.51	12.00	168.14	T = 7
Applicants in retained proposals	overall	573.41	5.27E+05	725.89	17.00	3036.00	N = 196
	between		5.13E+05	716.25	26.14	2463.14	n = 28
	within		29697.53	172.33	-169.73	1146.27	T = 7
Applicants in retained proposals pc	overall	40.18	613.28	24.76	3.60	121.93	N = 196
	between		514.89	22.69	6.74	75.72	n = 28
	within		114.23	10.69	14.24	98.22	T = 7
EC contribution to retained proposals	overall	190.24	74865.50	273.62	1.40	1209.30	N = 196
	between		73700.52	271.48	2.66	995.36	n = 28
	within		3432.63	58.59	-41.51	518.49	T = 7
EC contribution to retained proposals pc	overall	10.89	74.61	8.64	0.70	40.01	N = 196
	between		67.97	8.24	1.00	26.97	n = 28
	within		8.73	2.96	0.02	23.93	T = 7
Success rates of applicants	overall	0.20	0.001	0.04	0.11	0.28	N = 196
	between		0.001	0.03	0.14	0.26	n = 28
	within		0.001	0.02	0.14	0.30	T = 7
Success rates of EC contribution	overall	0.16	0.003	0.06	0.05	0.28	N = 196
	between		0.002	0.05	0.08	0.24	n = 28
	within		0.001	0.03	0.07	0.30	T = 7

Table 5-31: Correlation of explanatory variables: 3-year moving averages

Explanatory Variables	S&T	S&T ptr	SS	SS ptr	HUM	HUM ptr	Patents	Patents ptr	Citations	Citations ptr	FTE R&D personnel	FTE R&D pers. ptr	R&D Intensity	Int. collab.
S&T ptr	0.25	1												
SS	0.85	0.3	1											
SS ptr	0.17	0.79	0.41	1										
HUM	0.85	0.27	0.99	0.38	1									
HUM ptr	0.22	0.74	0.46	0.88	0.46	1								
Patents	0.83	0.21	0.56	0.07	0.55	0.09	1							
Patents ptr	0.38	0.77	0.28	0.53	0.25	0.44	0.53	1						
Citations	0.91	0.3	0.83	0.23	0.81	0.27	0.75	0.42	1					
Citations ptr	0.19	0.83	0.25	0.59	0.21	0.53	0.18	0.77	0.38	1				
FTE R&D pers.	0.98	0.22	0.78	0.11	0.79	0.16	0.89	0.41	0.88	0.16	1			
FTE R&D pers. ptr	0.21	0.81	0.22	0.6	0.19	0.5	0.25	0.86	0.25	0.71	0.23	1		
R&D Intensity	0.34	0.87	0.28	0.6	0.26	0.54	0.41	0.9	0.36	0.77	0.36	0.9	1	
Internat. collab.	-0.2	0.18	-0.12	0.32	-0.13	0.09	-0.07	0.38	-0.15	0.25	-0.17	0.38	0.23	1
GPD pc	0.23	0.54	0.23	0.48	0.22	0.35	0.22	0.68	0.28	0.53	0.21	0.75	0.55	0.57

S&T: Science and Technology publications, SS: Social Sciences publications, HUM: Arts and Humanities publications, ptr: per thousand residents, pc: per capita, FTE: Full-time equivalent, R&D: Research and Development

Table 5-32: Correlation of explanatory variables: 5-year moving averages

Explanatory Variables	S&T	S&T ptr	SS	SS ptr	HUM	HUM ptr	Patents	Patents ptr	Citations	Citations ptr	FTE R&D personnel	FTE R&D pers. ptr	R&D Intensity	Int. collab.
S&T ptr	0.28	1												
SS	0.85	0.32	1											
SS ptr	0.2	0.8	0.44	1										
HUM	0.86	0.3	0.99	0.41	1									
HUM ptr	0.26	0.77	0.49	0.89	0.48	1								
Patents	0.84	0.22	0.56	0.09	0.56	0.11	1							
Patents ptr	0.39	0.77	0.29	0.55	0.26	0.47	0.53	1						
Citations	0.93	0.33	0.86	0.29	0.86	0.33	0.76	0.44	1					
Citations ptr	0.22	0.86	0.28	0.65	0.25	0.62	0.19	0.79	0.38	1				
FTE R&D personnel	0.98	0.24	0.78	0.14	0.79	0.19	0.89	0.42	0.9	0.19	1			
FTE R&D pers. ptr	0.22	0.8	0.22	0.61	0.21	0.52	0.25	0.87	0.27	0.74	0.23	1		
R&D Intensity	0.35	0.87	0.29	0.61	0.27	0.56	0.41	0.91	0.39	0.81	0.37	0.9	1	
Internat. collab.	-0.22	0.13	-0.13	0.3	-0.15	0.09	-0.09	0.34	-0.19	0.19	-0.21	0.34	0.18	1
GPD pc	0.24	0.53	0.24	0.49	0.23	0.38	0.22	0.69	0.28	0.53	0.22	0.75	0.56	0.53

S&T: Science and Technology publications, SS: Social Sciences publications, HUM: Arts and Humanities publications, ptr: per thousand residents, pc: per capita, FTE: Full-time equivalent, R&D: Research and Development

Table 5-33: Correlation of dependent variables

Dependent Variables	Applicants	Applicants per mln residents	Money asked (in €mln)	Money asked pc	Applicants in retained proposals	Applicants in retained proposals pc	EC contribution (in €mln)	EC contribution pc	Success rates of applicants
Applicants per mln residents	-0.0696	1							
Money asked (in €mln)	0.9755	-0.0613	1						
Money asked pc	0.1131	0.8672	0.1598	1					
Applicants in retained proposals	0.9848	-0.0641	0.9683	0.1229	1				
Applicants in retained proposals pc	0.0152	0.9257	0.0274	0.8663	0.0518	1			
EC contribution (in €mln)	0.9534	-0.0589	0.9667	0.1465	0.9833	0.0624	1		
EC contribution pc	0.2465	0.6931	0.278	0.8687	0.2917	0.8433	0.3226	1	
Success rates of applicants	0.2977	0.0372	0.3133	0.1807	0.3993	0.3557	0.4256	0.4942	1
Success rates of EC contribution	0.4471	0.1219	0.4264	0.2474	0.5243	0.364	0.5462	0.6193	0.7658

6 COMPETITIVE RESEARCH FUNDING ALLOCATION: A PRINCIPAL-AGENT APPROACH WITH ADVERSE SELECTION AND MORAL HAZARD

We analyse the competitive research funding allocation mechanism within the context of a principal-agent model. The principal (policy-maker) awards grants for research projects in order to maximise the benefit from scientific research and optimise the technical progress of the production function in an endogenous growth model. The agent (scientist) wants to use the funding resources to increase his utility through additional monetary compensation and the probability of achieving high quality research output to boost his career. We consider the effects of adverse selection and moral hazard, and the role that past research productivity can play in dealing with such problems. It is asserted that a risk-averse principal that imposes bureaucracy in participation and monitoring of research projects cannot achieve optimal results due to the information asymmetry on the agent's expertise. Nonetheless, a risk-neutral principal can design an evaluation system of research proposals and a contract execution process that attracts high performers and maximises research output. This is achieved through benchmarking and observing only final research output instead of monitoring research effort.

6.1 Introduction

It is claimed that public competitive research funding schemes are important in shaping scientific advancement and technological progress. The enhancement of these factors is said to bring a positive effect in the economic growth of a country through the technological progress factor within the production function. The literature on endogenous growth theory has highlighted the endogenous nature of knowledge and technology in facilitating growth rates (Romer, 1986, Lucas, 1988, and Aghion and Howitt, 1992) implying that optimal earmarking of public research funds is likely to play a significant role in this process. In recent years, further attention has been placed on the optimal allocation of research funding as resources become scarcer. The cuts in core funding and the major shift to external research funding have underlined the need for a systematic approach in determining the

factors that drive the implementation of research funding policy and examining potential changes that could ensure optimality in the allocation process (Stephan and Levin, 1997).

The present chapter examines the allocation process of public research funding using the theoretical background of the principal-agent model. Within this context and in addition to the principal-agent model, the chapter combines elements from theories such as endogenous growth (Romer, 1986, Lucas, 1988 and Aghion and Howitt, 1992), research productivity over the life-cycle of academic scientists (Levin and Stephan, 1991) and Spence's (1972) education model with signalling. The goal is to apply a theoretical framework that matches all characteristics central to the public research funding process. These are mainly used to define the optimisation problems of the principal and the agent.

The main contribution of the chapter is to provide a theoretical insight into the economics of public research funding, drawing from both the empirical findings of Chapters 2 to 5 as well as from the existing literature. Moreover, it corroborates the need to use past published research productivity as a signal for academic researchers to optimally select and carry out funded research projects. This gains additional substance within the context of endogenous growth.

The social planner (principal) seeks long-term growth through optimisation of the knowledge element of the production function. Maximising research output is expected to be a catalyst for achieving this target. Here is where the allocation of public competitive research funding enters the equation. We examine three cases between the principal and the agent (researcher): perfect information, adverse

selection and moral hazard. We show how funding schemes that limit bureaucracy can rely on past research productivity to tackle adverse selection and moral hazard. We also often refer to two types of research policy options: science-push and demand-pull policies. The latter refers to research policy focused on research closer to the demands of the economy and society, i.e. applied research relevant to the productive sectors of the economy. The former refers to policies whereby freedom is provided to scientists to choose their research domain and the character of their research, which is usually curiosity-driven[8]. These policy choices shape, to a significant extent, the decisions and actions of both the principal and agent in our model.

The chapter is organised as follows. In the next section a concise review of the literature of the principal-agent model is presented where we endeavour to identify all previous attempts to set up a theoretical framework for public research funding. In Section 3 we outline the theoretical model and discuss the possibilities of adverse selection and moral hazard. Section 4 discusses potential policy implications and provides suggestions for the improvement of public research funding allocation. Section 5 summarises and concludes.

6.2 Literature Review

We do not carry out an extensive literature review of neither the principal agent theory nor research funding systems as this goes beyond the scope of this chapter.

[8] Science-push policies were largely triggered by the "Science: An Endless Frontier" report back in 1945, prepared by the Office and Scientific Research and Development (OSRD) of the USA. After the end of the 2nd World War, the USA President Franklin Roosvelt endorsed the suggestions of the Director of the OSRD Office, Vannevar Bush, to invest in science due to its multiple benefits for the society, economy and welfare. This report included the suggestion for the establishment of the National Science Foundation (NSF).

Instead we outline the most important concepts and look specifically at principal-agent models in research policy or other theoretical models in the same field that provide insights of the interaction between policymakers and researchers.

6.2.1 Principal-Agent Theory

The first formal principal-agent theory is attributed to Ross (1973) who presents a setting where the two actors trade in order to achieve Pareto efficient outcomes by maximising their utilities. However, the roots of this theoretical framework go back to Nash (1950 & 1951) and his theory on cooperative games. Nash had set the basis for the principal-agent theory by bringing to the forefront an alternative view of how competing or collaborating parties take decisions contingent on the strategy of the other party. This contribution was followed by a massive literature in game theory and is applicable to the principal and the agent model. A formal definition of the principal-agent model states that the principal-agent problem is a specific game-theoretic description of a situation and it is concerned with how the principal can design a compensation system (a contract) which motivates another individual, the agent, to act in the principal's interests (Stiglitz, 1987). The principal-agent model comes in a variety of versions. These are related to the degree of uncertainty encompassed in the model as well as the respective behaviour of the principal and the agent with regard to risk. Before we formulate the principal-agent model for research policy, in what follows, we will look at the literature concerning previous efforts to formulate a theoretical framework for research policy both within and outside the principal-agent framework.

6.2.2 Principal-Agent Model in Research Policy

There is a strand in the literature coming from different scientific disciplines that focuses on the application of the principal-agent framework in research funding and policy in general. This literature has more of a sociological character and is in contrast to the purely economic approach of this paper.

Braun and Guston (2003) review this literature which started with Braun (1993) who stressed the role of intermediate agencies in research policy-making using the principal-agent model. The authors identified the principal-agent model as the most appropriate way to deal with the "under-theorisation" in the field of research policy-making. On the other hand, Shove (2003), reviewed the application of the principal-agent model to research policy to conclude that the model cannot explain research policy. This weakness of the model is as a result of not being able to accommodate multiple agents, principals and research projects. It is true that such a task is limited by the complexity of the process. However, using the model to put a structure on the incentives and potential actions of policy-makers and researchers in the framework of public research funding does bring analytical benefits and this is the aim of the present chapter.

Guston (2003) examines how to assign policy problems to agents and asking for their expertise so that the policy-maker can reach an optimal decision. This approach is a demand-driven one for science but does not focus on directly improving the production function of the economy. Rather it focuses on the improvement of policy-making for areas like energy, environment and health rather than to achieving a permanent increase in the growth rate. There seems to be a

trade-off in choosing between science-push and demand-pull policies. This occurs, in the sense, that when a demand-driven policy is implemented, scientists adjust their research agendas and perhaps scientific orientation to the needs of the research priorities of the policy-maker. However, in all scientific fields there exist different schools of thought (Guston, 2003). Hence, there is no unique optimal way of selecting optimally the best scientist to perform predetermined tasks. Therefore it seems that, within a demand-pull research policy environment, output is limited both quantitatively and qualitatively. On the other hand, science-push policy environments offer the flexibility for scientists to retain their personal research agenda and thus maximise their research output. But many times this research output does not match the goals of the policy-maker as the results are either more relevant internationally than domestically or do not offer any value added to technological progress. Nonetheless, science-push policies may be much more impactful in the long-term since the enlargement of the overall scientific knowledge is said to drive technological progress slowly but more robustly.

Van der Meulen (1998) presents, in a game-theoretic setting, all possible combinations of strategies that the principal and the agent can choose in the frame of a repeated game in research funding and the result of this interaction. More specifically, the available strategies concern two different levels of trust from the principal and two different levels of productivity from the agent. The optimal result occurs when the principal trusts the agent and the agent complies with the "wants" of the principal. However, it is noted that for the optimum to occur in the science-push policy context, the interests of the principal and the agent must be the same.

If the policy-maker aims at long-term growth then he can give the agents the time and freedom to choose the scientific field and topic they would perform in optimally. This achieves the coincidence of wants. If the opposite is the case though, the policy-maker has specific needs and his time horizon is limited. Thus he directs the thematic orientation of the required research output to where the demand lies and this leads to a mismatch of the principal and agent's interests. In our theoretical model we discuss both possibilities.

It must be underlined that the purpose of the present chapter is not to prove that the principal-agent model can explain perfectly the research funding process. Rather, it aims to use its framework to showcase the importance of past publishing performance in selecting and monitoring research projects. Past research productivity could play the role of a signal for the mitigation of distortions such as adverse selection and moral hazard.

A limited number of studies have focused in exploring empirically the principal-agent rationale in research policy. One such example is Laudel (2006) who used a sample of physicists in Australia and Germany to examine whether, and to what extent, there is adaptation of research by the researchers to fit to the requirements of funding agencies. She found that researchers choose to apply to funding schemes that are more suitable to their field but they also tend to adapt their research in order to increase their probability of obtaining external funding. The findings also exhibit a compromise in research quality and novelty by researchers that choose to follow a demand-driven research portfolio. This is in line with our model which states that demand-pull research that falls outside the scientific curiosity of the researcher

will not produce optimal research results. The study also shows that demand-pull research funding affects both high and low performers in research. The difference between them is that high performers are likely to negotiate for more core funding from their institutions to pursue curiosity-driven research whereas low performers cannot act in this way.

In a recent study Borlaug (2015) examined how Sweden and Norway have shaped their funding systems and the principal agent theory is utilised to conclude whether adverse selection or moral hazard concerns coexist. The author examined the principal-agent interaction not only at the policymaker-researcher level but also at the funding agency-institution and institution-researcher levels. In particular, the author investigates the Centres of Excellence funding instrument and the evaluation criteria thereof to understand which aspects are given more emphasis. He concludes that in Sweden where the funding system is heavily reliant on competitive processes the problem of moral hazard is more vigorously pursued judging from increased weight on the evaluation criteria that involve organisational structure and monitoring. Essentially, the principal transfers the responsibility of monitoring researchers to their institutions. In Norway on the other hand where recurrent funding is provided to Universities to a greater extent, more attention is attached to solve potential adverse selection problems and ensure that the best researchers are selected to work for the funded institutions.

We now proceed to discuss our version of the principal-agent model in research policy.

6.3 Theoretical Framework

We consider the simplest of settings for the model. The principal and the agent behave as two rational economic agents aiming at maximising their utilities. The principal has money received from taxes. He wants to maximise research output to achieve the highest payoff for the improvement of the knowledge pool and its impact on economic growth. However, he also wants to control that money received from tax-payers and allocated for research are legitimately and efficiently spent for solely this purpose. Failure to achieve this will cause disutility to the principal. Therefore, he has a potential trade-off to face between maximising research output, by giving researchers the freedom to utilise the money as they see fit, and ensuring that moneys are spent on actual effort of producing this output, through imposing costly bureaucratic control over research agents.

The research agent has a dilemma for the allocation of his productive time. His aim is to carry out curiosity-driven research and pursue a career path in science. He can either carry out research with his existing means or he can apply for a grant from the principal with the possibility to secure funding, which will enhance his research potential and career. Nonetheless, he will be required to abide with bureaucratic processes which will cause him to experience disutility and reduce his productive time significantly. In this respect, the agent faces his own trade-off which forces him to choose an optimal combination of his productive time between research and bureaucracy.

Let us assume that the principal has an endowment of $(m, t) = (1,0)$ and the agent a respective endowment of $(m, t) = (0,1)$ where m is money and t is productive

time for research. Therefore, before any bargaining or exchange takes place between the two actors, the principal has all the money and no productive time for research and the agent has all the productive time but no funding for research. In this situation each of the actors can achieve a certain level of utility called reservation utility. This utility is dependent solely on their own endowments. It is nevertheless obvious that it is in the interest of both parties to exchange their endowments as it will make them better-off than before as they can have combinations of funding and research time instead of the two extremes.

Hence, the principal (A) and the agent (B) must find the best solution to their following joint optimisation problem:

$$\max[W(m_A, t_A) + \lambda U(m_B, t_B)] \quad (1)$$

with the budget and time constraints

$$m_A + m_B = 1 \quad (2)$$

$$t_A + t_B = 1 \quad (3)$$

Assuming that both functions are monotonically increasing and concave then the first order conditions give

$$\frac{W_{m_A}}{W_{t_A}} = \frac{U_{m_B}}{U_{t_B}} \quad (4)$$

The above identity implies that the optimal result is achieved when the marginal rates of substitution between money and research time for the principal and the agent become equal. This equality means that a) the conditions are such so that there is a balance of bureaucracy and research output and b) the level of monitoring

from the principal is at acceptable levels, such that both parties are satisfied, since it is combined with an offsetting level of research output. This balance is easy to achieve in the science-push context where the policymaker requires researchers to produce research output that matches their scientific curiosity (Laudel, 2006). If the principal imposes on the agents a research field which is contrary to their scientific curiosity, the latter will likely face a trade-off between money and research time where money will be seconded by two elements of disutility: bureaucracy and unwanted research orientation. The researchers can choose not to participate, and instead focus solely on their field of interest while maintaining their reservation utility, since the funding secured from the principal will cause disutility higher than the additional utility. If the best researchers choose reservation utility in this trade-off and do not participate in the funding schemes of the principal then the problem of adverse selection may arise. Even if this is not the case there is possibility that moral hazard may occur, with the agent taking advantage of his information advantage and present misleading evidence of effort and output to the principal while in reality he is secretly engaged in curiosity-driven research. These special cases will be examined in subsequent sections.

The model can also accommodate a demand-driven research funding system. If the principal is not interested in maximising scientific research output in general but he aims for applied research closer to innovation, it may be the case that researchers will have a stronger incentive to abstain from funding schemes, keep their reservation utility and follow their curiosity in selecting research topics. The only issue is that this rationale may result in a problem of adverse selection as the best

scientists that are not in urgent need of funding will not participate and low performers in need of funding will secure it from the principal. Low-performers may be more willing to shift their research interests towards the interests of the principal (Laudel, 2006) in order to remain in the research sector and the principal will fund low-performers as their participation will be asymmetrically higher than high-performers. Therefore, as highlighted above, disorientation from scientific interests may be another element of disutility affecting the decision of the agent in a demand-pull environment (Laudel, 2006). If, however, we assume that all agents are in need for funding regardless of their performance and the principal offers them a take it or leave it funding scheme, then the dilemma will be critical. Agents will then have to choose the optimal combination of time devoted to writing proposals and carrying out funded projects and time devoted to curiosity-driven research.

We now abstract from the above general theoretical framework and deal with the idiosyncratic features of the competitive research funding process, discussing in further depth the incentives of the two parties.

6.3.1 Agent's optimisation problem in competitive research funding

The agents have two incentives that contribute to achieving utility from a research funding contract: a monetary incentive, that is, their expected payoff from the project, and a professional incentive, that is, resources to realise the research contract. In a science-push context, the purposes of the contract more than contribute in helping researchers build their research record and profile. The following equation states that the utility that the agent enjoys from the contract is

the sum of the expected additional money m he will receive as compensation and the expected career impact n from achieving higher and better research output offered by earning the contract. In the equation, e represents the disutility from the effort of carrying out the work required by the contract and c_t the disutility from the transaction costs (applying for funding, negotiating, etc).

$$U_{contract} = m + n - e - c_t \quad (5)$$

If the utility function is written ex-ante then the probability of securing research funding should be incorporated as follows

$$U = p_f(m + n - e - c_t) + p_n(-c_t) \quad (6)$$

Where p_f is the probability of securing funding and p_n is the probability of not securing funding.

Nevertheless, the professional incentive, in the long-term, can be perceived as one of monetary nature as well. Given that research output , or even research funding itself, are included in the criteria for tenure and promotion of academics, career path incentives can be considered equivalent to the satisfaction of the scientist in discovering something new. This is coupled with the expected long-term monetary benefit coming from career development. Thus it can be stated that:

$$n = E(s) + E(m) \quad (7),$$

where E is the expectations operator and s is scientific satisfaction. Therefore, considering ex-ante utility and substituting (7) without the expectations operator into (6) yields

$$U = p_f(m + s - e - c_t) + p_n(-c_t) \quad (8)$$

where both types of monetary payoff are unified into m for simplification. When considering scientists working in the public sector it is important to note that usually they do not receive additional monetary compensation, as their salary provides for the revenue brought by external funding. Instead, they may be compensated by their institution with a reduction in teaching or administration workload denoted by ξ. Thus with $m = 0$ (8) becomes

$$U = p_f(s + \xi - e - c_t) + p_n(-c_t) \quad (9)$$

Now assume that the principal has perfect information about potential agents and by being risk-neutral he does neither monitor the evaluation nor the project progression since he can simply choose the appropriate scientist for the job. This implies a perfect mechanism, possessed by the principal, of always choosing the right agent. Therefore, Equation (9) simplifies to

$$U = p_f(s) + p_n(-d) \quad (10),$$

and the only disutility to the agent may be the disappointment of not being chosen by the principal denoted by d, which will be disregarded for simplicity in the model. It is clear that when the principal trusts the agent, the utility of the agent is not limited by transaction costs and, following the rationale for scientific satisfaction as underlined by Levin and Stephan (1991), neither by his effort. This unique feature of the utility function of scientists, where scientific satisfaction can plausibly be assumed as some form of leisure, can change the very concept of disutility in

research. This is also valid due to the alignment of the principal and the agent objectives in science-push policies.

We now go back to the basic setting of the model and assume that the agent was offered a contract for a research project. This helps to explore the ex-post version of the agent's utility function and the weights attached to each element of the utility. Given that among different scientific fields the usefulness of funding to produce research output varies, it is important that the utility function of the agent reflects this. As equation (11) shows, utility now depends on the importance placed on each of its components by the agent. The coefficients α, β, γ and θ express the marginal utility that the agent receives from the contract when any of the components increase by one unit. As the monetary resources m_r serve as the vehicle of the agent to achieve both his career and future monetary benefit targets, it replaces n in the following equation:

$$U_{contract} = \theta m + \alpha m_r + \beta s - \gamma e_r \quad (11)$$

m = monetary compensation
m_r = monetary resources for the research purposes of the contract
s = scientific satisfaction
e_r = effort placed on a research project
$0 < \theta < 1$ = importance given to additional monetary compensation.
$0 < \alpha < 1$= resource exploitation factor
$0 < \beta < 1$= importance given to scientific satisfaction
$0 < \gamma < 1$= willingness to devote effort without shirking (negative shirking or effectiveness factor)
Thus, marginal utility for each component is expressed by the respective partial derivatives.

$$\frac{\partial U}{\partial m} = \theta, \quad \frac{\partial U}{\partial m_r} = \alpha, \quad \frac{\partial U}{\partial p} = \beta, \quad \frac{\partial U}{\partial e_r} = -\gamma \qquad (12)$$

Given this theoretical background it is interesting to consider the special case where a) the academic institution does not allow the researchers to receive additional monetary compensation from research projects and b) the researchers have reached the top level of their scale and have no incentives for future promotion or tenure. This category of researchers would not apply for funding unless there are other types of incentives that drive their behaviour such as a relief from teaching workload or the widely discussed "satisfaction for solving the puzzle". Even a sort of *"duty to bequest their knowledge to younger generations"* could potentially push senior researchers to bear the transaction costs and effort of submitting a research proposal. Are such types of incentives powerful enough to counterbalance the lack of monetary incentives? In case these special assumptions apply, the utility function of the agent would draw from Equation (9) to become as follows:

$$U_{contract} = E(s) + E(\xi) - e - c_t \ (13)$$

since the monetary aspect of the utility is no longer valid.

The optimisation problem of the agent has provided us with insights as to how the principal can provide incentives so that the risk of devoting effort and time in monitoring agents without any result is minimised. In what follows, we examine the utility function of the principal with view to reflect on what we outlined for the agent.

6.3.2 Principal's optimisation problem in competitive research funding

The optimisation problem of the principal is complicated as he does not act for personal interest but as a social planner seeking economic growth. The principal

designs a research funding scheme and asks potential agents to submit research proposals. Carrying out this process entails transaction costs for the principal to prepare and communicate the funding scheme, evaluate the proposals, select agents and negotiate with them. When proposals are approved for funding, monitoring costs occur. If the project is successfully completed then the scientific research output produced creates positive utility for the social planner as he considers its potential contribution to long-term economic growth. Therefore, the purpose of the principal is to maximise scientific research output both in quantity and quality.

Ideally, both parties would be better-off through the reduction of the transaction costs of the agent (preparation of proposals and reporting requirements) and both the transaction and monitoring costs of the principal (evaluation of proposals, monitoring of projects). However, this scenario hinges on the need for the principal to control the actions of the agent. Equation (14) implies that the principal expresses his utility in terms of expected output and his disutility as a function of the money given to the agent and the transaction costs for monitoring the agent's effort. In this initial setting, all researchers are assumed to be equally productive by the principal. For a single one-type (in terms of research capability) agent the utility function is

$$maxE(U) = E[dS_a - m_a - \tau_a] \text{ , (14)}$$

and for multiple n one-type agents

$$maxE(U) = E[\sum_{a=1}^{n} dS_{a_i} - \sum_{a=1}^{n} m_{a_i} - \sum_{a=1}^{n} \tau_{a_i}] \quad (15)$$

given the budget constraint

$$\sum_{a=1}^{n} m_{a_i} + \sum_{a=1}^{n} \tau_{a_i} \leq B \quad (16)$$

B is the total budget for the funding scheme, $E(dS_{a_i})$ represents the scientific payoff (expected change in the country's research output) caused by the expected results of research project i.

The principal seeks research projects that maximise the potential growth in the country's output and more specifically $E(dY)$. Analytically, the principal, following a competitive process, seeks to offer contracts to multiple agents aiming at achieving the optimal value added to the existing levels of scientific knowledge. This usually follows a bidding process which implies that proposals are submitted by the agents and evaluated by the principal. The best proposals receive the grant according to the evaluation results but usually, as opposed to other processes (i.e. government tenders), the budget is not an evaluation criterion and tends to be fixed at an upper limit.

The maximisation problem with multiple agents is more intuitive than with one agent as it allows for $E(dY)$ to vary among agents and requires only that the collective net effect from all research projects is greater than the relevant costs of funding and monitoring. In the case of a single agent, the principal may be entirely risk-averse and may aim to assign a research project only when he knows *a priori* that the project will have a positive impact. The principal cannot realise at any time the magnitude of a single project's effect but can observe and assess the collective value of the policy after its effectuation in t years. Therefore, the principal is more

willing to accept some risk if multiple agents are involved in the process. In what follows, we depart from one-type agents and proceed in discussing the problem of adverse selection and incorporate it in the model.

6.3.3 Asymmetric Information and Adverse Selection

The optimal result could be achieved if the principal had access to all information and offered different types of contracts to different agents. However, this is difficult or impossible in practice since in public economics such discrimination is usually prohibited. In public funding schemes usually a maximum budget per funded project is fixed *a priori*. So in the case of adverse selection the norm for the principal is to offer the same type of contract to all agents that satisfy the eligibility criteria and try to maximise the probability to offer the contract to a high-performer through an efficient evaluation process. This is the case for a number of national funding schemes such as the EU Framework Programme.

In a rational set-up, it is assumed that there are two types of agents insofar as the principal is concerned: agents with low research capability and agents with high research capability. The first type refers to researchers with less talent for research albeit being scientifically proficient (*i.e.* having a PhD or teaching experience). The second type of scientists, those with a prominent talent for research, is the type that the principal considers more appropriate for achieving his knowledge maximisation goal. The principal is uninformed about any one agent's research competence or research effort. He is only aware of the probability level of assigning a contract to a high performer as he is also aware of the general state of the research sector in the country. Therefore, he sets his utility function as in Spence

(1973) based on the probabilities of appointing a contract to the two types of agents:

$$E(U) = \sum_{i=1}^{n} p_{iH}(1 - l_{iH})\left[(dS_H)\text{-}m_{a_{iH}}\text{-}\tau_{a_{iH}}\right] + \sum_{i=1}^{k} p_{iL}(1 - l_{iL})[(dS_L)\text{-}m_{a_{iL}}\text{-}\tau_{a_{iL}}] \quad (17)$$

$$1 - l_{iH} > 1 - l_{iL},\ m_{a_{iH}} > m_{a_{iL}},\ \tau_{a_{iH}} < \tau_{a_{iL}}, \text{ and}$$

$$p_{iH}(.)\ increasing\ in\ (1 - l_{iH}),\ and\ p_{iL}(.)\ decreasing\ in\ (1 - l_{iL}) \quad (18)$$

and the assumption that $$m_{a_{iH}} - m_{a_{iL}} = \tau_{a_{iL}} - \tau_{a_{iH}} \quad (19)$$

where l_{iH} and l_{iL}denote leisure of the high and low performers respectively. It is also assumed that dS_H is some form of per unit of effort outcome. In this setting of the model, the principal is interested in the agent's effort and we follow Spence's (1973) rationale that high research performers are more willing to devote effort to research and low performers face a more intense disutility of research effort. Thus, the optimum social result for the principal would be to allocate the resources to a high research-performer. The principal bears a probability p_H to offer a contract to a high research performer and a probability p_L to offer a contract to a low research performer.

The model above suggests that if the principal knew the type of the agent, but still wanted to keep all agents active by offering contracts to both types of agents, he would bear higher (lower) transaction costs when facing a low (high) research performer and would therefore offer a low (high) contract. Therefore, if the principal uses part of the funding as a cost to control low performers, but in the case of high performers he provides them with that funding instead, then, according to (19), whichever choice the principal makes, the funding he provides is always the same.

The key difference is on the output, as the high research performer, by devoting the same effort with the low research performer, would yield more and better output and have more funding to utilise due to lower monitoring costs according to (19). By intuition, in the case of research funding programmes these probabilities must depend upon the design of the evaluation process that the principal follows. Since the principal by definition is the uninformed party he has to deal with the problem of adverse selection through the evaluation process.

If the principal decides to trust the agents with respect to their effort on the project and select them through their past research productivity given the presence of adverse selection in the problem, then the result is optimal. The more the evaluation process takes into account the signalling offered by the agent (past performance in terms of quantity and quality of research output), the higher the probability p_H, as past performance is widely considered as a reliable indicator of research productivity. Conversely, if the principal chooses to follow the avenue of peer-reviewing research proposals, without taking past research productivity into account, he carries a significant risk of suffering from adverse selection. The reasons are simple. Firstly, despite the competence of the evaluating peers, evaluating a future research plan is subjective since the principal does not have the expertise to claim full control of the agent's foreseen actions. On the other hand, evaluating past performance and research results facilitates a more reliable set of criteria: the researcher has submitted the research results to his peers (peer-reviewed journals) and these have already been evaluated *ex post* and not *ex ante* as in the case of research proposals. It is safer to judge research competence from past actions

rather than future intentions even if a research idea seems promising. Moreover, the risk of subjective evaluation of peers due to conflict of interest has been highlighted in the literature. This risk of subjectivity can stem from various factors external to the evaluation criteria and process. These can be in the form of an ongoing scientific conflict owing to personal disputes, different schools of thought or mutual sympathy and friendship arising from past collaboration or alignment of ideas. Such bias in the evaluation process is difficult to detect. In the case of research results though, such problems are less likely. This is because published research results require a higher degree of verification and are open to the judgement of the scientific community. If a peer-review panel allows questionable research results to be published then this will become evident in the criticism to follow and will expose the scientific capacity and professionalism of the reviewers. Conversely, scientific evaluations tend to be kept confidential. The administrators that handle them do not have the expertise to judge whether they contain bias, as opposed to the editors of a peer-reviewed journal reviewing an article. In case a project does not produce research results, the principal is unlikely to ask explanations from a review panel for their past estimation of prospective success of a proposal but will rather ask this explanation from the researcher that carried out the project unsuccessfully. This creates a gap of accountability of the reviewers in the process, which can be mitigated if the signalling of past research productivity is primarily the criterion of research funding allocation.

Adverse selection could also occur when high-performing agents are likely to abstract from applying for funding. This may be a result of sufficient funding from

block grants, lack of available time to run a potential project, or lack of motivation (reached the desired levels of performance or have achieved tenure). This last argument was first proposed by Levin and Stephan (1991) who modelled the career of researchers and found diminishing research output as age increases, owing to limited motivation. This fact is more evident in institutional environments such as the public sector. In such institutions, researchers are not allowed to receive additional monetary compensation from externally funded research projects, albeit the funding is utilised to fund the research group of the funded researcher and may also result in a reallocation of workload from teaching to research. On the other hand, low performers are in need for funding. Not only for producing research output but also for remaining competitive in the sector, asserting a promotion or tenure (Stephan and Levin, 1997) and even avoiding their exit from the science sector. This may lead to inefficient earmarking of research funds to inexperienced or low research-performing agents since the probability of assigning the contract to a low research-performer p_L will be higher due to their increased participation and the imperfections in the evaluation system due to the human factor involved. The implication of this mismatch of performance and funding may lead to research results that are not of the expected quality. This will bring disutility to the principal as he will not maximise his utility. Implicit in the above failure is an opportunity cost whereby the principal could have given the money to another researcher who would produce research results of high quality or he could allocate the money to another productive sector of the economy.

Since it is assumed that research project contracts are characterised by asymmetric information and are the same across agents (as the maximum project budget the agents are entitled to claim is fixed) the principal cannot apply the principle of revelation[9] in order to deal with the problem of adverse selection. Even though compensations of researchers are dependent upon their salary at their employment institution, all researchers, irrespective of their status, are entitled to the same total of budget. So as the principal cannot offer a separate contract for each type of performance information, the best remedy to adverse selection may come by improving the selection process of agents.

Another potential cause of adverse selection is the bureaucracy of applying for funding and carrying out a funded research project. It is a contention of this model that low-performing researchers have a very strong motive to become familiar with the rules of participation of a funding agency in order to gain a competitive advantage over their peers. This applies when the evaluation process is imperfect. On the other hand, high performers have a tendency to focus on scientific excellence and are unwilling to devote time to assimilate bureaucratic procedures. This occurs due to their confidence that possessing research excellence is the sole determinant of success in securing funding from the principal. These assumptions generate a potential adverse selection problem and a natural trade-off for the principal in designing the funding scheme and the evaluation process. It also entails a hidden

[9] A definition of the revelation principle is: "To any Bayesian Nash equilibrium of a game of incomplete information, there exists a payoff-equivalent revelation mechanism that has an equilibrium where the players truthfully report their types (Gibbons 1992, p. 165)"

action from the low-performers who invest in mastering all bureaucratic processes of the funding scheme instead of focusing on performing better in producing research. By keeping simple participation rules, the principal attracts high-performers and does not offer alternatives to low-performers to be competitive against their high performing peers other than improving their research performance. He thus increases the possibility of maximising his utility through research output and future welfare. By being risk averse and setting strict project management rules he has more control over the process but may cause reluctance to high-performers to participate in the funding scheme or may have a number of research proposals not meeting the prerequisite typical requirements. This offers an additional opportunity to low-performers to outperform their high-performing peers, thus resulting in adverse selection. This theoretical assertion is described in the following expressions:

$$E(U) = \sum_{i=1}^{n} p_{iH}(1 - l_{iH})[(dS_H)\text{-}m_{a_{iH}}\text{-}\tau_{a_{iH}}] + \sum_{i=1}^{k} p_{iL}(1 - l_{iL})[\,(dS_L)\text{-}m_{a_{iL}}\text{-}\tau_{a_{iL}}] \quad (20)$$

Adverse selection:

$$1 - l_{iH} > 1 - l_{iL},\ \ m_{a_{iH}} = m_{a_{iL}},\ \tau_{a_{iH}} < \tau_{a_{iL}},\ p_{iH} < p_{iL},\ n < k \quad (21)$$

Optimal conditions:

$$1 - l_{iH} > 1 - l_{iL},\ \ m_{a_{iH}} = m_{a_{iL}},\ \tau_{a_{iH}} = \tau_{a_{iL}} = 0,\ p_{iH} \approx 1,\ k \approx 0 \quad (22)$$

Another version of the model occurs when adverse selection and moral hazard are in the model at the same time. A key difference may be that moral hazard may come from both high and low performers. Moral hazard for low-performers could be

the hidden action of not carrying out the work or not producing the expected results due to the information asymmetry that works on their advantage. In the case of high-performers, the incentive for moral hazard is less frequent. High-performers can produce the results in less time than the one observed by the principal and use part of the funding from the contract either for irrelevant research activities or, in extreme cases of inadequate institutional control, for personal benefit. An example of this hidden action is over-budgeting for an externally funded research project and using the money to hire personnel who can work on other activities as well. In the case of high performers this may occur due to lack of motivation or having a very high reservation utility. The model then implies that the problem of adverse selection comes strictly from low performers and moral hazard comes from both low and high performers. Thus, what is the optimal choice for the principal when facing such trade-off between adverse selection and moral hazard? The principal can potentially control these problems by a) selecting high performers, b) observing only final research output, c) split funding in instalments and render them contingent on actual segments of research output and d) apply ex-post verification. The latter option, however, entails high cost and duplication of work given that in publishing research output in journals this verification process is already in place through the peer-review process. In contrast with the usual principal problem of not being able to observe the final output, in research funding the quality of research output can be observed through considering solely peer-reviewed published output. The scientific community acts as an intermediate agent for the principal controlling research project agents through the screening of their research work. Regardless of

the inability of the principal either to observe or control the effort of the agent, by using peer-reviewed research output he has a greater possibility of optimising his utility. This makes the principal indifferent to the effort of the agent as long as the outcome of the contract is the desired one (Rees, 1984). This of course implies an ex-ante estimation from the principal of what outcome he wants to achieve and the corresponding cost. Once this is done, the principal will not be interested in how the money is spent and will not observe the effort of the agent. Thus by ignoring effort the principal is interested purely for output as shown below:

$$E(U) = \sum_{i=1}^{n} p_{iH}[(dS_H) - m_{a_{iH}}] + \sum_{i=1}^{k} p_{iL}[\,(dS_L) - m_{a_{iL}}] \qquad (23)$$

$$m_{a_{iH}} = m_{a_{iL}},\ \tau_{a_{iH}} = \tau_{a_{iL}} = 0, p_{iH} > p_{iL},\ n > k$$

The transaction costs are excluded from the model since they are now equal to zero. It is obvious that the principal benefited from choosing a high performer as the output is likely to be higher. In what follows, the moral hazard problem is examined in more detail and in a more formal setting.

6.3.4 Moral Hazard Model

We now circumvent the concept of high and low performers and assume one type of researcher and only moral hazard in the model. We derive the first-order conditions and explore hidden actions in more depth.

We apply the principal-agent model formulated in Bolton and Dewatripoint (2000, p.130) with only two outcomes and moral hazard to illustrate the application to research funding. Let us assume that a researcher can perform either what the principal desires (success) or not (failure), in terms of research output. This is

translated in having two probabilities: $p(r)$, representing the probability of the agent of reaching the desired outcome and $1-p(r)$ of not reaching it, where r is the choice of action of the agent. It is implied that the agent has the option of choosing between two types of effort actions: full effort or shirking. It is also implied that the principal can observe this effort. When researchers devote full effort they are always successful. It is noted that $p(r)$ must be monotonic and concave. Therefore, the utilities of the principal and agent are respectively:

$$W = s - m \tag{25}$$

$$U = m - r \tag{26}$$

It stands that the maximisation problem of the principal is represented by the expression:

$$\max\ [p(r)W(1-m_s) + (1-p(r)\,W(-m_f))]\ , \tag{27}$$

under the constraint:

$$p(r)U(m_s) + [(1-p(r)U\big(m_f\big)] - r \geq \bar{U} \tag{28}$$

Taking the first-order conditions with respect to m_s, m_f and r leads to

$$\frac{W\prime(1-m_s)}{U\prime(m_s)} = \frac{W\prime(-m_f)}{U\prime(m_f)} = \lambda \tag{29}$$

and

$$p'(r)\big[W(1-m_s) - W\big(-m_f\big)\big] + \lambda p'(r)\big[U(m_s) - U\big(m_f\big)\big] - \lambda = 0, \tag{30}$$

respectively, where λ is the Lagrange multiplier.

It is apparent from the model that the effort r of the agent plays a significant role in the optimisation problems of both the principal and agent, whereas in a classic principal-agent model without moral hazard, outcome is what matters. Since the interest for welfare economics lies mainly in the maximisation of the principal's utility, being a social planner, it is imperative to analyse the options he carries in terms of risk. In research funding, the term m corresponds to the monetary compensation of the agents as well as the amount used for enhancing their research.

The model with moral hazard carries some substantial shortcomings when it comes to research funding. Realistically, the principal cannot fully observe the researcher's actions as he does not possess the knowledge to act efficiently in such manner. Therefore, in the context of research, this assumption is restrictively strong as it deducts one of the main common characteristics of the classic principal-agent model and the research funding process. Even if the principal could base his judgement for the effort upon specific reporting signalled by the agent (progress reports, work timesheets, etc) there are still ways that the agent may act manipulatively and present misleading effort evidence to the principal. No single way exists to measure the effort of the agent, let alone a highly specialised agent such as a scientist. Another important difficulty in measuring effort is the uncertainty inherent in research. In some cases research results are not produced as expected due to complications outside the control of the researcher. As a result, the researcher may have to follow alternative techniques or experiments and this effort is not recorded. Even if a system is in place that captures these changes in research direction, in

some cases the agent may take advantage of this flexibility and present misleading information to the principal of such problems when in reality there were not any. This hidden action is another form of moral hazard.

Based on this discussion, it may be that the only viable solution is to consider research output as the only criterion for success and base funding allocation strictly upon the occurrence of output. Diamond (2005) traces this rationale of connecting academic funding to output back to Adam Smith. This approach suggests a risk neutral principal willing to trade effort monitoring with a pre-specified research output. Therefore, the principal can act proactively and apply as a success criterion a research output floor, under which no funding is given to the agent. Only in rare cases where the agent reports problems in carrying out research activities should the principal adjust his output expectations or perhaps provide a time extension to produce the desired results.

Hence, by keeping project management rules simple, the principal, being risk neutral, lacks control of the monitoring process risking some degree of moral hazard by researchers who lack motivation. By being risk averse and setting strict project management rules, although he claims more control of the process, he does not really achieve full monitoring as he does not possess the expertise to act so. He has the option of assigning this task to an intermediary agent who will be able to judge whether the agent's effort is realistic. However, apart from additional transaction costs, this gives rise to the need of monitoring both the intermediate and final agents, rendering the problem much more complicated than before.

The above analysis dictates that the principal in the research funding process cannot fully observe effort in an optimal way, whatever decision he takes. The only way to perform optimally is to observe final output and keep the compensation contingent on it. The rationale is the same as in adverse selection: publications in peer-reviewed journals (or patent applications if it is technological research) serve as cost-free monitoring of research output albeit they may not reflect effort perfectly in the presence of moral hazard. This can be also treated by observing intertemporal patterns of funding contracts' duration in conjunction with extracted research output and benchmark the expected floor of research output and the corresponding payoff. This will facilitate a more standardised process by setting clear criteria for research output upon which the allocation of funding will be based.

6.4 Policy Implications and Discussion

We should clarify at this point that the results of the present chapter cannot form the sole tool for formulating appropriate policies for research funding allocation. Such policy making needs to be contingent on the surrounding conditions of a research funding system in a country. As a result, the discussion and suggestions that follow must be considered within this framework. A general notion as to what is optimal for research policy according to the findings of the chapter will be provided.

The theoretical premises of the chapter support the use of past research productivity as a signal for the policy-maker to allocate research funding in an optimal manner. It is asserted that relying on such information to infer on the competence of agents maximises the probability of having high quantity and quality of research output.

Moreover this can help tackle problems such as adverse selection and moral hazard. In this light, what follows designates a number of suggestions along with related discussion. The general thesis is that past research productivity must be generally taken into account separately from the rest of the evaluation process of research proposals.

a) *Pre-specify and construct sophisticated metrics/benchmarks of research productivity to be used for evaluation purposes.*

This suggestion entails the quantification of research output of scientists, upon which the greatest weight of the funding decision will be placed. The creation of such indices or benchmarks at the national or even at the European level for all researchers applying for funding can make the process of proposal evaluation straightforward and fruitful. Researchers will be more focused on presenting their ideas in a concise manner rather than presenting a CV which can be biased, inaccurate and in certain cases useless if the wrong elements are considered by the evaluators. National research councils should focus on creating metrics which will be representative of the research productivity of the country's scientists, taking into account what is important for both the national priorities and the international dimension of science. For example, in some countries local journals may be of high quality but in other countries this may not be the case. On the other hand, for a country, it may be of paramount importance and urgency that the scientists produce research results with a local character rather than international dimension. These factors should be addressed through these indices if the countries want to retain a

balance between their rank position in the international research area and the positive spillovers of local-oriented research results in their economies.

It is imperative in such a development to take into account the stylised facts of different thematic areas. We have seen in Chapter 3 that there are different publishing patterns across different scientific fields. Also, in some fields, traditional metrics of research output such as journal publications are not the norm. These differences should be addressed in the creation of such a system so as to have separate benchmarking for each field and devise normalisation formulae when evaluation has to be done in comparison of researchers from different scientific fields. Such a normalisation methodology is already in place for measuring the quality of publications through citations according to the characteristics of the field and is used for evaluating and comparing journals from different disciplines[10]. Using this methodology requires its transformation to an individual-specific metric.

Another illustrative example is the importance of scientific collaboration. The intuitive notion is that scientific collaboration is desirable and thereby encouraged. Hence, it can be argued that co-authorship is a plus for publications when considering research productivity. Nevertheless, a scientist that produces only collaborative research work may be considered as an opportunist who builds a publication record based on efficient networking strategy rather than competence. If the evaluators review the list of publications without considering the actual contribution of the researcher to the output described then it is possible that

[10] Source Normalized Impact per Paper (SNIP). Available at http://www.journalmetrics.com/snip.php.

researchers with just excellent networking and communication skills can outperform their competing superior counterparts in the funding race. Judging on these extremes, it is of utmost importance that a thorough analysis be undertaken to design appropriate research productivity indices. Clear and easy to understand rules must be established as to which factors affect these indices and to what extent. The proposed system should be developed through a consultation process with the research community of each country.

b) *Design the evaluation system in such a way where only researchers with higher productivity and research quality are assigned to evaluate their peers.*

The thematic concentration of research proposals is often the sole criterion for selecting evaluators. Indeed, it is not straightforward to find a scientist with the same specialisation and a rich research portfolio in the same field of the proposal. However, this limitation may downsize the quality of the evaluation, if the evaluator does not have the scientific rigour and experience needed for evaluating the innovative potential of a research proposal. It can also harm the reliability of the evaluation process before the eyes of the research community, casting doubts and unwanted objections, especially in case the comments of the evaluators are not well substantiated on the basis of the merits of the proposal. In Chapter 4 where we empirically examined whether the best researchers get the money from a competitive funding scheme, a potential reason that leads to having recent research productivity rendered insignificant may owe to this factor. If the selection of the evaluators by the funding agency does not secure competence and experience both

in knowledge of the field and in judgement upon the merits of a proposal then it is no surprise that recent research is not important for selecting proposals for funding in our empirical study.

c) Use the indices to assign research funding directly to the researchers that rank highest in the relevant field if the funding scheme aims exclusively at high quality results.

The rationale for this measure is simple: who has the highest probability of producing high quality research results? A researcher that has presented a previous research activity of high quality and impact is the most promising in terms of producing the desired results, especially if the funding aims at maximising the value added for the economy of the country. Geuna (1996) studied the allocation of funding to higher education institutions within the EU FP and referred to the importance of exploiting the signals given by past research performance and reputation to reduce transaction costs. This study is representative of this point we make here. Less experienced researchers should be funded either within the framework of a project where more experienced researchers will be coordinating, or under the condition that the priority of funding will be focused upon integrating new and inexperienced researchers in their scientific fields (PhD students, recent PhD holders *etc.*). An alternative would be to set minimum criteria to be considered eligible for applying for this type of funding. An example is the EU FP funding scheme, which has two types of prerequisite criteria when it comes to fund research excellence. In the Marie Sklodowska-Curie fellowships for post-doctorate researchers there are prerequisite criteria such as minimum research experience. Therefore, a quantifiable measure to exclude less experienced researchers from the

evaluation process is in place. However, the second type of prerequisite criteria is more substantial and concerns the European Research Council grants programme. No researcher with more than two years of research experience after the PhD award is excluded but from that point there is a minimum expected research output. For example in the Starting Grant which is for researchers up to seven years of post-doctorate experience the quantitative criterion is at least five publications in journals with high impact factors without the participation of the PhD supervisor. Hence, if a minimum threshold is set *a priori* then the probability of assigning a grant to a high research performer is maximised as the low performers are left out of the evaluation process. This is in line with our model whereby an efficient evaluation system would secure the best research output and the maximisation of the utility of the social planner.

d) Formulate clear and value-added strategic priorities within which research projects will be funded.

Policy makers should decide which thematic areas are important for countries. If a demand-pull policy is the aim as we analysed in our model, thematic areas that enhance the comparative advantage of a country in an economic sector can be considered ideal, especially due to the on-going economic crisis. For example, in Cyprus, research undertaken in the field of solar energy may be promising both in terms of a) cost reductions through the immense local possibilities for low-cost renewable energy and b) originality and relevance of scientific contributions to the global pool of knowledge. These scientific fields have the advantage of aligning the interests of the principal and the agent in our model and, as discussed, in such cases

the result is optimal. We could state that this is a demand (principal's wants) and supply (agent's wants) equilibrium. If competitive funding is shifted through a well-designed research funding system towards such scientific sectors, then the desired research results are more likely to be produced on time and to be of high quality.

e) *Make the monitoring of funded research projects entirely output-driven and minimise monitoring costs and bureaucracy.*

It is implicit that the majority of scientists that secure research grants will try to fully exploit the funding to produce high quality research results. This output, in turn, will help them advance their careers. Scientists are one of the few professions whereby motivation is said to stem from personal interest and passion to solve the puzzles rather than seizing opportunities to deceive the system and commit fraud. This special characteristic of researchers alongside the uncertainty in the research process itself should be the bases on which monitoring systems of funded projects are established. Observing the effort of researchers is costly and most of times fruitless in the sense that the policy-maker cannot judge if the agent is doing what he committed to do through the funding grant. The solution of peer-review of a project is costly and constitutes duplication of work as scientists have their work reviewed by peers in the phase of publishing in journals. Therefore, setting what is expected *a priori* is critical for having the funding grant connected to tangible results that need not deviate from the usual forms: journal articles, book chapters, conference proceedings, patents etc. Progress reports that are not used for any purpose other than the update of the funding agency's registry should not be a part of a monitoring system. Scientists will only be judged on the quality of their research

output and not the effort they devoted in achieving it. David and Keely (2003) support that the complexity in science and its contemporary facet dictate increased flexibility in the related funding schemes. The policy-makers in the UK have implemented such an approach by choosing to trust the research agents and judge them only upon final output (Simmonds et al, 2010). On the other hand, the Research Promotion Foundation of Cyprus and the EU FPs, albeit to a lesser extent than before, continue to pose strict monitoring on research processes rather than output. Simplifying the bureaucratic process of the monitoring system is likely to attract scientists of higher calibre that will gradually improve the knowledge pool. The other desired effect will be that it will enable dealing efficiently with problems such as adverse selection and moral hazard as it will discourage opportunistic behaviour.

f) Make use of the Centres of Excellence funding instrument

A funding instrument that deserves further attention is one that draws from the centres of excellence rationale as described in Borlaug (2015). This instrument starts with a competitive call for proposals and proceeds with a detailed evaluation process of these proposals. A number of institutions are judged upon their quality of research, personnel, infrastructures and other research quality-related criteria. Then the most promising institutions are selected and they are provided with long-term funding to carry out high quality research. No monitoring of the effort is needed as the centres of excellence will aim to produce published research results, which will be immediately available to the policymaker. This detailed evaluation process shields the policymaker from the problem of adverse selection. For the problem of moral

hazard a plausible solution would be for the principal to transfer the monitoring to the centre of excellence and ensure that processes are in place to have internal control over the actions of the researchers. This is the case in the majority of research institutions across developed countries and the principal can carry out an initial monitoring to verify that structures are in place to prevent uncontrolled actions by the agents. In this case, the principal is forced to combine research output indicators and a panel-review process to evaluate the proposals, albeit a costly method. The reason is that the principal will not employ strict monitoring for the project execution and is willing to bear higher transaction costs for the evaluation to then secure a smooth progression of the project. In conclusion, the principal manages to avoid adverse selection and moral hazard, even though in tackling the former problem the costs become higher than optimal.

6.5 Conclusions

In this chapter a theoretical framework to explain the research funding process through the principal-agent model was presented. Three different versions of the model were considered that focused on outcomes under perfect information, adverse selection and moral hazard.

It seems that monitoring of effort and output of the agent by the principal, as well as the desired research orientation of both the principal and the agent, are the factors that determine to a great extent the incentives and the optimisation of their utilities. In all settings of the model, the most reliable form of signalling in our view, is past research productivity. This is able to play a catalytic role in harmonising the process between the two parties.

In the case of adverse selection, by providing the incentives of less bureaucracy and free research orientation, the principal attracts high-performers and maximises research output. This relies upon a fairly simple evaluation process where contracts are assigned to the researchers with the highest past research productivity. If optimal research orientation is not feasible a combination of curiosity-driven and applied research can mitigate the effects of adverse selection.

A similar pattern applies for the moral hazard problem. By following a simple evaluation process, the principal accepts the signal of past research productivity as indicative of effort and chooses to observe only final output by benchmarking what is expected from a funding contract. Even though the principal considers that all researchers are equal performers, he correlates in an averse manner the possibility of shirking with past research productivity and thus saves disutility from costs of strict monitoring, increasing the probability for optimal research outcomes.

The empirical chapters of the thesis have fed to a great extent the theoretical model of this chapter, as well as the policy suggestions. In Chapter 2 we established the concept that scientific research has a positive effect on subsequent economic growth. This finding is important as it substantiates the objective of the principal to maximise research output with view to experience this positive effect on growth. In Chapter 3 we explored the effect of different types of funding on research productivity and found that most funding types are important. This result supports the idea that researchers systematically seek funding and this funding impacts on their output helping us to understand the motivation behind the agent's choices and trade-offs. Chapters 4 and 5 deal with competitive research funding allocation at

the individual and country levels respectively and offer most empirical information to formulate the theoretical model in Chapter 6.

This chapter conveys the main limitations of the analysis with the first being that the three versions of the principal-agent model we present are not always substantiated by either analytical solutions or numerical simulations. Also, the fact that the model is static does not accommodate repeated games between the principal and the agent and does not discuss whether different solutions to the trade-offs of the two parties could be extracted. These are proposed as challenges for future research. What the model in this chapter does incorporate are the empirical findings from chapters 2 to 5 as well as the existing literature on this topic.

7 CONCLUSIONS

7.1 Synopsis of findings

The present thesis endeavoured to add to the literature of the economics of growth and science discussing extensively the related policy implications. The following figure depicts the ideal system through which the two fields of economics are linked and interact aiming at the socially desirable outcome of achieving economic growth.

The figure states that when designing R&D policies it is imperative that the target is set at maximising the efficiency of the funding available by implementing the allocation of the grants in the optimal way: giving the money to the best and most promising researchers. Then the process of monitoring the funded projects should be such that utilisation in terms of producing high quantity and quality of research output is the best possible. This step requires thorough policy making since the trade-off between bureaucracy and productivity may bring the opposite results if the optimal combination of the two is not secured.

Once the scientific knowledge is produced this should be exploited through its potential impact: use the pool of scientific knowledge to produce technological and social innovations and either improve the existing or develop new products, harvest highly skilled human capital from the higher education system, and use these enhancements to improve the factor of productivity in the production function. This impact sequence is likely to result in economic growth given that productivity is widely acknowledged in the endogenous growth field as the only factor of production that can generate increasing returns to scale. If the policy-makers

appreciate the contribution of scientific research to the enhancement of economic growth they will devote a higher share of the increased GDP for funding research activities and the process of the system will iterate in the same manner described above. There are two key differences from the initial figure that presented the system in Chapter 1 of the thesis as shown in Figure 7-1. Firstly, the block grants have been removed since it is strongly supported that these grants should be earmarked on a competitive basis as well, but at the institution level. Secondly, the optimal conditions for each step are described, stemming from the learning outcomes of the thesis. These outcomes are outlined and discussed in the next section.

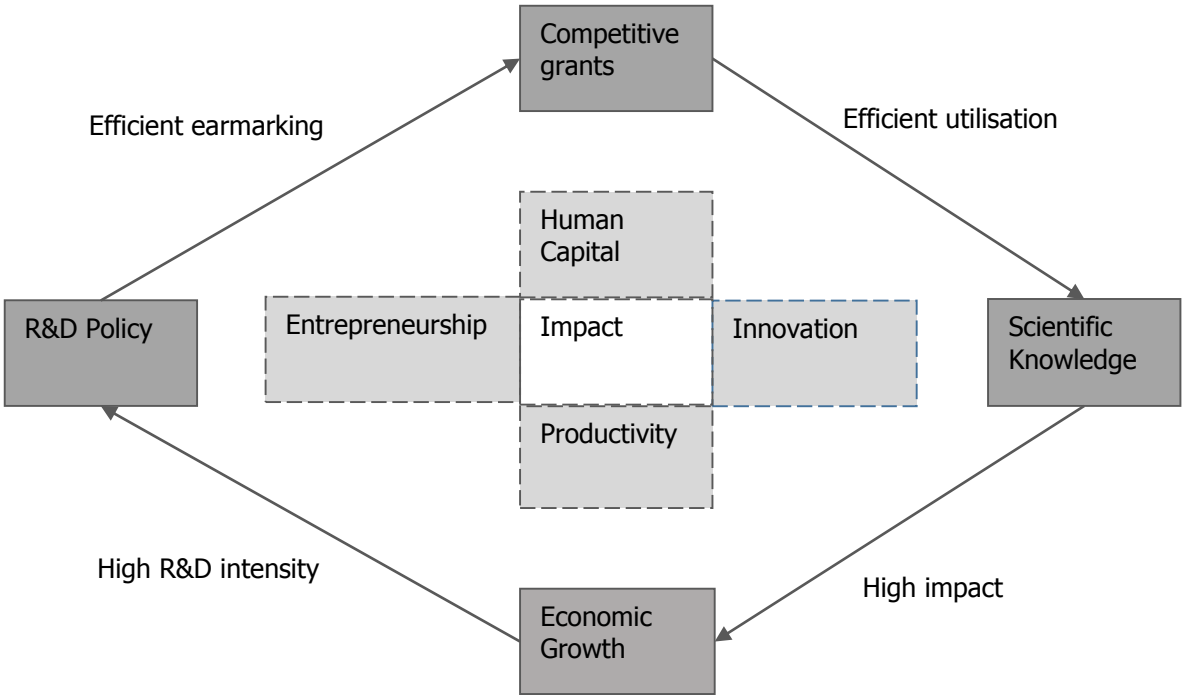


Figure 7:1: Proposed system of R&D policy to economic growth

7.2 Contribution to knowledge

The thesis has produced novel results that contribute to the literature in the economics of science and growth. All datasets used are either fully original or combine existing datasets and add new information to assert uniqueness.

Firstly, we are the first to construct and estimate a model of economic growth for the EU countries that studies the effect of research output in three broad scientific areas on subsequent growth. The study was largely based on endogenous growth theory, which is corroborated through the significance of lagged values of Science and Technology and Social Sciences research output on future growth, through patent applications, with a 10-year lag. This answers our research question of whether scientific research has a positive effect on national growth of the EU countries.

In the third chapter we analysed the effect of research funding on future research productivity. Although funding has been used in numerous studies as a control variable for explaining research productivity, it has been only superficially examined as a variable of interest, a deficiency overturned in the current thesis. The new knowledge arises from the use of different types of funding, studying their effect on the quantity and quality of research output in subsequent time intervals. Also, the econometric estimation and its challenges are addressed in detail, including three different techniques: fixed effects static modelling, dynamic panel data and multilevel modelling, being the first study in research funding and productivity to have done so. We detail on potential simultaneity whereas other studies either rely heavily on fixed effects to handle simultaneity or simply ignore the problem and

produce estimates with questionable consistency. This shortcoming was encountered even in some of the seminal works carried out in the field like in Levin and Stephan (1991). To tackle this shortcoming, we are the first to discuss and empirically apply alternative hypotheses that depart from the traditional theory supporting the existence of some form of research talent causing both funding success and high research productivity. Our assumptions are strong but provide an unconventional approach for the economics of science literature that can open doors for more efficient methods of estimation and analysis such as multilevel modelling. We pool together research output from different thematic areas and handle the heterogeneity with a three-level model where research output is nested in individuals and individuals are nested in scientific fields. We thus achieve considerably high efficiency in the estimators producing results in accord with the pertinent theoretical premises. With reference to our research question of whether different types of funding increase research output of individuals we found that, in the cross-section setting, national competitive funding along with non-conventional (other) funding are the only types that seem to be positively and significantly related to citations and impact factor related measures. In the panel setting, national competitive funding seemed to affect positively the quantity of research output as well, with both three-year and six-year lags. The other types of funding such as EU and internal seem to matter only in specific scientific fields whereas in some cases the sign of the coefficient is counter to intuition.

Chapter 4 endeavoured to explain research funding allocation based on research productivity; both from the quantity and quality perspectives. We constructed and

used a unique dataset of funding success as measured by counts of funded projects and grant amounts and used a wide range of research output indicators as predetermined regressors to investigate the effect of research excellence at the individual level on subsequent funding success. Even though there are a few studies that engaged in researching this vital issue, our detailed methodology both in terms of the variety of research output indicators as well as the use of moving averages, career averages and cumulative measures are a core contribution to the literature. We found an ambiguous answer to our research question of whether the best researchers get the money from competitive research funding schemes. If by best researchers we mean the ones with the best career research output and reputation then the answer is yes since our empirical findings show an association of career-wide research quality with funding success. If one the other hand, we mean best in terms of research productivity and recentness of research output then the answer is probably no as the majority of the corresponding estimates for the average productivity of both the three years before the proposal and the career are statistically insignificant.

Chapter 5 is the most original study of the thesis, in the sense that all its elements are novel. This is true to such extent that finding relevant literature was one of the hardest tasks of the present thesis. In economics, no single study exists that examines competitive research funding allocation at the country level since the EU FP may be the sole funding mechanism of this kind, where countries contribute to a common pot and then compete for funding from that pot. There are studies that focus at the individual, group, department or university level success for funding

from competitive grants from various types of funding agencies but no single paper engages in such research at the country level. We examine the determinants of applications and success of EU28 countries for the whole duration of the FP7 on a yearly basis. Aside from some technical reports of the European Commission, our contribution is novel and it can form the cornerstone for future studies for the next Framework Programmes or other EU collaborative programmes. We find interesting answers to our pertinent research questions of how funding is allocated and what is the role of research output and productivity. Comparing countries of low or high research capacity, we find that for research followers both scientific publications and international collaboration matter for FP7 applications and success. In contrast, for research leaders, publications matter for FP7 applications and citations matter for FP7 success rates.

Chapter 6 is the sole theoretical paper of the thesis. Its purpose is to discuss policy implications based on the findings of the empirical papers and utilise the principal-agent model to formalise the process in a structured manner in order to understand the motivation and the trade-offs between the social planner and the economic agents. In our case the research policy-maker is the principal and the researchers are the agents. It must be pointed here that the model does not have the usual outcome, that is, the derivation of the optimal payoff that lead both the principal and agents to maximise their utilities. It is implicit that optimal policies lead to that point but finding the optimal payoff goes beyond the scope of the thesis. However, apart from serving as a vehicle for discussing policy issues the paper contributes to the literature by setting the bases for elaborating such models in the future. It is a

major challenge on its own and it should be classified as such, since only very few studies have enquired in principal-agent models to put a formal theoretical structure on the research policy-research output matter. Our model and discussion helped us greatly to provide a plausible answer to the relevant research questions addressing optimality of funding allocation and research productivity. We support that through the reduction of bureaucracy to the minimum level the policymaker can achieve the highest possible payoff by limiting the possibility for adverse selection or moral hazard. We also conclude that, the closer the thematic orientation of research output of the principal and the agent, the more likely it is to have an optimal outcome. In case of perfect coincidence then the outcome is the optimal.

7.3 Limitations of the thesis

The thesis was engaged in a number of issues in the field of economics. Although it has provided useful insights on important problems, it still carries a number of limitations. The first is that albeit being an agglomeration of different studies in economics, the thesis did not provide as much as the author had envisioned in terms of interpreting the marginal effects of different explanatory variables. The marginal effects are very important as they form one of the core economic issues of concern when examining an economic model. However, this insufficiency was due to the complexity of the econometric estimation processes, whereby, in the majority of the cases, the transformation applied to the original datasets or the format of the data was such that dictated the use of models with weak interpretation properties. We mitigated this limitation by providing and discussing elasticities or semi-elasticities whenever that was possible.

The second limitation is that in the two chapters with Cyprus being the case study, the generalisability of the findings is questionable and one could argue for selectivity bias. As discussed throughout the thesis, researchers in the sample possess similar qualifications to their international counterparts and Cyprus has comparable characteristics to other economies, meaning that our findings can be generalised to other developed economies. Furthermore, our research methodology is also applicable to other countries. The econometric models and the extensive discussion of all possible alternative solutions are a paradigm of econometric approach that can be followed whenever examining research productivity and funding in any country and within any context, insofar as potential endogeneity is judged upon the attributes of the applicable country or universities under analysis.

Another limitation of the current study is that the theoretical model developed in the sixth chapter, where the incentives and interactions between the policymakers and the researchers are accommodated within the principal-agent framework, does not reach the standard conclusion expected in economics. The principal-agent model is utilised mainly to formalise and discuss the process of research funding allocation and research productivity. It is based on micro-foundations by discussing the utility maximisation and the choices and relevant constraints of the involved parties. This facilitated further discussion in terms of policy and suggestions for policymakers based on the findings of the four empirical chapters of the thesis. However, we did not proceed into finding analytical or numerical solutions to obtain the optimal payoff between the principal and the agent as this is beyond the scope

of this thesis. A suggestion for future research could be the validation of this model, although such an undertaking involves substantial research challenges.

7.4 Further research

The economics of science field is young and there is still plenty of room for new studies. On the other hand, the field of economic growth has been studied extensively in the last 60 years and the obvious suggestion for its improvement is to collect and exploit more recent data in an effort to substantiate empirically the endogenous growth theory, a development not yet present in the literature. Also, by using advanced technologies to collect data for countries, for which this facility was not available in the past, researchers in the field can enrich the knowledge pool for developing economies.

In the economics of science, it is very important for researchers across Europe to consolidate their efforts by carrying out collective, and preferably, longitudinal studies for research productivity and its determinants at pan-European level. The EU is allocating immense funds for research and innovation and the grounds for this policy direction should be rendered sound by obtaining a clear guideline as to the areas to which R&D policies should be concentrated.

In another relevant note, the EU must open access to funding and productivity data for research in order to optimise the results. Extracting data for the analysis in Chapter 5 was a difficult and time-consuming task. The difficulty in accessing EU-related data is in contrast to the ambition of the EU to make research results and datasets easily available to all researchers and other interested stakeholders. Greater availability of funding information could help extend the analysis carried out

in Chapter 5 beyond just FP7 to the previous and future framework programmes and could also provide an opportunity to examine the funding allocation efficiency at the institutional and individual level.

Also, further research is needed in the construction of a solid theoretical model to better understand the production of scientific research output. We have suggested a principal-agent model for discussing research policy and funding decisions but a model that takes into account the multiple output nature of research output is needed. In this thesis, we coped with this by using a reduced form model and considered all outputs other than the output of interest as exogenous. Nevertheless, at some point the metrics for the research output of scientists should be consolidated to accommodate new developments in the academic system.

Finally, the quest for investigating the determinants of research output should be extended to different directions. Numerous studies have addressed this issue but no consensus exists for the most critical factors that cause differences in research output among academics. While in the present thesis we focused heavily on the importance of different types of research funding for future output it is doubtful if this is solely responsible for the variation of output. Perhaps, addressing other issues such as group structure, collaboration, multi-disciplinarity and the very process of publishing which takes time and differs across disciplines could provide new insights.

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