ESSAYS ON FINANCIAL MARKETS

by

Aima Tahir

A thesis submitted to the University of Birmingham for the

Degree

of

DOCTOR OF PHILOSOPHY

Department of Economics

Birmingham Business School

College of Social Science

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University of Birmingham

November 2019

Dedication

To my mother for everything. Love you to infinity and beyond!

Acknowledgements

I would like to thank my supervisors Professor Zhenya Liu and Professor David Dickinson for letting me have the opportunity to study towards a PhD. I would like to extend a special thanks to Professor Dickinson for teaching me wisdom and supporting me through a phase of life where I could see nothing but darkness. He has and will continue to be a father figure in my life.

I do not have words to express gratitude towards my parents, Mr and Mrs Mehmood Mehdi, specially my mother. Without her support and motivation I would not have been able to achieve anything. I would like to thank my son, Aaiman, for understanding that mommy was missing for most parts of his early years since she was trying to finish her PhD. I appreciate my husband's understanding towards my career goals and his acceptance of me as a 21^{st} century Pakistani woman. I must mention that I am extremely grateful to my maternal aunt, Seema for all her love and kindness. I am also very grateful to my Aunt and Uncle, Mr and Mrs Masood Anwar for hosting in the UK and for loving me.

I would like to thank my very special friend Fahimullah Hayat for his motivation and love. I can not submit without thanking my childhood besties Zunash, Anum Ali, Mahwish and Yildiz for the memories we have made over the years.

At the end I would like to say that much of it is your own willingness to persevere in the face of adversities and that is what makes me proud of myself.

Abstract

The impact of uncertainty is one of the most widely studied topics in economics and finance. It has become a major concern for economists, policy makers, agents in financial markets and households. Pastor and Veronesi (2009) presented a theoretical model explaining how negative uncertainty causes contraction in economic activities, decrease in stock prices and reduction in demand. At the same time the model also shows that positive uncertainty such as advancement in technology and strengthening of trade links can have positive impact on real activity.

The effect of uncertainty on the financial sector is an empirical issue. By utilizing Baker, Bloom and Davis (2016) Economic Policy Uncertainty index which is a robust proxy of policy induced economic uncertainty this work shows that in the UK, Jegadeesh and Tittman (1993) momentum returns only exist following months of low uncertainty and is absent following months of high uncertainty. Further, using time varying dynamic conditional correlation it is shown that stock markets in the OECD region are adversely affected by economic policy uncertainty. The results of the third chapter indicate that economic policy uncertainty significantly adds to the long term volatility in brent oil, silver, palladium and aluminium futures.

The next part of the thesis empirically test the appropriateness of global optimization

technique to fit non-convex yield curves of the Nelson-Svensson-Siegel family using Bundes Bank data. Lastly, using canonical models of instantaneous interest rate the results show that real interest rate in the US does not follow mean reverting behaviour between 1978-2017.

This research adds to two strands of the existing literature. The first strand adds to research related to economic policy uncertainty, which is thus useful for policy makers and participants in the financial markets. The results provide evidence on reaping excess momentum profits following months of low uncertainty. The results also provide evidence against simultaneously investing across markets in the OECD region. Thirdly results show that metals like platinum and aluminium are safe hedges during periods of high economic policy uncertainty.

The section on interest rates, adds to the existing literature such that it improves the overall accuracy of yield curve which are further used in policy making by economists. Using inappropriate methodologies to fit yield curves would not only result in spurious curves but also in flawed polices and policy outcomes. Lastly by calibrating real interest rate for the US policy makers can probe the elasticity behaviour of consumers and target inflation accordingly.

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1 Introduction

This dissertation is a collection of six loosely tied essays spanning on the topic of Economic Policy Uncertainty (henceforth EPU) and interest rate modeling. The first three essays are based on EPU and the last two essays are based on interest rate modeling. A summary of the chapters is as following:

1. **Understanding Economic Policy Uncertainty**

   This chapter is aimed at explaining the concept of economic policy uncertainty to the reader as it is used as the main variable of interest in the following three chapters. EPU index is a news based uncertainty index developed by Baker, Bloom and Davis (2016). This index extracts information appearing in news articles and converts it into a consolidated index which can be used as a proxy for economic policy uncertainty. It also covers the construction methodology of the index and discusses the major trends in each country. Further

it comprises of selected literature which ensures the significant explanatory power of the EPU index.

2. **Economic Policy Uncertainty and Momentum Returns: Case of the UK**

   This chapter is aimed at testing the impact of economic policy uncertainty on momentum returns in the UK. This task indirectly helps in explaining the existence of momentum anomaly in London Stock Exchange. Momentum anomaly as studied in Jegadeesh and Tittman (1993) explains that portfolios formulated on buying past winner and selling past loser stocks results in gaining excess profits which remain unexplained by CAPM theory and Fama and French three factor models. This chapter shows that economic policy uncertainty significantly contributes towards the existence of momentum returns in the UK. The robustness has been tested after controlling for macro variables including market state, business cycle and market volatility. The results show that momentum returns exist following months

of low policy uncertainty and are insignificant after months of high policy uncertainty.

For UK's stock market the results confirm that momentum returns are absent following periods of high policy uncertainty. This could be due to investors loss of confidence in the stability of government policies that are covered in the EPU index. It also shows that investors respond to the political and economic news that appears in newspaper articles.The effect of EPU on UK stock market has not been covered in the past literature which is the main contribution of this chapter.

3. **The Impact of Economic Policy Uncertainty on Commodity Future Returns**

   This chapter looks at the impact of economic policy uncertainty on the long term volatility in commodity futures prices. Keeping in mind the frequency mismatch between uncertainty and commodity

futures prices I use GARCH-Mixed frequency data sampling. The results show that EPU effects futures prices for aluminium, palladium, copper and brent oil however similar effects are not evident in platinum futures. These findings are novel as past literature only covers gold futures.

4. **Does Economic Policy Uncertainty Cause Dynamic Movements in OECD Stock Markets?**

   This chapter aims at finding the time varying conditional correlation between EPU index and stock market indices within the OECD region. Results obtained through GARCH based dynamic conditional correlation exhibit that out of a sample of fourteen countries one month lagged uncertainty negatively affects index returns. However in the case of Australia and Canada the relation turns positive after 2016, aligned with the theoretical implications presented in Pastor and Veronesi (2009) explaining that uncertainty can have both positive and negative impact.

A thorough look into the impact of policy uncertainty on stock markets shows that investors indulge into conservative behaviour in times of high political uncertainty. However this correlation can become positive for brief intervals of time as shown by results for Australia and Canada.

This chapter fills the gap such it studies time varying conditional correlation for a large sample of OECD countries further it highlights countries that show unconventional behaviour.

Interest Rate Modeling

The second part of the thesis focuses on interest rate modeling. I discuss two aspects of interest rates which are yield curves and the elasticity of real interest rates. Yield curves are significant for financial institutions such as central and commercial banks as they have the ability to predict the future of the economy and they also help in determining the return

on medium and long term bonds. Where as the elasticity of real interest rates helps in determining household behaviour.

5. **Calibrating the Nelson - Siegel - Svensson Model**

   This chapter studies the two most widely used parametric yield curves including Nelson-Siegel and Nelson-Svensson-Siegel. The problem revolves around the non convex functional form of the curves which require global optimization techniques to obtain empirical solution. When compared to standard non-linear optimization techniques parameters obtained through differential evolution have shown lower standard deviation and higher out of sample forecast accuracy.

   Nelson-Siegel and Nelson-Svensson-Siegel type curves are parsimonious and are widely used by Central banks. Therefore enhancement in estimation methodology which contributes towards numerical accuracy of the results is the main contribution of this chapter.

6. **Elasticity of Real Interest Rates**

The aim of this chapter is to calibrate real interest rate for the US economy. Studying real interest rates for the US holds significance for economists and policy makers in terms of inflation targeting and it also helps house holds in understanding the value of money in real terms. The main contribution of this chapter is to empirically prove that real interest rates have shown non-mean reverting behaviour in the US between 1978-2017, with unit elasticity. The results are obtained using ex-ante measures of survey based inflation, the econometric analysis are based on seven uni-variate canonical models of instantaneous interest rates.

2 Understanding Economic Policy Uncertainty

2.1 Background

Economic policy uncertainty has become a focus in today's turbulent economic environment. However a numerical measure for uncertainty is a topic of debate. A recent and cumulative method of quantifying economic policy uncertainty is a news based index constructed by Baker et al. (2013) and Baker et al. (2016). The news based index is a numerical proxy for policy induced economic uncertainty. This index uses information appearing in news articles to proxy economic uncertainty. The index was initially formulated for the US based on the historical archives of six main newspapers.

Policy induced economic uncertainty is the part of economic uncertainty that is caused due to uncertainty about government's future policies regarding fiscal and monetary issues. It also includes uncertainty caused by changes in political regimes, instances of war and major events such as

signing of foreign trade deals. A major difficulty in handling economic policy uncertainty is that it is not exogenously observed however there are variables which when studied together give us the understanding of economic policy uncertainty.

2.2 Construction

Baker et al. (2013) constructed an index to be used as a proxy to calibrate policy induced economic uncertainty. Baker et al. (2013), the EPU index captures 'who', 'when', 'what', aspects regarding policy changes. The index is meant to capture information regarding *who* will make economic policy decisions, *what* economic policy actions will be undertaken and *when* they will be enacted, the economic effects of past, present and future policy actions and uncertainty induced by policy inaction.

2.2.1 Construction: Steps

The construction of the index is based on the following three steps:

1. Selecting newspapers articles on the condition that they contain the

trio of the following words, Economic (E), Policy (P) and Uncertainty (U).

2. In the next step other common words that appear with, Economic (E), Policy (P), Uncertainty (U) terms are highlighted and a count is collected. The most common words that were highlighted for the US included 'economic' or 'economy' for 'E' terms. 'uncertain' or 'uncertainty' for 'U' terms. Where as the Policy (P) terms for the US included "regulation", "budget", "spending", "policy", "deficit", "tax", "federal reserve", "war", "white house", "house of representatives", "government", "congress", "senate", "president", and "legislation" (and variants like "regulatory", "taxation", etc).

   For newspapers in different languages economists and specialists in native language are consulted. Policy (P) terms differ by country in order to include geographically correct policy related terms however 'E' and 'U' terms remain unchanged.

3. In the last step a raw count of the number of articles containing these words is standardized (to mean zero and standard deviation one). And an average of these standardized indices was calculated in order to formulate a consolidated index.

2.2.2 Construction: Pilot Study

The index was first formulated for the US using a pilot study. The authors formulated a pilot study in which the authors studied a few hundred articles themselves (a team of researchers was hired for the entire study) to analyze the information in the articles that contained the E (economy, economic), P (policy) and U (uncertainty) terms. They also short listed other words which occurred frequently in these articles to highlight policy related words. This human based pilot study was also used to mitigate any faults in the soft-wares used to search online archives. Then codes were used to collect the data from online archives of these newspapers.

The index covers three channels of information for the US. These three

channels include newspapers, Federal tax expiration codes and the Survey of professional Forecasters. For the rest of the countries the index is based on news paper articles and Survey of Professional Forecasters only. Federal tax expiration provides information regarding changes in future taxation regulations. The information on tax expiration codes in the US is obtained from the Beige Book, this book also contains deeper economic information and economic outlook. Survey of Professional Forecasters provide information on disagreement between professional forecasters which allows a forward looking view into future of inflation and other macro variables. These variables play a significant role in creating future economic uncertainty.

The index trend included peaks during major political and economic events such as World War I and II , Versailles conference in 1919, 9/11, Gulf war, and the major election time periods. In order to test for the empirical robustness and accuracy of the index Baker et al. (2016) tested the EPU index for the US using firm level data in a vector auto-regressive

framework including macro variables such as output, employment, interest rate, inflation rate and production. A 6 to 12 months lag in the VAR framework showed that higher EPU levels lead to downfall in GDP, employment and growth in the US. Further they bifurcated firms on the basis of those which had government loans and contracts and those firms which were not linked to the government. The results showed that independent and private firms had a weaker relation with EPU as compared to those which had business contracts with the government. Numerically VAR results indicate that a rise in policy uncertainty cause over all industrial production to fall by 2.5% between 2006-2011 in the US. When innovations were introduced to the EPU index in the VAR model to study the respective effect on GDP and employment the results showed a decline in both the GDP and employment.

After the success of the US index the construction of the EPU index for G10 countries was discussed in Baker et al. (2016). A human audit study of 5000 national newspapers was carried out for each country. The pol-

icy related terms were highlighted in the local language by the help of domestic economists.

2.3 Country Specific Terms and Graphs

2.3.1 USA

The index reflects the frequency of articles in ten leading US newspapers that contain the following trio: “economic” or “economy”; “uncertain” or “uncertainty”; and one or more of “congress”, “deficit”, “Federal Reserve”, “legislation”, “regulation” or “White House”. This index shows accuracy such that it spikes near tight presidential elections, Gulf Wars I and II, the 9/11 attacks, the 2011 debt-ceiling dispute and other major battles over fiscal policy. The US index is based on three three things; tax expiration codes, words occurring in the newspapers, disagreement between professional forecasters about inflation forecast.

Since tax expiration in an idiosyncratic measure therefore this component is only included in the US index. However all other indices have

two components; data from newspapers and professional forecasters disagreement on interest rate, inflation and unemployment rate. Each component has a weightage of 50%.

The words for European news papers include ‘policy’, ‘tax’, ‘spending’, ‘regulation’, ‘central bank’, ‘budget’, and ‘deficit’.

2.3.2 Australia

The news based Australian Economic Policy Uncertainty Index covers six newspapers; Daily Telegraph, Courier Mail, The Australian, The Age, The Advertiser, Mercury, Sydney Morning Herald, and The Herald Sun (from November 1999). In order to construct the index the number of articles containing the terms ”uncertain” or ”uncertainty”, ”economic” or ”economy”, and one or more policy-relevant terms: regulation, ”Reserve Bank of Australia”, RBA, deficit, tax, taxation, taxes, parliament, senate, ”cash rate”, legislation, tariff, war are counted. To get a EPU rate of each newspaper the raw EPU is scaled by the number of articles in the

same newspaper containing the above mentioned words, in the next step each newspaper's EPU is standardized to one standard deviation for every month, and then the consolidated index is formulated using the average of all the newspapers.

2.3.3 Canada

The Canadian EPU is based on five newspapers including The Gazette, The Vancouver Sun, The Toronto Star, The Ottawa Citizen, and The Globe and Mail. With additional articles from Canadian Newswire. Each newspaper is searched for the following terms; uncertain or uncertainty, economic or economy, as well as policy relevant terms (scaled by the smoothed number of articles containing 'today'). Policy relevant terms include: 'policy', 'tax', 'spending', 'regulation', 'central bank', 'budget', and 'deficit'. To get a EPU rate of each newspaper the raw EPU is scaled by the number of articles in the same newspaper containing the above mentioned words, in the next step each newspaper's EPU is standardized to one standard deviation for every month, and then the consolidated

index is formulated using the average of all the newspapers.

Figure 1: Economic Policy Uncertainty Canada

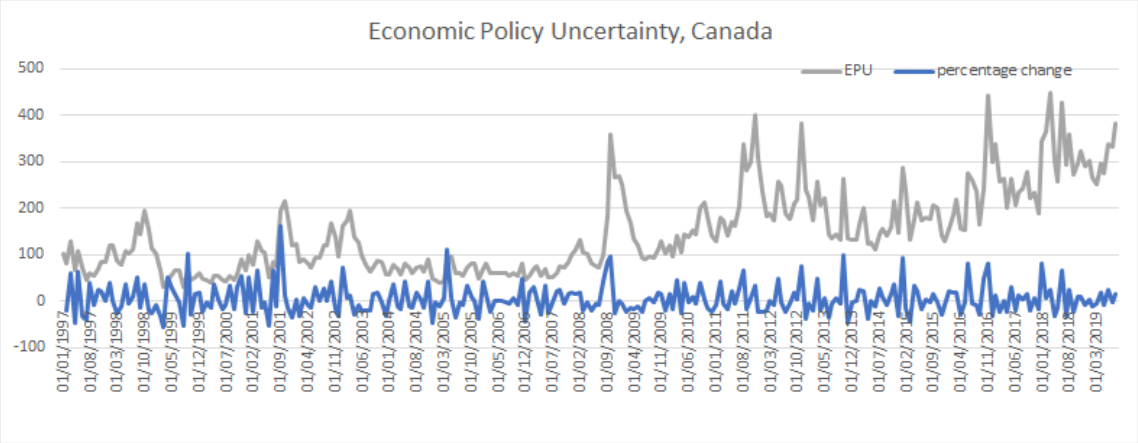


Figure 1, shows us the raw and percentage change in the EPU. The raw EPU count shows an upward behaviour, however percentage change in EPU shows more stable behaviour. The major spikes are observed in 1999, 2001, 2005, 2008, 2013, 2016, 2018 where as the highest spike is seen in 2001. This peak points towards 9/11 and the reporting that took place around that. In 2005 Canada, formulated an independent armed task force with Mexico and North America. Where as the peak in 2008 relates to British Columbia pipeline bombing along with regional elections in Alberta and changes in regional tax codes. The peak in 2015

points towards the general elections in Canada where as the peak in 2016 marks provincial elections. In 2018 Canada faced heated diplomatic dialogue over human rights with Saudia Arabia . The second major event in 2018 was the provincial elections in Quebec.

2.3.4 Germany

The German index is based on two newspapers Handelsblatt and the Frankfurter Allgemeine Zeitung. The newspaper archives were searched for words including the following E, P and U terms in German language. (E) wirtschaft (economy) OR wirtschaftlich (economically) ; (P) steuer (tax) OR wirtschafts politik (economic policy) OR regulierung (regulation) OR regulierungs (regulations) OR ausgaben (expenditure) OR bundes bank (Federal Bank) OR EZB (ECB) OR zentral bank (Central Bank) OR haushalt (household) OR defizit (deficit) OR haushaltsdefizit (Budget deficit); and (U) unsicher (uncertain) OR unsicherheit (uncertainty).

Figure 2: Economic Policy Uncertainty Germany

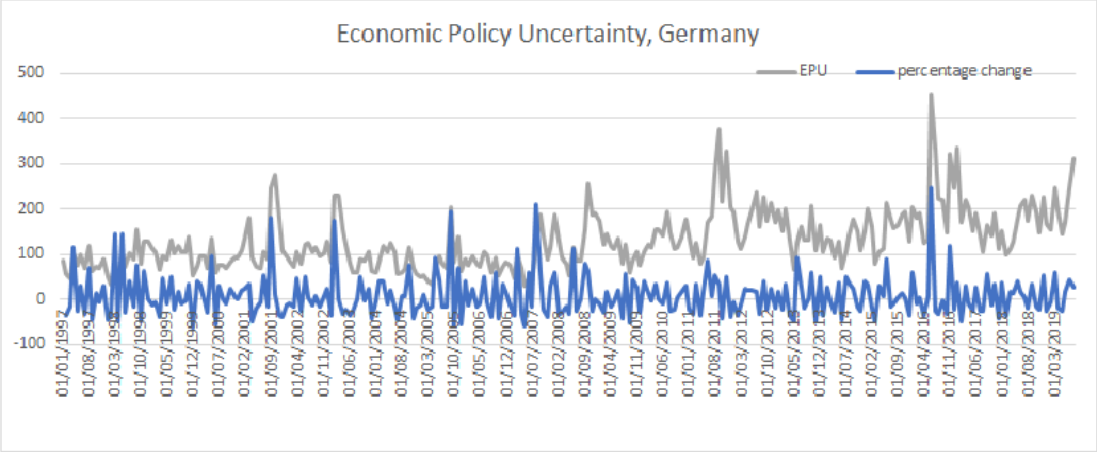


Figure 2 describes the raw and percentage increase in German EPU. Some of the major peaks include the first one in 1998 which indicates major political events in which the socialist party won the general elections. Followed by the nuclear phase out events in 2001 including the 9/11 attacks as Germany allied USA to send troops to Afghanistan. The peak in 2002 points towards the adoption of Euro as a combined currency. In 2005 marked early general elections after which the first female chancellor was elected. The next peak points towards the global financial crises in 2008. The 2016 highest peak points towards a major immigrant

controversy when several men were involved in raping women in a new years night event in Germany. This took a political controversy against mass immigration allowed by the government.

2.3.5 Japan

The Japanese index is constructed using four main newspapers including Yomiuri, Asahi, Mainichi and Nikkei. These newspapers routinely translate some of their articles into English. Using these translated articles E, P and U terms were highlighted. In the next step Japanese research assistants were employed to review Japanese-language versions of the same articles to identify the Japanese terms that correspond to the English-language terms of interest.

The E, P and U terms are given in the following table:

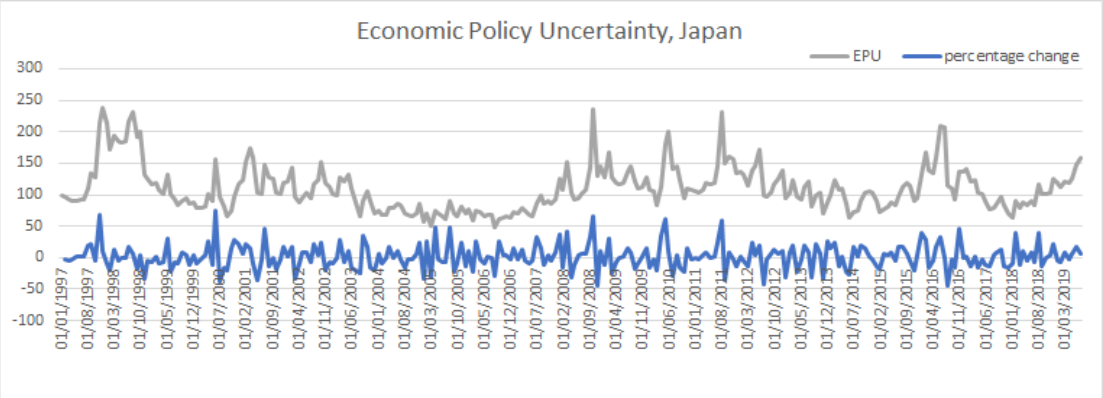
Figure 3: Japanese EPU Terms

Term Sets for Japan EPU Index, with Translations to English

Category	English	Japanese	In Chinese Characters
U	uncertainty OR uncertain	futoumei OR fukakujitsu	不透明 OR 不確実性
E	economic OR economy	Keizai	経済
P	Policy	Seisaku	政策
	Tax	Zei	税
	government spending	saishutsu OR kokyo-jigyohi OR kokyotoushi OR kokuhi	歳出 公共事業費 公共投資 国費
	Regulation	Kisei	規制
	Bank of Japan OR BOJ	nihonginko OR nichigin	日本銀行 日銀
	budget	Zaisei	財政
	Deficit	akaji OR fusai	赤字 負債
	Federal Reserve	Renpou junbi OR rengin	

Source: Arbatli et al. (2017)

Figure 4: Economic Policy Uncertainty Japan



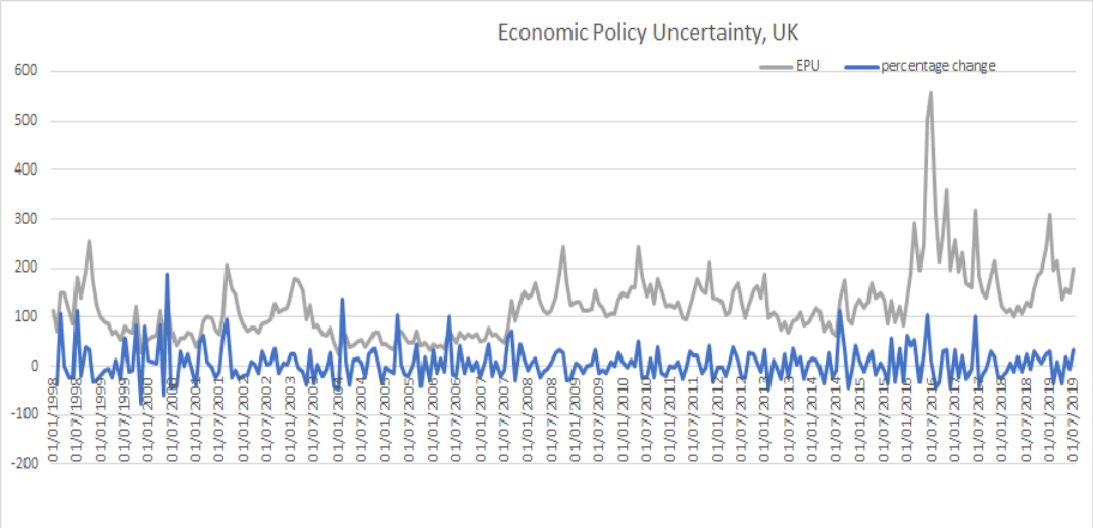
In the midst of 1997-1998 there was an increase in the consumption tax in Japan from 3 to 5%. Spikes in 1999, 2005, 2010 and 2017 point to-

wards general elections. There was a rise in 2001 due to 9/11. Along with general elections in 2005 there was also a major trade deal signed between Mexico and Japan. In 2008, Japan faced financial crises as the stock exchange crashed and the yen majorly depreciated in comparison to the dollar. The earthquake of 2011 caused a big blow to the Japanese economy which is depicted by the sharp peak in EPU. 2018, also marked by flooding and natural catastrophes.

2.3.6 United Kingdom

The EPU index for the UK is based on ten newspapers including The FT, The Times and Sunday Times, The Telegraph, The Daily Mail, The Daily Express, The Guardian, The Mirror, The Northern Echo, The Evening Standard, and The Sun. The terms included are E: economic or economy , Policy relevant terms include: 'policy', 'tax', 'spending', 'regulation', 'Bank of England', 'budget', and 'deficit', (U) uncertain OR uncertainty.

Figure 5: Economic Policy Uncertainty UK

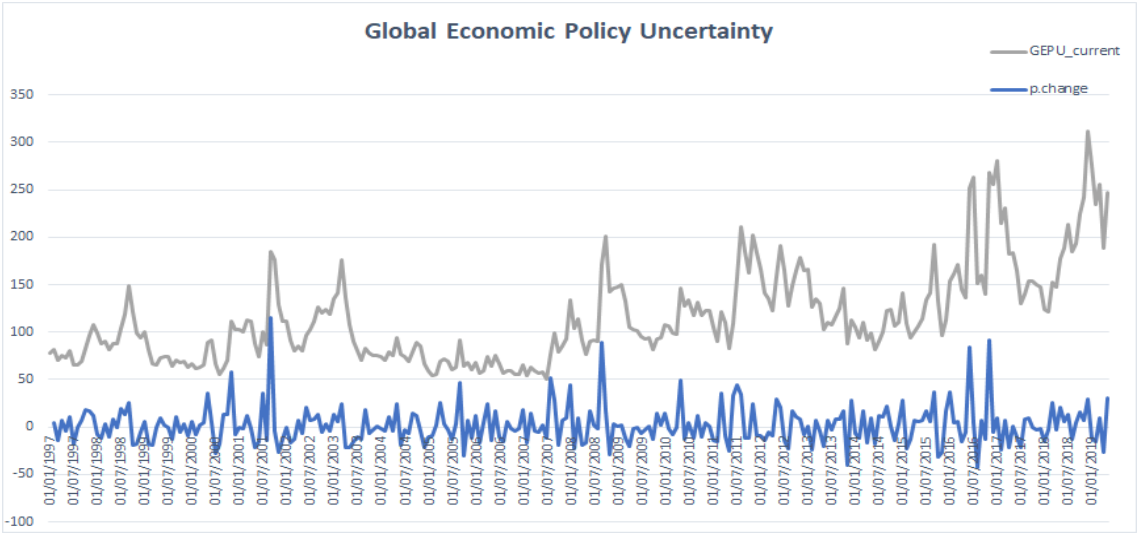


Some of the major peaks are around 1999 which coincide with the rising fuel prices and protests in UK. The graph shows a spike in 2001 due to 9/11. Followed by a peak in 2004 when Tony Blair announced a referendum for the EU constitution. Peaks in 2008-2009 are caused due to global financial crises. The highest peak is seen during 2016 and points towards Brexit referendum. The bumps from 2016- 2018 show the sensitivity towards various political issues such as by-elections, change in the party leadership and the general uncertainty caused by Brexit related issues.

2.3.7 Global Economic Policy Uncertainty

Global Economic Policy Uncertainty index was formulated in Davis (2016). This index is a GDP weighted average of the monthly EPUs of twenty countries including Australia, Brazil, Canada, Chile, China, France, Germany, Greece, India, Ireland, Italy, Japan, Mexico, the Netherlands, Russia, South Korea, Spain, Sweden, the United Kingdom, and the United States. The EPUs of all countries start in 1997 except Australia, India, Greece, the Netherlands and Spain, therefore these values are covered using regressions of the available data points. The twenty countries included in the global measure account for 70% of global output and PPP adjusted GDP roughly account for 79% at market exchange rate.

Figure 6: Global Economic Policy Uncertainty



The smaller peaks at the beginning such as the one in 1998 align with the Asian and Russian financial crises. However bigger and abrupt peaks are seen during the Eurozone crises, US fiscal fights and China leadership transition during the years 2011-2013. Followed by 2016-2017 Trump elections. Including the Russian crisis, 9/11, treaty of accession to enter the EU and the Gulf War II in, Northern Rock and Global Financial Crisis, Lehman Brothers Failure, Euro zone crises, Scottish referendum followed by UK general elections and Brexit.

The graph shows peak at all major international events. Beginning from the Asian and Russian Financial crises of 1998 when the Russian Central Bank defaulted on its debt and the rapid devaluation of the rubble. The graph also peaks in 2001-9/11 crises, followed by the war in Iraq. Another major peak is during 2008-2009 global financial crises. The index also shows an a steep upward behaviour before a series of financial crises within Europe. Other sharp peaks occur at major political events such as Brexit and Trump election.

2.4 Debate

One of the initial debate on the robustness of EPU index was carried out in Perić and Sorić (2018). Two main issues discussed in his report were related to the accuracy of the articles that were chosen on the bases of containing the terms starting with E, P and U and the timings of tax code expiration.

The first critique targeted the accuracy of the E, P and U terms since

these terms are chosen by the software based on the starting alphabet only however despite the starting alphabet being the trio there is no fixed condition that the word would still be Economic, Policy and Uncertainty since many words begin with these three alphabets. Specially when the exact topic of the article remains unknown to the software.

The second critique is related to the tax code expiration date. It so happens that codes that are set under one regime may expire in another regime which will result in an unevenly distributed uncertainty. On the other hand codes can also expire at similar timings showing a sudden rise in uncertainty. This point was addressed by removing the idiosyncratic factor of tax expiration codes from all indexes apart from the one for US.

2.5 Other Measures of Uncertainty

2.5.1 VIX

What is the VIX Index?

VIX index was created by the Chicago Board Options Exchange based

on the 30-days implied volatility of the S&P 500 index as a measure of market volatility. It is a real-time market index that represents the market's expectation of 30-day forward-looking volatility. The index is constructed from a weighted average of European-style call and put options on the SP500 that straddle the 30-day maturity. The purpose of the VIX index is to provides a measure for the overall market risk. It is a common high frequency measure of volatility.

Although VIX also measures volatility it still has a marked difference when compared to the EPU index. The two indices are based on two different measures such that VIX is based on one month put call options on European style option with one month maturity in S & P 500 index. However in comparison the EPU index highlights incidences occurring in the news which may cause economic uncertainty. However when tested for correlation Baker et al. (2016).

VIX and EPU show high correlation in the long run as compared to short

run in the US. The reason for difference in correlation could be the fact that VIX is a forward looking implied volatility index whereas EPU index has no explicit horizon because news articles can relate to any past, present or future event. Another possible reason could be the fact that both indexes are based on distinct information sets.

2.5.2 World Uncertainty Index

The World Uncertainty Index (henceforth WUI) has been proposed by Ahir et al. (2018). The index is based on the quarterly readings of The Economic Intelligence Unit reports. These reports are produced by The Economist magazine. However EPU is based on daily news paper articles as well as disagreement between Professional Forecasters therefore it includes a larger source of information.

The EPU index by Baker et al. (2016) is available on a monthly frequency where as WUI by Ahir et al. (2018) is only available at quarterly frequency. For some countries such as Canada EPU starts as early as 1985,

however WUI starts from 1996. WUI covers 143 countries where as EPU only covers 24 countries, therefore even though WUI is only available in lower frequency it still covers a broader geographical area.

Behaviourally EPU and WUI global indexes show peaks on all major events such as the 9/11 attack, SARS outbreak, Gulf War II, Euro debt crisis, El Niño, European border crisis, UK Brexit vote and the 2016 US election.

Nicholas Bloom is the common author for both the EPU index as well as WUI index therefore a common VAR framework is used in both the papers; Measuring Economic Policy Uncertainty, Baker et al. (2016) and The World Uncertainty Index (2018) to test the relation between the two indices, stock market volatility and GDP growth to test the empirical significance of the indexes.

By construction the EPU index covers E(economic), P(policy), U(uncertainty)

words however, WUI scales the raw counts of the U (”uncertainty”, ”uncertain”, ”uncertainties”) words only. The WUI index is based on a single course (Economic Intelligence Unit reports) however EPU index has two sources. WUI is a panel measure therefore it allows extended econometrics in a panel arrangement however EPU can be used in time-series.

The main difference difference between the two indices is that WUI covers a greater geographical range (143) countries and has a quarterly frequency while EPU has monthly frequency. Higher frequency and diverse source of information makes EPU more fit for empirical analysis, however in terms of data availability WUI is more convenient.

The nature of the WUI is exogenous explanatory variable such that events included in WUI affect stock markets, commodity futures and momentum anomaly similar to that of EPU. However while using WUI in panel data techniques endogeniety issues might arise which can be tackled using instrumental variables and seemingly unrelated regression models. How-

ever in a time series econometric model such as VAR identification is not usually an issue.

2.6 Selected Literature

Pastor and Veronesi (2012) developed an asset pricing model in which they accounted for the impact of changes in government policy. In the equilibrium model they studied two types of effects, the first related to the uncertainty of the policy change directed towards a specific sector and the second studies the impact of the specific policy change after it occurs. The impact of the policy change depends on the impact that the new policy will have as compared to the existing policy. Most of the effects depend on the nature of the new policy and how it compares to the existing policy. In a general equilibrium model they deduced that changes in policy that are deemed worse than the ones already in place reduce stock prices. The results show that if old strategies are replaced with better ones then stock prices will rise. This paper lays the theoretical framework of how news effects stock prices. Baker et al. (2016) index

aligns with the theoretical model of Pastor and Veronesi (2012) since in their model stock prices are primarily affected by the component of news only.

Leippold and Matthys (2017) show that high levels of EPU lead to reduction in nominal interest rate yields. Their study also shows that government policy uncertainty is the most vital aspect in deriving yield curves in the US and that high levels of global and domestic EPU reduces nominal interest rates including long run growth and productivity. This means when economic uncertainty is high investors move to safer assets such as Treasury Bills. They confirm that government policy uncertainty is the main driver in term structure of interest rates and volatility modeling. In order to test the robustness of EPU index as an explanatory variable for reduction in interest rate yield Leippold and Matthys (2017) used time series regression analysis. In the first analysis they used EPU as the independent variable, while the controls included treasury bond implied volatility index (TIV), the Chicago Fed National Activity Index, Indus-

trial Production index and CPI inflation. In the second analysis VIX was used as an additional control. In the third analysis EPU was removed where as VIX remained as one of the explanatory variables. In all the three analysis the dependent variables was the average of 1, 2, 3, 5, 7, and 10 years maturities government bond yield. The results showed that EPU had a higher impact as compared to VIX however when VIX and EPU were simultaneously tested VIX became insignificant which confirms the higher significance of EPU as an explanatory variable.

The impact of economic policy uncertainty on the firm level employment in Canada has been studied in Caggiano et al. (2017). Using VAR they probe the effects of US economic policy uncertainty on the overall employment level in Canada. In VAR construction they use US EPU, while controlling for Canadian EPU, industrial production, inflation and short term interest rates. Their results show that fluctuation in the US index causes fluctuations in Canadian interest rates, real activity and short term interest rates which shows cross border effects of EPU indices. Further

firm level investments in Canada, have been studied in Gulen and Ion (2015). Using regression analysis their study shows that high level of uncertainty leads to high precautionary savings by businesses, this leads to lower investments and also high unemployment. These studies show that uncertainty causes favourable delays in investment. A further categorization of the firms show that firms with greater linkage into government sale and purchase are more responsive to changes in EPU.

Bordo et al. (2016) studied the impact of economic policy uncertainty on credit channels in the US. In order to conduct this study they used quarterly loan growth rates of commercial banks. By using a VAR framework their results reduced that EPU negatively effects loan growth rate between 1985-2014. This means as EPU becomes higher commercial banks become reluctant to issue loans to clients. Through further investigating they deduce that banks who have larger cash holdings as shown in their accounting information are less reluctant in issuing loans as compared to those who have low cash holdings.

Klößner and Sekkel (2014) study the evidence of international uncertainty spillover effects in six developed economies. The VAR based study focuses on how spillover effects can cause increase in uncertainty in other countries. They concluded that policy changes in the UK and US were the biggest source of policy uncertainty in Canada, Germany, France and Italy.

Bilateral trade, geographical distance and common language are common contributing factors for trade spillovers. The effect of economic policy uncertainty on trade spillovers is studied in Balli et al. (2017). Using VAR analysis the bi-directional trade spillover is calculated between pairs of countries. This is calculated using a vector-auto regressive set up. The net pairwise spillover index is calculated from the forecast coefficient of the errors obtained from VAR. The spillover coefficients show that US, Canada and Australia have the highest spillover effects. In order to determine the determinants of spillover effects regression analysis

between the spillover coefficients and other variables including common language, sharing border, trade deficit, budget deficit, terms of trade were carried out. The results show that bilateral trade and sharing of common language are the most significant contributing factors followed by terms of trade to the spillover effects.

Stock prices in the US are affected by high levels of EPU as studied in Brogaard and Detzel (2015). Using a generalized methods of moments model and controlling for variables such as risk free rate, business cycle dummy, price dividend ratios they discover that EPU holds a significant relation with CRSP value weighted index. In another study to probe the impact of EPU on S&P 500 index, Liu and Zhang (2015) used five minutes high frequency data in a heterogeneous auto-regressive realized volatility model and found that EPU has a significant impact on the volatility of the index as high EPU leads to higher market volatility while low EPU is followed by periods of low volatility. Using a regime switching model Arouri et al. (2016) study the long run relation between

historical US-EPU and S&P 500. Among the three regimes (low, medium and high volatility) according to their results the impact of EPU becomes more persistent during high volatility regime and that EPU is a vital forecasting variable during high volatility regimes.

The significance of EPU on stock prices has been tested even after controlling for oil supply shocks. One such study was conducted by Kang and Ratti (2013) to test the impact of EPU on stock market returns in the US using a VAR model while controlling for positive oil demand shock. Increase in oil demand leads to an increase in prices which then leads to high precautionary savings. Finding the sequential relation between EPU, oil price shocks and stock price variation it is seen that rise in oil prices leads to an increase in EPU which then causes an effect on the over all stock prices.

In terms of the US economy EPU has also been used to predict future recessions. One such study has been conducted by Karnizova and Li

(2014). They tested if indexes of economic policy uncertainty could predict future recessions. They conducted in-sample and out-of-sample of recession forecasts using logit model. According to their findings EPU can forecast recessions beyond five quarters and that EPU enhances the long term forecast-ability of recessions.

The significance of EPU is tested in terms of it being a spillover agent. In one such study Bernal et al. (2016) test for the risk spillover effects of the EPU index in Eurozone bond markets. Using VAR framework they showed that within Eurozone there is a transmission effect for the level of EPU such that if the uncertainty in countries that issue debts (Germany and France) goes up then the uncertainty in peripheral countries will also go up. The spillover of US EPU on BRIC markets has been studied in Dakhlaoui and Aloui (2016). The spillover effects show that US effects the stocks in BRIC countries and the relation is oscillating between negative and positive. Christou et al. (2017) study the impact of uncertainty in the US on stock markets in PacificRim countries including Australia,

Canada, China, Japan, Korea and the US. The negative impact of US EPU on all PacificRim countries is undisputed, with Australia being the only exception.

In order to verify the explanatory power of the index, Baker and Bloom tested their index against alternate measures of uncertainty including VIX. EPU showed higher explanatory power as compared to VIX for firms in defence , health care, engineering service, heavy construction, using firm fixed effects and showed how VIX had become insignificant. The question regarding the efficiency of EPU as an exogenous explanatory variable has been answered in (2018)Duca and Saving (2018). The exogeniety of the EPU Index which is its ability to provide additional explanation to the model when controlled for macro variables such as inflation and employment. Focusing on the US and five western European countries including UK, Germany, France, Italy and Spain the results show that 60% of the movement in the EPU index comes from factors apart from the major macro economic variables.

2.7 Conclusion

In this chapter I discuss the concept behind the EPU index developed by Baker et al. (2016). The intuition behind the construction of this index is to capitalize on newspapers as a medium to disperse policy related news. This can clearly be seen as a major chunk of the information utilized in the index comes from words that appear in news articles. A small component of the indexes information comes from Survey of Professional Forecasters in order to support the information that is picked from news articles. The indices are updated at the end of each month or the beginning of the following month such that complete information till the last day of the month is included in the index.

A discussion on the construction method of the index reveals that two term: E for economy and U for uncertainty remain same among indices for all the countries however policy related terms differ between countries. This feature of the index makes it more robust to capture policy

related uncertainty in a specific country. From this it is also evident that policy related terms have geographical boundaries.

From graphical representation we see that although the raw count of the index shows an increasing behaviour with timely peaks on major political events the percentage increase a more stable behaviour. Some of the reasons accountable for higher overall magnitude of the index could be due to certain news being in focus. It could also be due to increasing number of articles being published. Also, national indexes cover different number of papers e.g. US and UK indices cover ten national newspapers each, however other countries such as Japanese index is based on four newspapers, while all other countries are based on two newspapers each, which means certain countries have a higher overall proportion in the global index.

An account of the recent and selected literature that utilized EPU index as an explanatory variable is also presented. The exogeniety of the EPU

index in relation to implied volatility index such as VIX and macro variables including inflation, business cycle and industrial production among other is proven in Baker et al. (2016), Duca and Saving (2018). The index has also enhanced the explanatory power of recession and business cycle models. Furthermore stock markets have also shown significant relation with the EPU index.

After studying the construction methodology, over time behaviour and considering the existing research using EPU index as an explanatory variable I use it as a variable of interest in the following three chapters.

3 Economic Policy Uncertainty and Momentum Returns: Case of the UK

3.1 Introduction

Policy induced economic uncertainty is reported to have significant impact on stock market returns and has shown correlation with OECD stock indices. The news based measure of policy uncertainty developed by Baker et al. (2016) has proven to be significantly related to many financial variables such as investment behavior and stock price volatility. Economic policy uncertainty is the non-zero probability of existing policies to change such that they may affect the existing rules for economic agents Baker et al. (2012).

Gu et al. (2018), study the impact of EPU on momentum returns in the US and deduce that one month lagged EPU has shown to significantly reduce momentum returns in the US by 1.11%. In another study Xavier and Vasconcelos (2018) show that US EPU significantly effects momen-

tum returns in Brazil and momentum returns are higher when EPU is low and lower when EPU is high.

The crux of the momentum strategy is to buy and sell stocks based on their past returns. It relates past returns to current performance. Jegadeesh and Titman (1993), studied the winner/loser strategy and documented that stocks with high(low) returns over a past 3- to 12- month period have high(low) abnormal average returns over the subsequent 3- to 12- months. The resulting strategy produces positive excess returns. This behavior can not be explained by the CAPM of Sharpe (1964), Lintner (1965) and Fama and French (1996) therefore it is categorized as an anomaly. However momentum is a strong and robust strategy and is deemed to be associated with many variables including business cycle, state of the economy , firm size Fama and French (2008) among others. Price momentum based strategies offer its investors highest Sharpe ratio as compared to strategies based on market value, size factors also makes it the most widely used trading strategy in the US Barroso and Santa-

Clara (2015).

Numerous variables have been associated with momentum, however a consensus on its determinants has not been reached, Fama and French (2008). Momentum is shown to be dependent on business cycles, Chordia and Shivakumar (2001) and Griffin et al. (2003)), Past market returns, Antonakakis et al. (2013) and market volatility Wang and Xu (2015)). Griffin et al. (2004) made an extensive study on momentum returns and deduced that macro variables alone can not explain momentum regions of the forty regions included in the study.

Momentum also prevails in the UK's stock markets and the earliest study was done by Hon and Tonks (2003), where they highlighted that momentum trading based on past price trends yields positive returns for horizons up to 24 months in the UK. Chelley-Steeley and Siganos (2008) study the existence of momentum in alternate exchanges conjecturing on the premise that momentum exists due to difference in trading systems. Sev-

eral studies have used behavioral and fundamental factors to study momentum returns. This study fills the gap by studying the effect of EPU on momentum returns in the London Stock Exchange. The two closest works to this study include Gu et al. (2018) which study the effect of EPU on momentum returns in the US and found out that momentum is present following low EPU periods and is non-existent otherwise. Xavier and Vasconcelos (2018) study the effect of EPU for Brazil a small open economy and deduced that local momentum exists after low and high EPU periods however momentum is stronger following months with low EPU.

London Stock Exchange is the seventh largest stock exchange in the world by market capitalization and has great significance in the financial world. This chapter is aimed at seeking the ability of EPU to predict momentum profits (losses) in the UK. This chapter makes at least three contributions to the literature: 1) momentum returns in London Stock Exchange are positive and significant after periods of low uncertainty 2) EPU remains a significant explanatory variable after controlling for mar-

ket volatility and business cycle 3) momentum returns are significantly impacted by global policy uncertainty index.

The remainder of the chapter is organized as follows: section 1) provides background and review of the literature, section 2) provides data and methodology, section 3) provides results and section 5) provides the conclusion.

3.2 Background and Literature Review

3.2.1 Momentum

Price momentum based strategies were studied in Jegadeesh and Titman (1993). This anomaly was highlighted by the abnormal profits reaped by buying and selling stocks based on the three, six, nine and twelve months past returns. Trading strategies were based on cumulative returns followed by three month holding period. Equal weighted portfolio returns were calculated and the existence of abnormal returns was tested after controlling for systematic risk factor and by using a dummy vari-

able to control for announcement effect. The results however show that the premise that momentum anomaly only existed due to lead lag relation of earnings announcements can not be accepted as returns remained significant after controlling for announcement date and Fama French three factor models.

Chordia and Shivakumar (2001) study industry specific momentum for companies listed on NYSE and AMEX. Using Jegadeesh and Titman (1993) strategy they studied industry specific momentum. Since macro variables are significant in explaining the momentum they added firm specific factors to explain momentum is specific industries. Their study finds that industry specific momentum can not be explained by standard macro variables such as t-bill rates and default spread. Their study concludes that momentum profits are greater following expansionary phases of the economy and insignificant otherwise in the US. Macro variables have significant explanatory power to explain momentum returns therefore it is necessary to control for these variables in order to test for the

explanatory power of economic policy uncertainty.

Cooper et al. (2004), studied the effect of market states on momentum returns and deduced that momentum generates higher returns when the overall markets returns are positive and vice versa however these returns can not be explained by macro variables alone. They also studied the impact of sentiments on momentum, where investor overconfidence based on past 3-6 months return helps in explaining abnormal momentum returns. In the context of US investor sentiments follow the behaviour of the market, if the market returns are increasing then investors will feel more confident about the market and then invest more which will lead to increase in momentum. According to Cooper investors hold long positions which causes higher momentum returns in the short run. In order to account for this they introduced a dummy variable called market state which measured previous month positive returns as one and zero other otherwise. By controlling for market state they deduce that macro variables are no sufficient to explain momentum and thus dummy to explain

market state should be added.

3.2.2 Momentum and Size

Fama and French (2008) studied the anomaly behavior for companies listed on AMEX and NYSE and deduced that momentum anomaly is powerful and existed for small medium and large cap companies within the US and was not merely a data mining or trend following behavior. They also deduced that profitable companies provided larger profits however the momentum returns for less profitable companies is not that large. They studied the cross-sectional behaviour of stock returns. After controlling for behavioural factors such as announcement effect they deduced that momentum even existed after controlling for time these factors.

Asness et al. (2013) carried out a comprehensive study on value and momentum trading. They worked on momentum strategies in four sectors: stocks, commodities, futures and currencies. And noted that the momentum is most evident in stocks as opposed to commodities and futures.

Looking at the effect of liquidity risk on the covariance between value and momentum based strategies they deduced that four factors including business cycle, default risk and consumption can have a weak relation with momentum returns. They also deduce that momentum strategies are attributed to performance chasing mutual fund flow. Their findings indicate that none of the behavioural factors alone can explain the value and momentum returns.

3.2.3 Momentum and Risk

The riskiness of the momentum strategy has been studied in detail by Barroso and Santa-Clara (2015), and this strategy has proved to generate extreme negative returns. Daniel and Moskowitz (2016) study momentum crashes and the occurrence of prolonged strings of negative returns as a result of high market volatility, prolonged bearish behaviour of the market and overall panic states. The causes of momentum are not a common consensus however momentum crashes as those studied in Daniel and Moskowitz (2016) and Barasso and Santa-Clara(2015)Barroso and

Santa-Clara (2015) are commonly highlighted in the literature. Therefore any variable that can add to the forecasting of positive and negative momentum returns can act as a safeguard against failure in momentum and possibly market crashes.

3.2.4 Momentum in the UK

Hon and Tonks (2003) studied the existence of momentum effect for UK over a span of forty years (1955-1996). Their study reveals that momentum is strong from (1977-1996) and weak between 1955-1976, which could be due to less volatile pre 1976 market. They tested a total of 64 strategies, with a base time period between 3-24 months and a holding period between 1-24 months and found that the momentum effect exists in the UK on all investment horizons. However measuring the volatility of markets as a control they deduced that high volatility means higher momentum.

Agyei-Ampomah (2007) studied the post-transaction cost profitability of

momentum returns in the UK and deduced that even though momentum strategies were profitable at 3 month horizon but post cost profitability was only present in longer run strategies such that 6 months and beyond. This is deemed to be a consequence of high re-balancing cost for the short run period.

The premise, that prior winners keep performing well, explains high momentum returns and not the difference between the winner/loser portfolio is studied in Siganos (2013), they used fundamental values and deduce that small, low price and young companies are the most prominent companies of winner stocks. They studied the premise that the winner and looser companies show common characteristics as these are the extreme companies, by trading these extreme companies higher profits can be reaped.

3.2.5 Momentum and Economic Policy Uncertainty

Economic policy uncertainty has adversely affected stock returnsArouri et al. (2016). This behaviour has been seen in the US from 1900-2014 and deduced that rise in EPU decreases stock returns under a regime switching model. Tsai (2017), studied how EPU could explain contagion risk in global stock markets. They studied the impact of EPU on global risk of contagion in four regions: UK, China, Japan, USA and Europe on twenty two markets (the chosen markets were a mix of emerging, developing and developed based on Morgan and Stanley ranking for economic conditions). They determined that Chinese EPU is the most influential in affecting global stock markets and European stock markets are most vulnerable including the UK. Due to this effect it makes it an important question to study the impact of domestic and foreign EPU on momentum and volatility in UK stock market.

Chang et al. (2015) study the impact of EPU on seven OECD countries

including the UK. They studied the lead lag causality in EPU and consolidated stock index formulated by OECD. Their highly robust test based on bootstrap panel causality deduced that in the UK high stock market volatility is caused by high economic policy uncertainty. This makes the price behaviour of stocks life on LSE vulnerable to policy uncertainty changes.

The anomalous behavior of momentum has been thoroughly studied and its existence has been accepted. However the underlying cause of the existence is still an area to be worked on. Based on earlier studies on momentum anomaly in the UK and its significance in causing momentum crashes which then have a greater impact. This research aims to find the impact of economic policy uncertainty on the commonly observed and momentum anomaly in stocks listed within UK.

3.3 Data and Methodology

Data

The sample is constructed using stocks listed on the London Stock Exchange (LSE) from 2000-2018 at monthly frequency from DataStream. There are two types of markets in the LSE, i.e. main market and the alternative investment market. This study focuses on stocks listed on the main market because; AIM includes companies which are small and growing in nature including start-ups, venture capitalist and other businesses that aim to grow. These stocks do not include companies that fulfill the requirements of the main market companies. There are 1003 companies included in the dataset.

In order to ensure that the sample is free from survivor-ship bias all delisted companies are included in the sample (following Siganos (2013)). After a company becomes delisted its returns are replaced with zero. I used the standard approach of deleting companies with missing data. This

approach is widely used in accounting and finance literature. All companies listed in the UK come under the code FBRIT, delisted companies come under the heading of 'dead'. Share types include exclude preferred stocks because they have limited trade. This study covers the main market shares and account for the survivor-ship bias which may make the results spurious.

Portfolios are constructed following Jegadeesh and Titman (1993) and Lui et al. (1999), (this is the most widely used method of formulating momentum portfolios) to construct our portfolio. All stocks are ranked on the basis of monthly cumulative returns, for a period of one to six months. This means that all stocks are listed for one, two, three and up to 6 months. And then cumulative sum for each stock is calculated. Finally listing stocks in terms of ascending order of returns (the entire data is ranked in ascending order). Stocks are then divided into ten equal sized decile portfolios, the top portfolio being the loser portfolio (it contains stocks with the lowest returns) and the bottom being the winner (contain-

ing stocks with the highest returns). The holding period is one month and portfolios are rebalanced every month on an equal weight basis following Jegadeesh and Titman (1993), this is done to check the effect of one month lagged EPU on momentum returns. Long term re-balancing horizons are not used since, long term horizons can severely mis-specify returns Hon and Tonks (2003). Gu et al. (2018) have also reported to use one month re-balancing for US.

The Economic Policy Uncertainty - EPU was collected from the Baker and Bloom's website[1]. This study uses the time series for UK, Europe, Italy, France, Germany, Spain and the global index. The data for Fama and French three factors is collected from Exeter Business School data link[2]

The following time series controls are used following the literature to check the robustness of EPU on stock returns.

- Market Volatility (MVOL): It is the standard deviation of the lagged

[1] http://www.policyuncertainty.com/

[2] http://business-school.exeter.ac.uk/research/centres/xfi/famafrench/files/

12-months daily market return. Daily FTSE 100 data is used to calculate lagged-12 returns: $ln(r_t)$ - $ln(t_{t-12})$. Market volatility is calculated by calculating standard deviation on monthly basis. Market volatility is obtained using this procedure.

- Market State (MSTATE): It is measured through the UP market dummy Cooper et al. (2004). Dummy equals 1 if the prior two month cumulative market return is non zero and 0 otherwise.

- Business Cycle (BC): Is the OECD recession dummy for UK, this data variable is collected from St. Louis Fred database[3]. A value of 1 is a recessionary period, while a value of 0 is an expansionary period (available at monthly frequency). To check the effect of phase of the business cycle on the momentum returns. To control for the possible positive link between expansionary phases and positive returns and negative returns during contractionary phases.

[3]https://fred.stlouisfed.org/series/GBRRECM

3.4 Empirical Findings

In order to analyze the long term relation between EPU and momentum the econometric model proposed in Gu et al. (2018) is used, this model has also been adopted by Xavier and Vasconcelos (2018). This model enables us to study the impact of EPU on stock returns based on momentum by using regression.

3.4.1 Sort Analysis: Low and High Economic Policy Uncertainty

The aim of this section is to check the significance and existence of momentum profits during high and low EPU periods, this sorts the effect of high policy uncertainty on the excess returns of winner portfolios over loser portfolio. This allows us to analyse how low and high policy uncertainty levels separately affect momentum profits.

Low Economic Policy Uncertainty

$H_0 : \alpha_L = 0$

$H_A : \alpha_L \neq 0$

$$R_t = \alpha_L D_{L,t} + \beta_1 MKT_t + \beta_2 SMB_t + \beta_3 HML_t \quad (1)$$

High Economic Policy Uncertainty

$H_0 : \alpha_H = 0$

$H_A : \alpha_H \neq 0$

$$R_t = \alpha_H D_{H,t} + \beta_1 MKT_t + \beta_2 SMB_t + \beta_3 HML_t \quad (2)$$

Equation 1, tests the effect of low economic policy uncertainty while equation 2 tests the effect of high policy uncertainty on momentum returns. R_t on the left hand side is the return of the portfolio at month t. On the right hand side $\alpha_H D_{H,t}$ and $\alpha_L D_{L,t}$ are dummy variables such that, $\alpha_H D_{H,t}$ is equal to 1 if EPU in the previous month is above the median

value. Where as $\alpha_L D_{L,t}$ is equal to 1 if EPU in the previous month is below its median value. MKT_t is the value weighted market excess over the risk free rate, SMB_t is the return spread of a long portfolio composed by low market capitalization stocks minus the return of a short portfolio composed by high market capitalization stocks at time t. HML_t is the return spread of a long portfolio composed by high book to market stocks minus the return of a short portfolio composed by low book-to market stocks at time t.

Column (2) in table 1, exhibits the results for equation 1 and column (3) exhibits the results for equation 2. A positive and significant value of $\alpha_L D_{L,t}$ shows that momentum returns are positive and significant after periods of low EPU. Column (3) of table (1), exhibit results for H_2. The results show that momentum returns are insignificant (although negative) after periods of high uncertainty.

From the results show that the gains of a winner minus loser portfolio are

only significant after periods of low uncertainty. This means low policy uncertainty months are followed by an excess return of 1.90%. Momentum returns although negative become insignificant following months which have high uncertainty.

High and low EPU periods are calculated using median EPU. If the EPU of a given month is greater than the median value of EPU , the given month is categorized as high EPU month and is designated a value of 1. Where as a low EPU month is given a value of zero when the EPU is less than the median value.

Table 1: Impact of low and high Economic Policy on Momentum Returns

	Low EPU	High EPU
Constant	-3.3983***	-1.4825
t-stat	(-17.819)	(-7.888)
$\alpha_H D_{H,t}$	-	-1.9458
t-stat	-	(-7.278)
$\alpha_L D_{L,t}$	1.9038***	-
t-stat	(7.083)	-
MKT_t	0.1097**	0.1094**
t-stat	(3.153)	(3.151)
SMB_t	0.0846*	0.0839*
t-stat	(2.154)	(2.150)
HML_t	-0.1069*	-0.1064
t-stat	(-2.433)	(-2.434)

This table exhibits results for equation (1) & equation (2). $_t$ is the winner minus loser portfolio returns calculated at the beginning of each month t, such that all common stocks are sorted into decile portfolios based on past six-month returns (the cumulative return from month t-6 to month t-1). I skip first month, buy the winner portfolio, sell the loser portfolio and hold the Winner-minus-Loser portfolio for one month. I then calculate the equal-weighted returns (R_t) for this portfolio. Economic policy uncertainty (EPU) is the news-based measure developed by Baker, Bloom and Davis (2016). $\alpha_H D_{H,t}$ & $\alpha_L D_{L,t}$ are high & low market dummies. MKT_t, SMB_t & HML_t are Fama & French three factors 100 portfolios formed on size and book-to-market ratio.
In this table,$\alpha_H D_{H,t}$ & $\alpha_L D_{L,t}$,MKT_t, SMB_t & HML_t are expressed as percentage per month and the t-statistics are presented in parenthesis. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. The sample period is from January 2000 to November 2018.

3.4.2 Fama and French Factors

This part is aimed at testing the effect of one month lagged domestic policy uncertainty on excess winner minus loser momentum returns. The hypothesis for equation (3) and equation (4) are as following:

$H_0 : \beta_1 = 0$

$H_A : \beta_1 \neq 0$

$$R_t = \alpha + \beta_1 EPU_{t-1} + \varepsilon_t \tag{3}$$

Where R_t monthly momentum return in month t. EPU_{t-1} is the Economic Policy Uncertainty Index for UK and ε_t is the error term.

Equation 3, enables us to study the effect of EPU after adding Fama and French three factors as controls.

$$R_t = \alpha + \beta_1 EPU_{t-1} + \beta_2 MKT_t + \beta_3 SMB_t + \beta_4 HML_t + \varepsilon_t \tag{4}$$

Where MKT_t is the value weighted market excess over the risk free rate, SMB_t is the return spread of a long portfolio composed by low market capitalization stocks minus the return of a short portfolio composed by high market capitalization stocks at time t. HML_t is the return spread of a long portfolio composed by high book to market stocks minus the return of a short portfolio composed by low book-to market stocks at time t. Equation (4) checks the robustness of the effect of lagged EPU after controlling for Fama and French components.

Table 2: EPU, momentum, Fama and French

	(3)	(4)
Constant	-1.2335***	-1.21875***
	(-7.064)	(-7.190)
EPU_{t-1}	-1.4130***	-1.39543***
	(-6.924)	(-7.048)
MKT_t		0.13604***
		(3.839)
SMB_t		0.10843**
		(2.711)
HML_t		-0.09324*
		(-1.905)

This table contains results for equations (3) & (4). Where EPU_{t-1} is one month lagged EPU and MKT_t,SMB_t,HML_t are Fama & French factors. Equation (4) checks the robustness of the effect of lagged EPU after controlling for Fama and French components.
In this table,MKT_t, SMB_t, & HML_t & EPU_{t-1} are expressed as percentage per month and the t-statistics are presented in parenthesis. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. The sample period is from January 2000 to November 2018.

The results show that one month lagged EPU, significantly affects momentum returns. Column (2) of table 2 exhibits the effect of UK domestic economic policy uncertainty on the momentum returns. According to the results one standard deviation rise in EPU reduces momentum returns by 1.41 % this slightly higher than the the effect experienced in the US

which is 1.11% studies in Gu et al. (2018).

Column 3 of Table 2 shows the impact of EPU on momentum after controlling for Fama and French three factors. This only reduces the momentum returns by 0.02 %. The reduction in similar to that in the US market where returns reduce from 1.13% to 1.11% after controlling for Fama and French three factors. However this relation remains highly significant even after controlling for Fama and French three factors.

3.4.3 Controlling for Time Series Variables

In this section I test the significance of one month lagged EPU in a winner minus loser momentum portfolio after controlling for market state, market volatility, and OECD business cycle dummy. Table 3 comprises of the results.

Market State

$$R_t = c + EPU_{t-1} + MSTATE_t + MKT_t + SMB_t + HML_t + \varepsilon \quad (5)$$

I use market state as a variable to explain momentum as introduced in Cooper et al. (2004). Market state is a dummy variable created to check the performance of the market in comparison to FTSE 100 index. The dummy variable takes a value of 1 when the cumulative return of FTSE 100 in the past two months is positive and zero otherwise.

The results for equation 5 and represent in column 2 of table 3. The coefficient of MSTATE is positive and significant at 90%, where as the coefficient of EPU is significant at 99%. After controlling for market state EPU still reduces momentum returns by 1.4%.

Market Volatility

$$R_t = c + EPU_{t-1} + MVOL_t + \beta_2 SMB_t + \beta_3 HML_t + \varepsilon \qquad (6)$$

Market volatility has been studied by Wang and Xu (2015)Wang and Xu (2015) as a predictor of market momentum. The results of equation 6 are represented in column 3 of table 3.

According to the results market volatility subsumes the explanatory effects of other variables such as business cycle and market states lose their significance when market volatility is added to the regression.

Economic policy uncertainty significantly reduces momentum returns by 1.47 % after controlling for market volatility. Where market volatility also negatively effects momentum returns by 0.242 %. However the overall negative impact of economic policy uncertainty increases when market volatility is high.

Business Cycle

$$R_t = c + EPU_{t-1} + BCYCLE_t + MKT_t + \beta_2 SMB_t + \beta_3 HML_t + \varepsilon \quad (7)$$

Business cycle dummy is used following Chordia and Shivakumar (2001), to explain the significance of recessionary and expansionary phases of the overall momentum profits. The business cycle dummy is equal to 1 during the recession phase and 0 during expansionary phase.

The results of equation 7 are represented in column 4 of table 3. Adding the effect of the business cycle to the overall model nullifies the effect of economic uncertainty since the coefficient of EPU becomes insignificant. This has a rather intuitive explanation such that during recession phase markets lack momentum as markets are slow.

Table 3: Impact EPU on Stock Returns after Controlling for Additional Factors

	Market State	Market Volatility	B-Cycle
Constant	-1.28507***	-1.34970***	-1.23491***
	(-7.817)	(-7.716)	(-7.456)
EPU	-1.466384***	-1.55515***	-1.416795
	(-7.645)	(-7.574)	(-7.317)
MSTATE	0.009253*	-	-
	(3.329)	-	-
MVOL	-	-0.24132*	-
	-	(-2.442)	-
BCYCLE	-	-	-0.006304*
	-	-	(-2.168)
MKT	0.132056***	0.13655***	0.125186***
	(3.908)	(3.989)	(3.632)
SMB	0.078775*	0.10369**	0.104913
	(2.011)	(2.670)	(2.694)
HML	-0.083492’	-0.0926*	-0.109118
	(-1.925)	(-2.118)	(-2.496)

This table contains results for equations (5),(6)&(7). MSTATE represents market state, MVOL represents market volatility, BCYCLE represent business cycle dummy.

In this table, EPU,MKT_t, SMB_t, & HML_t & are expressed as percentage per month and the t-statistics are presented in parenthesis. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. The sample period is from January 2000 to November 2018.

3.4.4 Global and European Economic Policy Uncertainty Effect

Due to the inter-connectedness of the stock markets in the Euro zone the impact of cross border policy uncertainty index on domestic momentum return is also tested. EPU index picks words that are related to policy uncertainty from the news this step will enable us to test the impact of words appearing in foreign news on domestic momentum effect. Investing across borders is easy and convenient considering free trade agreements and tax leniency. The inter connections of the nations and the markets in general makes it a natural next step check for cross border linkages.

Germany, Italy and France are the three largest economies in Europe with annual GDP of $4.4 billion , France $3.03 billion and Italy has an annual GDP of $2.52 billion. Momentum returns are based on past price behaviour where as EPU index measures the uncertainty in the lagged month. A lagged response of the an external EPU on domestic returns

thus helps us in determining the impact of external uncertainty on domestic markets. This further helps in forecasting the occurrence of momentum in successive one month. This part also increases the use of global and consolidated indexes in domestic contexts.

The results show that momentum returns in UK are affected by cross border policy uncertainty including global EPU, European EPU German and French EPUs. Global policy uncertainty has a negative impact of 0.062%, while the European uncertainty index has a negative impact of 0.057% however the results for the European index are significant at 95% where as the results for global EPU are significant at 99%.

Policy uncertainty in Germany, Italy and France significantly reduce the momentum returns in the UK by 0.05278 %, 0.09158 % and 0.04089 %. Momentum returns in the UK are most effected by domestic economic policy uncertainty. While the impact of foreign policy uncertainty in small but significant. The difference between the coefficients of global

and European is 0.005%, which means that the consolidated index of five countries including UK, Germany, Italy, France and Spain has a comparatively higher impact as compared to the global economic policy uncertainty index which covers twenty two countries. This also brings us to the conclusions that countries in closer vicinity and common financial regions have a higher impact as compared to those that lay further away. Global EPU and European EPU indices have significant impact on momentum returns however this impact is much weaker than the impact of domestic EPU. This could signify the effect global and European economic policy uncertainty has on the activity in the stock markets however investors seem to have more confidence in domestic conditions as opposed to foreign interventions.

After adding the fourth Fama and French factor the effect of economic policy uncertainty reduces to 1.37% from 1.41% also the HMD factor becomes insignificant.

Table 4: Cross Border and Local Evidence of EPU on Momentum Returns

Returns	**EPU UK**	**EPU Global**	**EPU Europe**	**EPU Germany**	**EPU Italy**	**EPU France**	**MKT UK**	**SMB UK**	**HML UK**	
	-1.41 (-6.924)									
	-1.379 (-7.089)***						1.3697175 (0.00113)**	1.9812032 (3.86e-05)***	0.1856782 (0.74386)	- (
		-0.06238 (0.07509).					1.3350909 (0.00143)**	1.9598390 (3.98e-05)***	0.1249677 (0.82497)	- (
			-0.05736 (0.015078)*				1.3728311 (0.000958)***	1.9437586 (4.01e-05)***	0.1324149 (0.812587)	- ((
				-0.05278 (0.02958)*			1.2901797 (0.00203)**	1.9194589 (5.51e-05)***	0.1640382 (0.76933)	- (
					-0.09158 (0.0237)*		1.3227427 (0.0015)**	2.1107407 (8.85e-06)***	0.3429613 (0.5389)	-
						-0.04089 (0.00988)**	1.4012942 (0.00074)***	1.9545268 (3.47e-05)***	-0.0577475 (0.91910)	- (

* Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.5 Conclusion

In this chapter I have tested the impact of policy induced economic uncertainty on forecasting momentum returns. In order to check the robustness of the results I have carried out sort analysis. Sort analysis allow me to test the significance of my results following periods of low and high policy uncertainty months. Low and high uncertainty months are categorised on the bases of full sample median EPU. The results show that momentum results are positive and significant only after periods of low EPU and are non existent after periods of high EPU.

Positive momentum profits after periods of low uncertainty remain significant after controlling for Fama and French three factors. The robustness is further tested using time series variables that have been used in past literature business cycle (Chordia and Shivakumar (2001)), market state (Cooper et al. (2004)), market volatility (Wang et al. (2014)). EPU index remains a significant explanatory variable in the regression model when

tested after controlling for market state and market volatility. However the results show that once controlled for business cycle which explain the expansionary and recessionary phases of the economy, EPU becomes insignificant. One of the possible reasons could be that during expansionary phases (which is 1 under this variable) investors find alternate avenues of investment outside the stock markets.

Further I test for the significance of momentum returns in London Stock Exchange after controlling for policy uncertainty in Germany, Italy and France. Momentum profits in the UK are negatively affected by policy uncertainty in the above listed Euro countries. Furthermore global and European indices also have an overall negative effect.

This study focuses on the time series explanatory variables of momentum such and Fama and French, business cycle, market volatility and market state. The results show that the returns of winner minus loser portfolios which are re-balanced on monthly basis are significantly affected by

policy induced economic uncertainty.

4 The Impact of Economic Policy Uncertainty on Commodity Future Returns

4.1 Introduction

Commodity future markets have become popular since early 2000. It occurred at the time of Financialization in commodity markets. Financialization is a term used to explain the expansion of commodity markets by inflow of funds. Between 2000-2008 Commodity Futures Trading Commission totalled $200 billion Cheng and Xiong (2014). Financialization resulted in increased trading volume and rise in commodity prices as well as volatility. Another major incidence to be noted in terms of commodity markets is the Commodity Modernization Act of 2008. This Act was bought into structure in order to regulate the markets and safeguard against future financial crises.

Commodity future markets have existed since the beginning of 19th century in Chicago and have grown massively since then. According to

Bank of International Settlements June 2018 report, there is a total of US $1898 Billion outstanding amount of commodity instruments. The amount has shown an upward behaviour since Commodities Modernization Act (2000).

Commodities have great impact on geopolitical risk for several reasons such as geographically fragmented supply of metals and a mis-matched global demand of metals. This uneven pattern of demand and supply causes volatility dissipation internationally. With the advancement in technology and progression of financial engineering metals are not only physically exchanged after sale and purchase but they are traded as derivative instruments electronically on organized exchanges.

Under the changing political and policy dynamics it is essential to study the impact of economic policy uncertainty on investor sentiments which further impacts their decisions regarding investing in commodity markets. Studying this is beneficial in two ways: how policy dissipation

effects metals futures returns to understand their ability to hedge. The second benefit lies for policy makers in commodity exporting countries as economic polices can have a direct impact on the pricing of the commodity which can then effect their trade. This allows in understanding the strategies and behaviour of future returns.

Given the marked fluctuations in commodity prices with changing economic environment and the international linkages of commodity prices it makes it a vital question to study the long-term volatility in commodity futures prices. This papers looks into the predictive power of global economic policy uncertainty in estimating the long and short term volatility components in widely traded metals. Due to the mis-match in the frequency of the two variables under study I use Mixed Data Sampling (MiDaS) GARCH. This method allows me to study the long and short run volatility contribution of global economic policy towards fluctuations in aluminium, brent oil, platinum, palladium and silver futures.

Economic policy uncertainty has shown significant negative impact on stock returns as studied in Davis (2016). Fang et al. (2018b) studied the impact of global economic policy uncertainty (GEPU) on gold futures and deduced that monthly GEPU lead to an increase in the volatility of gold futures returns. Most studies are restricted to gold futures however it is essential that attention is given to other precious metals. Global economic policy uncertainty index is used because uncertainty in returns can be sourced by many different aspects such as market volatility, political situation, major events and so on. However not all commodities or sectors are equally affected by external conditions. Some commodities exhibit more sensitivity while others exhibit counter cyclical behavior.

GARCH family of models are widely used for studying volatility however MIDAS regression enhances the explanatory power of the model by adding macro variables which contribute towards the the accuracy of volatility calculation. Fang et al. (2018a) discussed the impact of global economic policy uncertainty on gold futures using GARCH MI-

DAS. Where as GARCH-MIDAS is utilized to predict stock market variability using macro variables by Asgharian et al. (2013). Yu and Song (2018) studied the impact of global economic policy uncertainty on futures aggregated monthly volatility. Using regime switching framework they deduced that GEPU has high impact on high volatility regions and low impact on low volatility regions.

Commodities are important in many ways as they provide intrinsic store of value when uncertainty is high. Gold is an undoubted precious metal and has intrinsic store of value and was used as a medium of exchange in the past. Followed by silver, platinum and palladium. Which are high in demand due to their wide scale usage in construction projects, technology, pharmaceuticals, bullion and ingots. Some of the highest traded precious metals are: gold, platinum, palladium and silver. Where as the highest traded industrial metals include copper, lead, zinc, aluminium, nickel and cobalt [4].

[4]Source: CME website

Precious and industrial metal futures are high frequency exchange traded high instruments. Therefore in order to check the impact of macro variables a suitable method has to be employed. The aim of this chapter is study the impact of global economic policy uncertainty on future return, where GEPU is a monthly index therefore I use Engle et al. (2013), component GARCH model which is based on Mixed Data Sampling (MiDaS) to as a method of choice. This method allows us to model the long and short run volatility structures of the metal futures.

Global economic policy uncertainty has attracted large scale research interest since 2016. However this study explores the effect of GEPU on precious and industrial metals futures using Engle et al. (2013) framework which provides the benefit of adding macro variables along with financial time series. A closely related work by Fang et al. (2018b) focuses on gold futures only however our scope is broader and the conclusions are novel.

Based on current studies there exists a narrow gap in studying the effect of global economic policy on commodity futures such as aluminium, silver, platinum, palladium and brent oil. Through this my main aim is to see if global economic policy uncertainty effects the listed commodities as it affects gold so that investors may use these metals as portfolio hedge during time of high uncertainty.

The rest of the chapter is construed as follows: section 1) literature review, section 2) data and methodology, section 3) results and section 4) conclusion.

4.2 Literature Review

The literature discusses three strands related to the research question. The first strand relates to the underlying properties of the process followed by the return behaviour of futures. A major chunk of literature discusses the the long memory properties which can be captured by GARCH methodology framework.

The next strand of the literature discuses the importance of studying commodities as an instrument to hedge. However this is a much explored topic and the results vary from commodities being strong and most profitable hedge to the diminishing power of commodities to hedge.

Where as the third strand discusses the significance of economic policy uncertainty in explaining the behaviour of commodity returns. This provides room for further research in the domain of commodities in relation to global economic policy uncertainty.

Global economic policy uncertainty index has been studied in recent literature and has proven to be a significant indicator of the economy. The literature below sheds light on three aspects; the importance studying volatility in commodity markets, enhancing portfolio returns by using commodities as an instrument, studies focusing on the importance of global economic policy uncertainty index.

4.2.1 Dynamics of Commodity Futures Returns

Commodity returns are deemed to follow long memory processes (processes that have a slowly decaying auto-regressive moving average function). This property is seen in precious metals including gold, silver, platinum, aluminium and leads to volatility persistence in metal futures volatility. Cochran et al. (2012) studied commodity future returns using fractionally integrated GARCH processes in order to confirm the presence of long memory properties using ten year data from 1999 to 2009. The results confirmed that all four metals (gold, platinum, copper, silver) depict a slowly decaying auto-correlation function which confirms the existence of long memory behaviour. Among the four metals copper has the shortest and platinum and the longest term as a long memory process. Further testing revealed that VIX and commodity returns are negatively related which means when stock market implied volatility rises commodity future returns fall.

In order to highlight a suitable model to capture the volatility dynamics of commodity futures (precious and industrial metals) within an investment portfolio (2014)Chkili et al. (2014) utilized four linear and three non-linear GARCH models. The forecast accuracy is measured against the Value-at-Risk bases as dictated by the Basel II Accord. According to the results fractionally integrated asymmetric power ARCH (FIAPARCH) comply with the VaR restrictions of Basel II accord at all significance levels and for all metals. The improved performance of FIAP-ARCH is associated to the asymmetric element of the model. Information asymmetry in commodity markets is associated to the occurrence of negative shocks such as wars, geopolitical risk and trade deals.

4.2.2 Diversification Benefits of Commodity Futures

The second strand of the literature focuses on the diversification benefits of commodities when added to a stock and bond portfolio. Substantial amount of literature focuses on the diversification benefits of commodities due to low covariance with stock and bonds. Below are the main

studies testing this idea empirically.

In order to probe the benefits of adding commodities to a (stock-bond) portfolio Cheung and Miu (2010) conducted an in-depth study focusing on US and Canadian economies (resource rich economy). The US based portfolio included US equities, Non-North American equities and US bonds compared to a Canadian investors portfolio which included Canadian equities, non-North American equities and Canadian bonds. The proxies of these equities included MSCI-Canada, MSCI-EAFE, MSCI-US and ten year government bond returns for US and Canada. The index for commodities is taken from Gorton and Rouwenhorst (2006). By comparing the Sharpe ratios of these portfolios with and without commodities they deduce that commodities produce statistically significant diversification benefits. Secondly they also deduce that the correlation between equities and commodities follow a regime switching behaviour during booms and bust such that during high volatility periods commodities reap higher returns [in international equity markets where interna-

tional equities follow opposite behavior]. Overall their results show that commodities are most beneficial for diversification during bull markets and not bear markets.

A detailed analysis of portfolio returns based on six investment techniques including strategically weighted portfolios, risk parity, minimum variance, reward to risk timing, mean-variance, Black-Litterman strategies are tested in order to probe the effectiveness of adding metals and agricultural commodities to stock-bond portfolios, Bessler and Wolff (2015). Their results show that adding precious metals (gold, silver, platinum) diversify the overall risk of a portfolio. However adding agricultural commodities did not generate significant profits. Further they tested for the existence of profits in various states of the economy the results showed that the profits were highly state dependent (higher during boom and vice versa).

The relation between stocks, bonds and commodities has been studied

in Silvennoinen and Thorp (2013). This study is based on testing the diversification properties of commodities by testing the correlation between stocks and bonds using double smooth transition conditional correlation-GARCH. According to their results the diversification benefits have weakened after 2000. They formulate portfolios of twenty-four commodities including grains and oil seeds, meat and livestock, food and fibre, metals and petroleum. Prior to 2000 the correlation between commodity returns was insignificant making them attractive investment choices. However the correlation is much stronger and significant in post 2000 period and strengthens when VIX is high.

Oil, copper and gold futures and current prices have been studied in Sadorsky (2014). The relation of commodity futures with emerging economies stock markets is studied using Dynamic Conditional Correlation-GARCH (DCC-GARCH) and vector auto regressive-GARCH (VARMA-GARCH). These two methodologies allow to study the inter volatility patterns. Using MSCI emerging market index to represent the stocks for twenty one

stock markets and check their dynamic correlation with copper and gold futures. Their results based on dynamic conditional correlation show that correlation is most sensitive during the financial crisis of 2008-2009 and also shows long term persistence in volatility behaviour.

Basher and Sadorsky (2016) study the use of commodity markets to hedge stock market risk using GARCH models. In a comparison between the use of of oil and gold futures in comparison to VIX and bonds as an instruments to hedge in emerging markets they concluded that oil futures are the best hedge for emerging market stocks.

The causality between commodity future returns and their drivers has been studied in Andreasson et al. (2016). The causal relation between gold, silver, platinum and palladium returns with five driving factors including FRED trade weighted exchange rate index, S&P 500 index, CBOE implied volatility index, commodity market speculation index was calculated. Five commodities including copper, gold,platinum, silver and

crude oil show a unidirectional relation with speculation index. According to their results gold Granger causes rise in US policy uncertainty while copper, platinum, silver and crude oil are affected by policy uncertainty index, moreover only crude oil index has a bidirectional relation with the speculation index.

4.2.3 Economic policy Uncertainty, Realized Volatility and Futures

Economic policy uncertainty has proven to be a significant factor in improving the forecastability of S&P 500 index , Liu and Zhang (2015). Using Heterogeneous Auto-regressive framework and utilizing realized volatility as an autoregressive variable the results show that economic policy has a significantly positive impact on S&P 500 volatility. Economic policy uncertainty adds to the over all in sample fit of the model and adds to the the out of sample performance measured through mean squared error.

Khalifa et al. (2011) discuss the return distributions of metal futures

(gold, silver and copper future returns). By using realized volatility as an efficient measure to proxy volatility in metal futures, they deduce that the return volatility behaviour is similar to GARCH (1,1) model. They also confirm the superior forecast ability of realized volatility.

Engle et al. (2013) study the behaviour of daily stock returns using monthly macro variables. The aim of their work is to study the short and long run components of volatility observed in daily stock returns. They present a framework in which the short run volatility is expressed through a GARCH(1,1) process and the the long run component is modelled through regression which may or may not include realized volatility. Their theoretical work links the concept of volatility and macro variables. They provide an over view of reduced form models over structural models to incorporate the macro variables and their contribution towards volatility of financial variables.

Volatility in oil futures returns has been studied in Ma et al. (2017).

Their work gives a comprehensive survey of volatility modeling in oil markets. Using five minutes data they calculate realized variance which is then modeled using Heterogeneous Auto-regression (HAR). To capture the persistence in the behaviour of realized volatility twelve different HAR specifications were tested. HAR models are parsimonious models which allow auto-regressive models with varying frequency to estimate the volatility behaviour. They test models with jump, symmetry and a-symmetry. Their empirical analysis show that mid and long term components are significant while the short term component is insignificant, however jump components show a mixed effect. Based on out of sample performance they conclude that realized volatility is an appropriate measure for forecasting future returns. Their work confirms realized volatility as measure of predicting future volatility in oil futures.

Ghysels et al. (2007) explored volatility structure in mixed data sampling. They analyzed various lags of realized volatility and explain the parsimonious class of models in order to predict the future volatility of

the dependent variable. Further they studied parametric volatility models using mixed frequency data. In their framework they incorporated the arrival of both good and bad news and how they impact the overall volatility structure. They also deduced that incorporating additional variables after realized volatility enhance the volatility petitions of the overall model.

Through Cochran et al. (2012) work we see that it is important to verify the impact of policy induced economic uncertainty on commodity returns as their work highlights that stock and commodity markets face similar sources of uncertainty. The asymmetries highlight in Chkili et al. (2014) are associated to sudden events such as wars, natural catastrophes and political events therefore as a whole EPU index is a steadfast barometer to study these things concurrently. Further the volatility in commodities has been studied using realized volatility Ma et al. (2017). study the effect of global economic policy uncertainty on gold futures using GARCH mixed modeling. Their results show that global economic policy uncertainty significantly adds to the long term volatility in gold futures.

From the literature it is evident that commodities such as platinum, palladium, aluminium and silver are important to be studied alongside gold. On the other hand global economic policy has shown to be a significant indicator of long term variance in gold based on which similar avenues must be explored for other commodities.

4.3 Data Description

Global Economic Policy Uncertainty

Uncertainty has been numerically calibrated in different ways such as standard deviation of returns and variance of risk premia however these measures of uncertainty are the standard deviations of historical prices and not the uncertainty based on economic events. In this chapter my aim is to check the impact of global policy uncertainty change on commodity future returns therefore I use the proxy index for policy induced economic uncertainty developed by Davis (2016). Newspaper based measures have an additional advantage since they cover for broad range of uncertainty

Moore (2017). The details on the construction of this index can be found in chapter 2. Global Economic Policy index is constructed as a GDP weighted average of twenty national economic policy uncertainty indices. These countries contribute towards more than 70% of global output on a PPP adjusted bases and roughly 79% at market exchange rates[5].

Commodities

The five commodities included in this chapter are platinum, palladium, silver, aluminium and brent oil. A commodity future is a contract that obligates the holder of the contract to either buy or sell a pre-determined amount of a commodity at a specific price at a specific date in future.

Commodity futures including platinum, palladium, silver and aluminium are traded on New York Mercantile Exchange (NYMEX) while brent oil is traded on COMEX. NYMEX stands for New York Mercantile Exchange and it is the world's largest physical commodity future exchange.

[5] https://www.policyuncertainty.com/global$_{m}onthly.html$

It became a part of Chicago Mercantile Exchange (CME) in 2008 making CME the worlds most diverse commodity exchange. NYMEX indices present world leading commodity indices. COMEX and NYMEX are regulated by Chicago Board of Trade (CBOT).

According to Chicago Mercantile Exchange handbook all future contracts have an expiration date, prior to that this date contract holders have a number two option: to close their contract through settlement or to extend their open position. However some traders choose to hold the contract and go to settlement. The clearing takes place through CME clearing board.

4.4 Methodology: GARCH-MIDAS

Model

This chapter is based on a new class of GARCH component model known as GARCH-Mixed Frequency Data Sampling (MIDAS). Generally MIDAS models are distributed lag models in which the independent vari-

ables vary in frequency and present a causal relation with the dependent variable over time. Within MIDAS framework returns are modelled as a product of long and short term component. Long term component is modelled using regressions and a component from this regression is added to the GARCH (1,1) model which models the high frequency/short term variable. The τ component from the long term equation model captures the variance component. It is a function of the weighted average of return variance and the macro variable. The short term component is modeled as a GARCH (1,1) model. MiXed Data Sampling regression (MiDaS) framework allows a parsimonious framework to incorporate macro variables that are sampled at different frequencies to explain the behavior of higher frequency financial variables, this allow ease of application.

The long term component is the macro variable, however in order to increase the robustness of the results I add smooth realized volatility to the model. This component is adopted from Engle et al. (2013) framework where daily fluctuations in stock returns are modeled using smooth

volatility. Realized volatility is also used in other studies such as Ma et al. (2017) and Fang et al. (2018b). Weights of the smoothing function are distributed in a descending (monotonically decreasing) order starting from the most recent years, which is intuitively correct as bulk of the volatility is associated to the most recent events.

Another supporting feature of using MIDAS to study the impact of GEPU (a news based measure) on commodity futures return is conceived from Campbell and Shiller (1991). In both the studies authors study the impact of news on stock prices using a horizon of consequences stretching from short to long term effects. The dependent variable y_t is measured at daily frequency and the independent variable x_t is measured at monthly frequency. The aim here is to find the impact of lagged one month x_{t-k} on the variable y_t.

$$y_t = \beta_0 + \beta_1 x_{t-1} \tag{8}$$

The GARCH-MIDAS can be explained through following equations:

$$r_{i,t} = \mu + \sqrt{m_t}.g_{i,t}\zeta_{i,t}, \qquad \forall_i = 1,\ldots,N_t (9)$$

where $r_{i,t}$ is the high frequency variable. $g_{i,t}$ accounts for short term fluctuations that are based on high frequency data and m_t which accounts for long term fluctuations. Further the short term fluctuations follow follow a GARCH (1,1) process:

$$g_{i,t} = (1-\alpha-\beta) + \alpha\frac{(r_{i-1,t-\mu})^2}{m_t} + \beta g_{i-1,t} \qquad (10)$$

where $\alpha > 0$ and $\beta > 0$, $\alpha + \beta < 1$..

τ component is based on realized volatility over a monthly, quarterly (used in Merton (1980), Schwert(1989)).

The $_t$ is the is the smooth realized volatility of:

$$m_t = m + \theta \sum_{k=1}^{k} \psi_k(\omega_1, \omega_2) RV_{t-k} \qquad (11)$$

$$RV_t = \sum_{i=1}^{N_t} r_{i,t}^2 \tag{12}$$

Equation 8 is used to smooth the volatility over K periods. Additional variable is added to equation 7, in this study I add global economic policy as an additional variable to realized variance.

Weighted average of the two variables is calculated as in equation 7:

$$m_t = m + \theta_{RV} \sum_{k=1}^{K} \psi(\omega_1, \omega_2) RV_{t-k} + \theta_X \sum_{k=1}^{K} \psi(\omega_1, \omega_2) X_{t-k}^{EPU} \tag{13}$$

This is based on the quadratic variation theorem. Barndorff-Nielsen and Shephard (2005) show that realized volatility is less subject to measurement error and provides estimates that are less noisy. Smooth realized volatility has been used as a significant indicator to study stock market behaviour in auto-regressive models as well as in conjunction with economic policy uncertainty. It is also robust to market micro structure noise.

Steps

Data Cleaning and Preparation

The daily future average adjusted price have been obtained from Data Stream. The time span of the data is 01/01/1997-19/06/2019. We use log returns of the daily adjusted commodity price using the formula below. All points with zero returns are deleted as they signify no change in price level therefore these data points would add no value to the overall results. Data starts from 1997 matching to the availability of GEPU data.

1. Returns are collected as the log difference of daily adjusted price

$$r_t = log(price_t) - (price_{t-1}) \tag{14}$$

2. Realized volatility is calculated as the sum of squared returns for a given time intervals such that the given time intervals are non overlapping.

$$RV_t = \sum_{i=1}^{N_t} r_{i,t}^2 \tag{15}$$

3. The macro variable is the log value of Global Economic Policy Uncertainty index used at one month lag.

Table 5: Data Description

Variable	Mean	Max	Min	SD	Skewness	Kurtosis
Platinum	0.008728	5.228345	-5.289254	0.9260246	-0.05927592	5.011876
Silver	0.00882	8.32401	-8.72233	0.826293	-0.6698	9.690803
Brent Oil	0.01937	6.87305	-11.59109	0.9906149	-0.5143029	10.35331
Aluminium	-1.079e-05	2.328e-02	-2.628e-02	0.004160477	-0.2514988	7.50804
Palladium	0.019366356	6.873051889	-11.59108792	0.990614889	-0.514445292	7.361209653

Table 5 reports the descriptive statistics of the data. Data description is presented is calculated for the returns series. Five metals and show negative skewness and high kurtosis which explains the non-normality observed the commodities returns. However GARCH is compatible with non-normal returns as GARCH models residuals and is compatible with our data.

Model Specification

I use three model specifications following the original work of Engle et al. (2013):

- Global Economic Policy Uncertainty Model: This model only captures the effect of global economic policy uncertainty on the long run variance component of the model, specified as:

$$\tau_t = m + \theta \sum_{k=1}^{K} \phi_k(w_1, w_2) GEPU_{t-k} \tag{16}$$

- Realized Volatility Model: This model captures the effect of smooth

realized volatility on the long run variance component of the model, specified as:

$$\tau_t = m + \theta \sum_{k=1}^{K} \phi_k(w_1, w_2) RV_{t-k} \tag{17}$$

- Dual Model: This model tests the simultaneous effect of realized volatility and global economic policy uncertainty on the variance returns on the long run variance component of the model, specified as:

$$\tau_t = m + \theta_1 \sum_{k=1}^{K} \phi_k(w_1, w_2) RV_{t-k} + \theta_2 \sum_{k=1}^{K} \phi_k(w_1, w_2) GEPU_{t-k} \tag{18}$$

Interpretation of the parameters

Three models are estimated for each commodity. The first model is based on global economic policy uncertainty , under this model the estimation procedure follows equation 12. Therefore the long term variance is associated with GEPU only. Where as the equation for short term component stays unchanged. In the second model the long term component comes from realized volatility, as in equation 13. In order to prove the robust-

ness of the overall model I estimate a third model which includes both the variables together in equation 14.

4.5 Palladium

According to the results in table 6, 7 and 8 the first three parameters μ, α, β explain the short term behaviour of returns. All three parameters are significant which confirm the existence of GARCH effects in daily palladium futures returns. The next three parameters γ, m, θ, explain the long term variance in futures returns caused by GEPU, RV and the combined effect.

From Table 6 θ is significant and positive which shows that if one month lag GEPU increases the long term variance in commodity returns will also increase. In Table 7 the theta component which explains the effect of realized volatility on palladium returns is significant and is greater than that of GEPU as shown in Table 8, which means that realized variance which has a higher impact on long term variance.

To check the additional information content of the GEPU index a third model is estimated, this model contains both explanatory variables. The results in Table 8, show that θ_1 which is the coefficient of GEPU and θ_2 which is the coefficient of RV both are significant, which confirms the additional information content of policy uncertainty. On the basis of likelihood and BIC functions the results show that RV and EPU together make the strongest model.

Table 6: Palladium: GEPU

μ	α	β	γ	m	θ	W
0.0292	0.0946	0.9006	-0.0132	0.0506	0.0025	24.8938
(0.0009)	(0.000)	(0.000)	(0.03)	(0.09)	(0.009)	(0.06)
LLH	-7097.825	BIC	14255.82			

Table 7: Palladium: Realized Volatility

μ	α	β	γ	m	θ	W
0.0234	0.0070	0.9890	0.0005	-0.0942	0.0342	1.2563
(0.0271)	(0.0014	(0.0000)	(0.8740)	(0.0000)	(0.0000)	(0.2978)
LLH	-7001	BIC	14354			

Table 8: Palladium: GEPU and Realized Volatility

μ	α	β	γ	m	θ_1	θ_2	W
0.0232	0.0077	0.9899	-0.0003	-1.0039	0.00086	3.3555	3.7967
(0.0304)	(0.0015)	(0.0000)	(0.0916)	(0.0000)	(0.0473)	(0.000)	(0.0977)
LLH	-6881.552	BIC	13840.47				

4.6 Platinum

Table 9 exhibits the results for platinum. θ_1, the parameter which explains the effect of GEPU on platinum is insignificant and the results do not support the fact that one month lagged GEPU can explain the variance in platinum future returns on its own. However in Table 10, all variables are significant which means realized volatility can independently explain

the variance in platinum returns to some extent. Table 11 shows the additional explanatory power of GEPU, in a model that controls for realized variance and GEPU together. And shows that overall realized variance has an additive explanatory power in explaining the long term variance in returns.

Table 9: Platinum: GEPU

μ	α	β	γ	m	θ	W
0.0103	0.1032	0.8867	-0.0106	-0.3364	-0.0013	28.6790
0.1769963	0.000	0.000	0.3813051	0.3896248	0.4645609	0.1497076
LLH	-4863.283	BIC	9786.674			

Table 10: Platinum: Realized Volatility

μ	α	β	γ	m	θ	W
0.0149	0.0974	0.6826	-0.0032	-1.5086	5.4677	25.8013
(0.0461)	(0.0182)	(0.0000)	(0.0954)	(0.0000)	(0.0000)	(0.3380)
LLH	-4760.18	BIC	9580.468			

Table 11: Platinum: GEPU and Realized volatility

μ	α	β	γ	m	θ	W
0.0131	0.0551	-0.0928	-1.475	0.0094	4.7509	7.217
0.0786	0.0081	0.000	0.0464	0.000	0.04	0.000
LLH	-4765.958	BIC	9609.198			

4.7 Brent Oil

The results in Table 12 show that GEPU will positively affect the long term variance in brent oil futures. According to Tables 13 and 14, GEPU remains a significant explanatory variable after controlling for realized volatility. The results confirm that global economic policy uncertainty is a significant factor in explaining the volatility in brent oil futures.

Table 12: Brent Oil: GEPU

μ	α	β	γ	m	θ	W
0.0113	0.0304	0.9522	0.0301	-0.4749	0.0050	1.000
0.0261	0.000	0.0000	0.0002	0.0111	0.0072	0.0688
LLH	-7016.19	BIC	14092.84			

Table 13: Brent Oil: Realized Volatility

μ	α	β	γ	m	θ	W
2.6700	0.0162	0.9638	0.0400	-0.5551	295.7644	20.9840
(0.0192)	(0.0000)	(0.000)	(0.0000)	(0.0000)	(0.0537)	(0.0165)
LLH	-32875.7	BIC	65811.85			

Table 14: Brent Oil: GEPU and Realized Volatility

μ	α	β	γ	m	θ_1	θ_2	W
0.0148	0.0083	0.9872	0.0079	-0.9408	0.0017	1.4042	1
0.0119	0.0000	0.0000	0.0468	0.0000	0.0235	0.000	0.0864
LLH	-5800.5	BIC	11678.43				

4.8 Silver

Tables 15-17 exhibit the results of the effect of global economic policy uncertainty and realized volatility on silver futures. The results show that GEPU and realized volatility significantly effect the long term volatility in silver future both independently and when combined.

Table 15: Silver : GEPU

μ	α	β	γ	m	θ	W
-9.49e-05	5.21e-02	9.52e-01	-1.57e-02	-6.29e-01	3.55e-03	3.08e+00
0.992	0.000	0.000	0.164	0.040	0.053	0.023
LLH	-6028.348	BIC	12116.92			

Table 16: Silver: Realized Volatility

μ	α	β	γ	m	θ	W
0.0112	0.0141	0.9880	-0.0083	-1.0803	1.0543	22.8189
0.0196	0.00	0.00	0.0076	0.00	0.00	0.00331
LLH	-6002.3	BIC	11199.23			

Table 17: Silver: GEPU and Realized Volatility

μ	α	β	γ	m	θ_1	θ_2	W
0.0115	0.0140	0.0988	-0.0837	-1.05	3.42	3.63	1.28
0.0188	0.00	0.00	0.0711	0.00	0.075	0.00	0.0018
LLH	-5800.5	BIC	11678.43				

4.9 Aluminium

For aluminium the results show that global policy uncertainty alone can not explain the volatility in aluminium futures return (the results did not converge therefore could not be added here). However when modelled together with realized volatility, global economic policy uncertainty still remains insignificant. These results show that aluminum future returns do not greatly respond to changes in global economic policy uncertainty.

Table 18: Aluminium: Realized Volatility

μ	α	β	γ	m	θ	W
0.0011	0.1317	0.8828	-0.0306	0.6283	0.1883	3.9848
7.64e-01	0.0000	0.0000	0.0000	3.8256e-05	3.4074e-03	2.8370e-01
LLH	-1765.054	BIC	3589.899			

Table 19: Aluminium: GEPU and Realized Volatility

μ	α	β	γ	m	θ_1	θ_2	W
-0.0002	0.1165	0.8895	-0.0134	0.5988	-0.0002	0.1924	1
0.9491	0.000	0.000	0.000	0.4698	0.6012	0.0019	0.7453
LLH	-1766.517	BIC	3609.909				

4.10 Conclusion

Through the empirical findings of this chapter it is evident that global economic policy uncertainty is a significant indicator for long term volatility in palladium, brent oil and silver futures. Based on these findings the four commodities may not prove to be safe havens during periods of high uncertainty. However global economic policy uncertainty indicator does not explain the changes to long-term volatility in platinum futures.

However the accuracy of the results for aluminium futures improve after controlling for realized volatility where realized volatility is the measure

of historical volatility. The results also show that although significant the parameters of global economic policy uncertainty are smaller than that of realized volatility. This means that global economic policy uncertainty although a significant contributor towards the long-term volatility in the commodities under study has a smaller impact as compared to realized volatility.

Shahzad et al. (2017) prove that global economic policy uncertainty Granger causes volatility in gold, platinum and silver prices. However using regime switching models Thongkairat et al. (2019), studied the impact of global economic policy uncertainty on gold, platinum and silver price. Their results concluded that global economic policy uncertainty effects gold prices where as there is no evidence of the effect on platinum and silver prices. Fang et al. (2018b) confirm that global economic policy uncertainty adds to the long term volatility in gold futures.

However using GARCH-MIDAS this chapter has produced evidence that

global economic policy uncertainty contributes towards long term volatility in silver, palladium and brent oil futures. However the results turn out insignificant for platinum which are in line with Thongkairat et al. (2019) who also focus on volatility using regime switching model.

To the best of my knowledge there are currently no published papers that study aluminium futures and global economic policy uncertainty together. Aluminium futures are traded on restricted days and eye ball of data shows relatively very small changes in the prices of future instruments. This can be one reason for atypical results.

However the immunity shown by platinum futures can be best linked to the high and stable demand by various industries including technology, automative and chemical. Since demand for platinum remains stable therefore it shows an insignificant relation with global economic policy uncertainty.

However a more sophisticated model with inclusion of shocks and structural breaks may provide a deeper insight to the current work.

5 Does Economic Policy Uncertainty Cause Dynamic Movements in OECD Stock Markets?

5.1 Introduction

Economic policy uncertainty index has shown an increasing trend in the US and the Euro zone since 2010, (Baker et al. (2016)). Other nations including Australia, Canada and Japan have shown similar trends. Stock markets on the other hand hold immense importance in today's financial world. Tokyo stock exchange has a market capitalization of $5,679 Bn [6], while Toronto and Sydney stock exchanges have a capitalization of $ 2,095 and $ 1,326 each. Stock markets have proven to react to political and news events such as 9/11 (Baker et al. (2016)) . Further stock markets have a known spillover effect factor. This makes it a vital question to study the impact of economic policy uncertainty on stock markets.

Uncertainty is caused by changes in political regimes, fiscal and mon-

[6] This data is dated to 30/11/2018

etary issues and inter alia issues which include taxation, subsidies and other spending channels. High import, sectoral taxes and government privatization acts can change the way businesses operate specially in the absence of sufficient information. This triggers the process of collecting extra information which adds to the overall cost of the business. The concept of uncertainty has been a question under study for economists for nearly three decades, Marcus (1981), Bernanke (1983).

Marcus (1981), discussed the effects of uncertainty on innovation and advancement. The three aspects highlighted in their study include; the impact of uncertainty on the rational decisions of businesses and investors, the second aspect discusses the significance of policy related terms appearing in the news, the third point that is highlighted is the impact of policy uncertainty on technological advancement. These issues are further translated into finding the effects of policy uncertainty on on macro variables including GDP, output, employment.

The aim of this chapter is to investigate the effect of uncertainty on stock market indexes within the OECD area, using the economic policy uncertainty index by Baker, Bloom and Davis(2016) as a proxy for uncertainty. Policy uncertainty is a measure of ambiguity of future economic events and it can not be observed directly. It is essential to study the impact of policy induced economic uncertainty on stock prices as it causes lack of clarity about future economic decisions as perceived by people and businesses, Moore (2017).

Dynamic conditional correlation compares to rolling correlations. But rolling correlations are deemed to be consistent only under special circumstances such that within the window all observations are given equal weight and all values beyond that window are given zero weight, Engle and Sheppard (2001). However under dynamic conditional correlation there are no set windows and all information until time $t-1$ is added to calculate the correlation coefficient at time t. The method dynamic conditional correlation refers to the dynamically correlation correlation matrix

is time varying/ as it is calculates on the past whole sample until that time without eliminating any past values.

This study includes fifteen OECD countries based on the availability of economic policy uncertainty data. It look at the time varying relation between stock markets and policy induced economic uncertainty. Utilization of OECD based stock indices as a measure of stock market activity is beneficial because these indices include all common stocks listed on the respective stock exchanges. To build this relation we follow dynamic conditional correlation (DCC) model of Engle and Sheppard (2001). This model has been executed in Antonakakis et al. (2013) and Jones and Olson (2013). However these papers only focus on the US using S&P 500 however there exists a need to carry out more geographically dispersed analysisWisniewski (2016).

The results show that policy induced economic uncertainty and stock index returns have a historically negative correlation in UK, Russia, Mex-

ico, Korea, Japan, Italy, Greece, Germany, Chile, Brazil. However the correlation for Canada and Australia turns positive for Australia and Canada after 2016. These correlations are significant for investors aiming to invest parallel across different countries. They are also significant in understanding the flow of capital from a country which has a high correlation with EPU to one which has low correlation.

The remainder of this chapter is organized as follows: section 2) discusses the literature, section 3) discusses data and methodology, section 4) presents the results and section 5) is the conclusion.

5.2 Background

GARCH models are used to study the volatility behaviour in the residuals of the fitted model. The intuition behind using dynamic conditional correlation is setting a GARCH model and then using the covariance matrix of the errors to calculate the dynamic conditional correlations over time. GARCH modeling is done for volatility clustering and to capture

the heteroskedastic behaviour of errors. DCC-GARCH has the benefit of uni-variate GARCH as well as obtaining the most parsimonious parametric model to capture the behaviour of the correlations. DCC-GARCH is used to construct time varying conditional correlation based on the heteroskedastic errors of a GARCH (1,1) model. This method allows us to calculate a number of independent correlations over time. The real strength of of DCC-GARCH is its ability to flexibly model the dynamics of the volatility process.

It is important to model economic and political uncertainty as rise in uncertainty in area such as fiscal policy can delay investment decisions. However the economy does rebound after uncertainty is resolved. Rodrik (1989), discuss the effect of uncertainty on private equity banking, through a series of equations the papers highlights the negative impact of uncertainty on investments. Uncertainty has been a subject of extant literature for more than three decades, Marcus (1981).

Taking it further the aim of this paper is to find the historical time varying relationship between EPU and stock market index returns using the volatility captured by dynamic conditional correlation (DCC-GARCH) since this approach will help us in understanding the relation between EPU as a measure of risk/uncertainty and the market index as a dynamic phenomenon. DCC-GARCH was introduced in Engle (2002) and has been used to study the relation of S&P and EPU by Jones and Olson (2013)J.

Engle (2002), proposed multi-variate GARCH with time varying conditional correlations in a two step procedure. In the first stage this method allows us to fit a volatility model based on heteroskedastic errors, where as in the second stage these the errors are used to build correlations, which are dynamic and time varying. Static correlation models are less robust as they present correlation as a single figure over the entire time period. However DCC-GARCH optimises time varying correlation based on the frequency of data. It is also robust in terms of depicting the direction

through change in sign and the intensity based on the magnitude of the correlation factor.

The benefits of using this methodology are manifold such as, the ease of fitting as compared to multivariate models where estimates have to be made for the starting value. It also allows large correlation matrices to be estimated over the entire period of time under study. An additional benefit of this method is that it allows the user to distinguish between periods of negative, positive and no-correlation over time. It also takes into account both time variation and conditional heterogeneity in correlations. This paper is based on Engle (2002), GARCH with time varying conditional correlations. Correlations are important in financial management since they allow forecasting and taking hedge position in investment by keeping in view the correlation patterns.

5.3 Literature Review

5.3.1 Stock Prices, News and Politics

A theoretical model that incorporates the effect of uncertainty on stock prices has been discussed in Pastor and Veronesi (2012). This paper studies the effect of political uncertainty on risk premium. In order to study this relation they incorporate the effect of three types of shocks namely; capital, impact and political on asset prices. Capital and impact shocks come from aggregate capital while political shocks are driven by the political changes and the costs associated to the new policies. The effect of these shocks is studied in a Bayesian setting where government and agents do not have prior knowledge of changes in polices and believes are readjusted after policy change occurs. The process of policy change is based on three things; at a particular point in time government decides if the policy needs to be changed and if so which policies need to be changed, the new policies are heterogeneous a-priori to both government and agents, if a policy change occurs then new believes are set. Their

results show that weak economic conditions are associated to higher political uncertainty which give rise to risk premia.

Further Pástor and Veronesi (2013) develop a theoretical model to study the effect of government policies (those which directly effect the economic environment) on stock prices. The two aspects that are included in the model are; political uncertainty (government policy will change) and the impact uncertainty (the probability that the policy will change). The asset pricing model is set up as a Bayesian model where profits follow stochastic process similar to Pastor and Veronesi (2012). The model is set up as a step function in which three scenarios are studies; without policy change, announced but non-implemented policy change, a policy change that is announced and implemented. They determined that the the arrival of news effects stock prices as prices begin to fluctuate at the arrival of news. In a global model they deduce that stock prices go up after policy change occurs and the existing policies are deemed to be replaced by better policies. However stock prices start to show fluctuations

on days when news about inflation, unemployment or interest rates in announced.

According to the two studies conducted by Pastor and Veronesi it is theoretically evident that policy induced economic uncertainty causes fluctuations in stock prices. Further, we review literature which presents empirical evidence on the relation between economic policy uncertainty and stock prices.

5.3.2 Economic Policy Uncertainty and Stock Price

Liu and Zhang (2015) study the predictive power of economic policy uncertainty in detecting stock price volatility using high frequency S&P data. Using a heterogeneous VAR model the in sample results show that high level of EPU leads to higher volatility in stock prices and out of sample forecasts show that EPU is a significant predictor of volatility in stock prices. Thus, adding EPU as an explanatory variable to the forecast model increases the overall explanatory power of the models by 5%

irrespective of the the extension of the model used. Further, by utilizing heterogeneous vector auto regressions their results explain that stock prices deteriorate where as volatility increases as a result of rise in EPU.

Brogaard and Detzel (2015) study the time series effect of government economic policy uncertainty on asset returns for US both in time series and in cross-section. Their results show that high level of EPU demands higher risk premia on 3- 6- 12- months bonds future returns. On average 1.5% rise in uncertainty increases the demanded return by 6.5%. There exists negative contemporaneous correlation between changes in EPU and portfolio returns. Using GMM technique they show that innovations in policy uncertainty significantly impact portfolio returns after controlling for monthly volatility.

Ko and Lee (2015) use wavelets approach to study the pattern of stock prices and EPU overtime. Wavelets allow to study the behavior in both time and frequency domain. Studying the time domain allows us to re-

view the behaviour of signal as it arrives in time, however the frequency domain allows us to study the low or high intensity of the signal. Their findings show that EPU and stock indexes do not comove in eleven countries including Canada, China, France, Germany, India, Italy, Japan, Russia, Spain, the UK, and the US. This confirms the negative impact of EPU on stock market performance. Their results also show an overlapping behaviour such that when the EPU index rises in the US following that the EPU in other countries in the study also starts to rise. Their result confirm that there is international dispersion of policy uncertainty.

Chang et al. (2015) study the causality between stock market returns and uncertainty in OECD countries. The aim of the study is to investigate uni and bidirectional relation between EPU and stock markets returns. Among the seven OECD countries that were studied including Canada, France, Germany, Italy, Spain, UK, and the US their results show that in Italy and Spain changes in stock markets cause significant changes in uncertainty. However policy uncertainty causes stock prices to change in

United Kingdom and United States. However the results for Germany, Canada and France showed no significance relation in either direction.

The effect of US EPU on stock indices in the BRIC region has been studied in Dakhlaoui and Aloui (2016). By using rolling window and cross correlation functions they concluded that US EPU has negative effect on the average US stock returns. Their methodology consists of two stages, the first stage involves fitting an ARCH model. ARCH allows capturing time varying conditional mean and variance. In the second stage correlation functions are constructed for individual error residual terms.

Wisniewski (2016) present an in-depth literature review focusing on the impact of political events on stock prices. Combined review of studies focusing on the effect of business cycle, elections, wars, international political crises, military coups, terrorists attacks and international political tensions show that stock prices and stock market activity soars during these events. and overall higher uncertainty leads to negative impact on

stock returns.

The time varying correlation between stock market returns, implied volatility and economic policy uncertainty has been studied in Antonakakis et al. (2013). Using DCC GARCH they show that higher volatility in EPU dampens stock index returns to a greater degree. They find that dynamic conditional correlation is significantly affected by US recessions and oil supply shocks.

Jones and Olson (2013) find the time varying correlation between output, EPU and inflation using Engle (2002) method of time varying GARCH. They test the time varying correlation between EPU and inflation and EPU and output separately. Their results show that EPU consistently negatively impacts output in the US between 1986-2011. However the correlation between EPU and inflation showed a negative relation in the late 1990s and early 2000s between 1985 - 2011 and remained positive at other time periods.

Beginning from Pastor and Veronesi(2012, 2013) it is evident that policy uncertainty causes fluctuations followed by decrease in stock price. This relation has been tested empirically for various countries. EPU significantly causes reduction in stock prices ad overall portfolio returns in the US (Chang et al. (2015), Brogaard and Detzel (2015)). EPU also shows similar patterns of up and down turns globally as shown by Ko and Lee (2015). Results presented by Chang et al. (2015) show that EPU and stock indexes show no significant uni and bi-directional causal links in Germany, Canada and France. The literature review by Wisniewski (2016), shows that political news does effect stock prices and the index developed by Baker and Bloom includes all the words that link political, militant and other such issues. On the usage of dynamic conditional correlation this chapter follows Antonakakis et al. (2013) and Jones and Olson (2013). The main aim to find the time varying correlation between OECD stock markets and their respective policy uncertainty indexes.

5.4 Data

5.4.1 Stock Index and Economic Policy Uncertainty

This study is based on OECD monthly stock index data from OECD data bank. The OECD indexes are calculated from the monthly closing prices of common stocks which are listed on the national stock exchanges of the specific country. Monthly data is the simple arithmetic average of daily data. The share price index is formulated to measure how the value of the stocks in the index is changing. Price indices measure the change in market capitalization of the basket of shares in the index and to calculate return on investments in price index and the value of dividend payments assuming they are reinvested in the same stocks. OECD indices cover all common stocks as opposed to using specific stock market indices which include stocks based on performance such as earnings. [7]. The details of the EPU Index are explained in chapter 2.

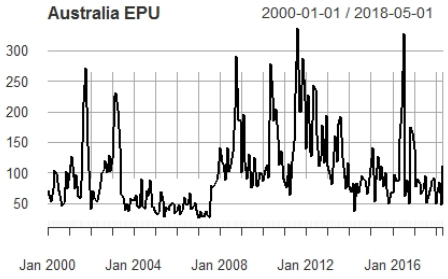
[7] http://www.oecd.org/std/leading-indicators

5.4.2 Graphical Representation

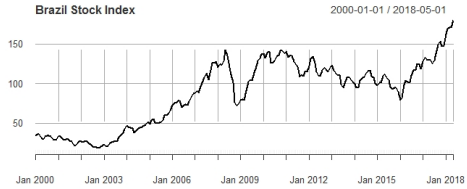
The graphs in the left panel of figure 7 through figure 11, represent the OECD stock indices where as the corresponding right panel contains graphs of EPU indices. A common pattern among the raw stock indices is that they show a dip towards the end of 2008 which is the time of the global financial crises. However if we look at EPU, which is a normalized index for each country we see that the overall behaviour of the index depicts more spikes, including the one during 2008 crises.



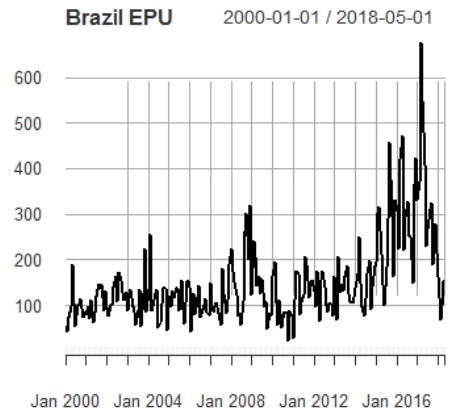
(a) Australia



(b) Australia

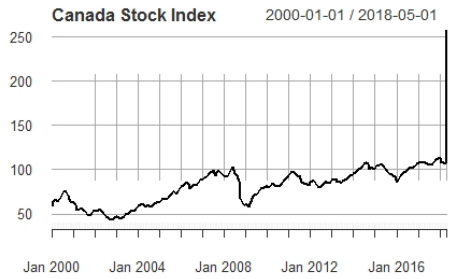


(c) Brazil

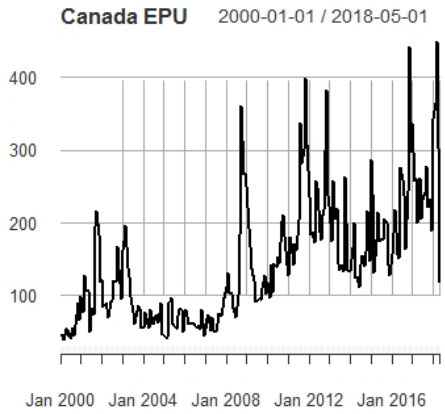


(d) Brazil

Figure 7: Data Representation



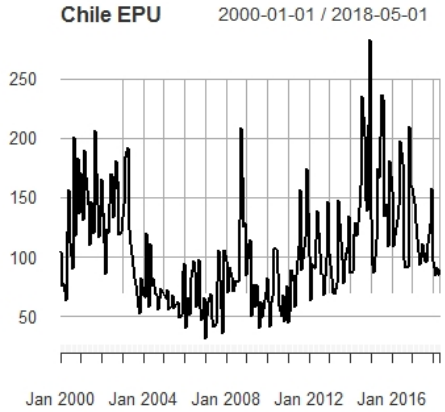
(a) Canada



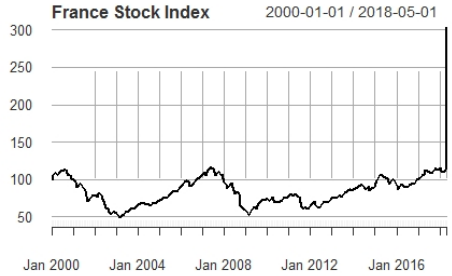
(b) Canada



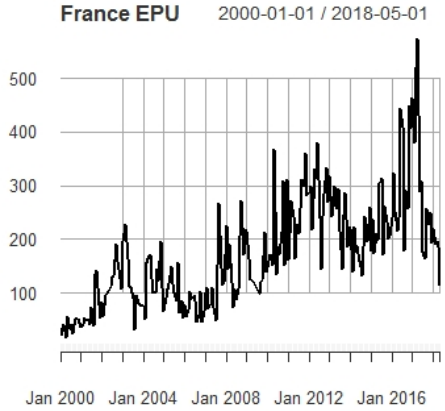
(c) Chile



(d) Chile



(e) France

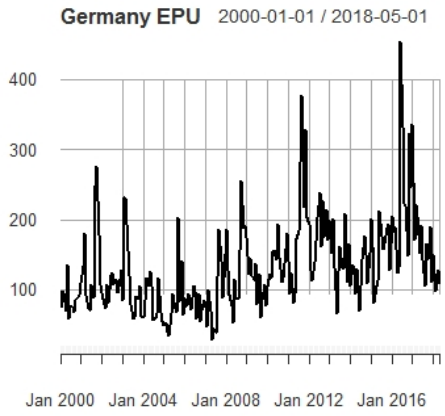


(f) France

Figure 8: Data Representation



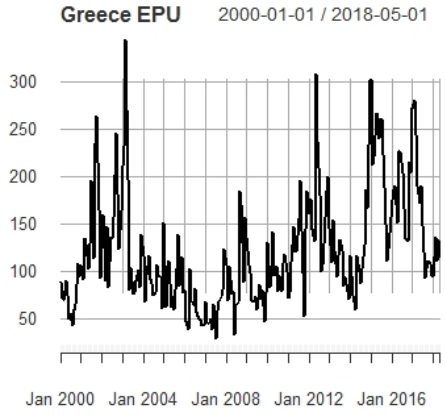
(a) Germany



(b) Germany



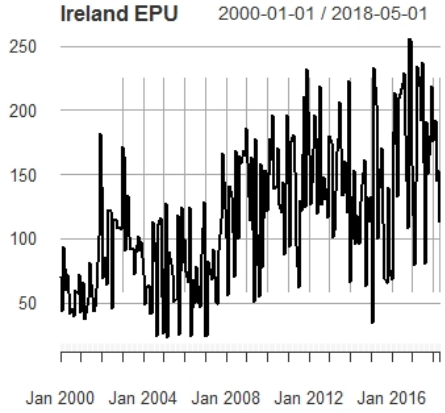
(c) Greece



(d) Greece



(e) Ireland

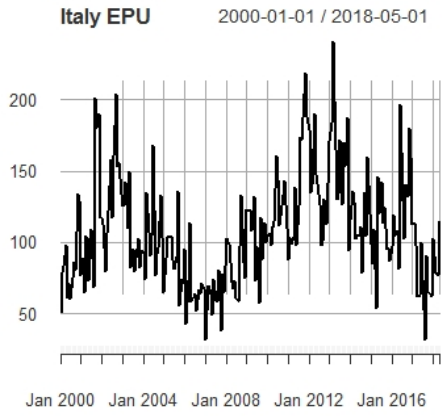


(f) Ireland

Figure 9: Data Representation



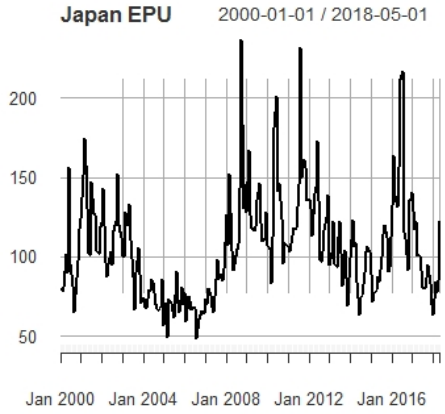
(a) Italy



(b) Italy



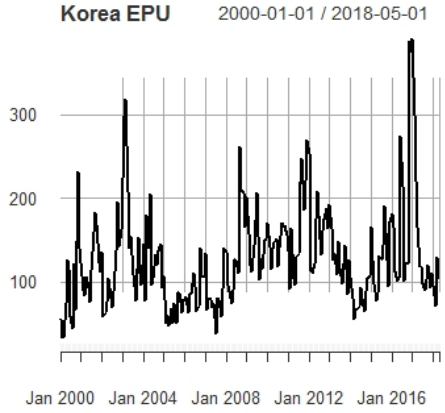
(c) Japan



(d) Japan

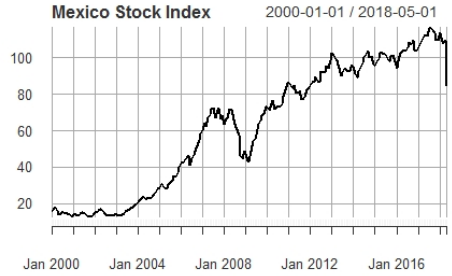


(e) Korea

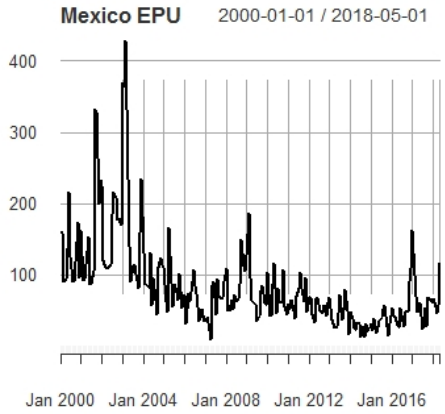


(f) Korea

Figure 10: Data Representation



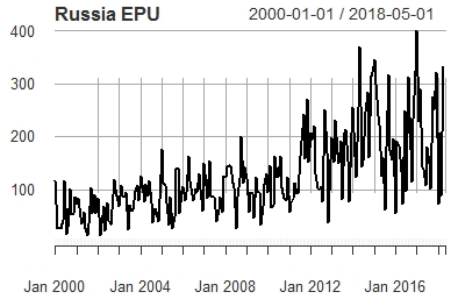
(a) Mexico



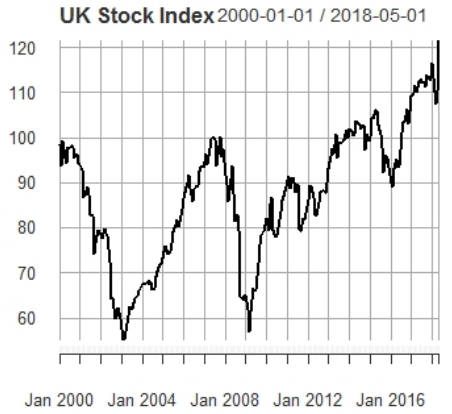
(b) Mexico



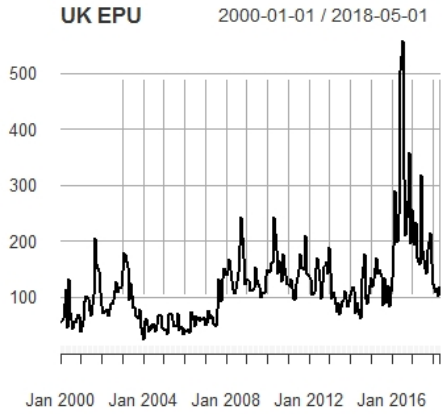
(c) Russia



(d) Russia



(e) UK



(f) UK

Figure 11: Data Representation

5.5 Methodology

We use log returns of stock indices and normalized EPU index to work out DCC coefficients. The two indices are at the same period because the OECD index and the EPU index are computed at the end of the month using corresponding daily data, therefore in order to check the historical correlation it is justified to use both the index from the same time subscript, t.

The results are based on dynamic conditional correlation GARCH adopted from Engle (1992). The process includes two steps. In the first step GARCH (1,1) model is estimated in order to capture the volatility behaviour followed by the calculation of correlation using the residuals from step one.

Model

The dynamic conditional correlation model measures the inter-dependency between returns and financial time series. The model assumes that the

return on index r_t are conditionally normally distributed under the following conditions:

$$r_t|\phi_{t-1} \sim N(0, H_t)$$

Where H_t is the conditional covariance matrix.

$$H_t \equiv D_t R_t D_t, \tag{19}$$

where r_t is a k x 1 vector of returns. H_t is a covariance matrix. R_t is the k x k time varying correlation matrix. $D_t = diag\sqrt{h_{it}}$ is a k x k matrix containing the time varying standard deviations of the uni-variate GARCH model. Following the conditionally assumption which explains the essence of dynamic conditional correlation all information included up to t-1 is contained in ϕ_{t-1}.

The standard deviation in D_t are governed by stand GARCH process de-

picted by the following equation:

$$h_{it} = \gamma_i + \Sigma_{p=1}^{P_t} \alpha_{ip} \varepsilon_{it-1}^2 + \Sigma_{q=1}^{Qi} \beta_{iq} h_{iq-q} \qquad i = 1,2 \qquad (20)$$

GARCH parameters follow the standard restrictions of stationarity and non-negativity under which $\alpha_{ip} + \beta_{iq} < 1$. Under this conditions H_t will be positive definite for all r.

In the next step we divide returns r_t by h_{it} to obtain standardized returns, $\sqrt{h_{it}}$, such that $\varepsilon_t = D_t^{-1} r_t$. This vector gives us the dynamic conditional correlations:

$$Q_t = \left(1 - \Sigma_{m=1}^{M} a_m - \Sigma_{n=1}^{N} b_n\right) \bar{Q} + \Sigma_{m=1}^{M} a_m (\varepsilon_{t-m} \varepsilon_{t-m}^{'}) + \Sigma_{n=1}^{N} b_n Q_{t-n} \qquad (21)$$

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1}$$

where $\bar{Q}$ is the conditional covariance of the standardized residuals obtained from GARCH (1,1) in the first step and Q^* is a diagonal ma-

trix composed of the square root of the diagonal elements of Q_t. The time varying conditional correlation indices of the R_t are represented as $\rho_{i_t,j_t} = \rho_{ii_t} / \sqrt{q_{iit} q_{jj_t}}$, where q_{ij_t}, q_{ii_t} and q_{jj_t} are the elements of Q_t corresponding to the indices.

5.6 DCC-GARCH Result

Table 20, exhibits the Dynamic conditional Correlation - GARCH results:

Table 20: DCC-GARCH Results

Australia						
α_1	α_2	β_1	β_2	a	b	Q
0.00	0.37	0.99	0.36	0.04	0.96	7.44
(1.00)	(0.01)	(0.00)	(0.00)	(0.08)	(0.00)	(0.9999)
Brazil						
α_1	α_2	β_1	β_2	a	b	Q
0.00	0.26	0.99	0.72	0.008	6.96	5.04
(0.24)	(0.02)	(0.00)	(0.00)	(0.05)	(0.00)	(0.9926)
Canada						
α_1	α_2	β_1	β_2	a	b	Q
0.11	0.32	0.89	0.68	0.01	0.99	5.84
(0.00)	(0.02)	(0.00)	(0.03)	(0.05)	(0.00)	(0.78)

Chile						
α_1	α_2	β_1	β_2	a	b	Q
0.22	0.12	0.78	0.81	0.13	0.67	2.14
(0.04)	(0.04)	(0.00)	(0.00)	(0.08)	(0.00)	(0.9913)
France						
α_1	α_2	β_1	β_2	a	b	Q
0.55	0.12	0.44	0.72	0.20	0.00	-
(0.78)	(0.02)	(0.92)	(0.00)	(0.96)	(1.00)	-
Germany						
α_1	α_2	β_1	β_2	a	b	Q
0.00	0.00	0.99	0.99	0.005	0.97	11.493,
(1.00)	(1.00)	(0.00)	(0.00)	(0.06)	(0.00)	(0.4872)
Greece						
α_1	α_2	β_1	β_2	a	b	Q

0.11	0.15	0.86	0.71	0.02	0.91	15.582
(0.23)	(0.03)	(0.00)	(0.00)	(0.04)	(0.00)	(0.04877)
Ireland						
α_1	α_2	β_1	β_2	a	b	Q
0.00	0.041	0.99	0.93	0.012	0.94	9.8821
(1.00)	(0.06)	(0.00)	(0.00)	(0.04)	(0.00)	(0.42)
Italy						
α_1	α_2	β_1	β_2	a	b	Q
0.08	0.00	0.84	0.99	0.001	0.97	3.81
(0.38)	(0.00)	(0.00)	(0.00)	(0.07)	(0.01)	(0.87)
Japan						
α_1	α_2	β_1	β_2	a	b	Q
0.00	0.58	0.99	0.22	0.03	0.72	2.29
(0.00)	(0.01)	(0.00)	(0.04)	(0.04)	(0.00)	(0.96)

Korea						
α_1	α_2	β_1	β_2	a	b	Q
0.10	0.16	0.89	0.75	0.00	0.91	5.77
(0.02)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.21)
Mexico						
α_1	α_2	β_1	β_2	a	b	Q
0.09	0.08	0.81	0.91	0.006	0.85	2.41
(0.03)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.49)
Russia						
α_1	α_2	β_1	β_2	a	b	Q
0.24	0.09	0.65	0.89	0.004	0.92	
(0.03)	(0.01)	(0.00)	(0.00)	(0.09)	(0.00)	
UK						
α_1	α_2	β_1	β_2	a	b	Q

0.16	0.33	0.75	0.64	0.02	0.97	2.82
(0.08)	(0.02)	(0.00)	(0.00)	(0.01)	(0.00)	(0.61)

The results are presented at 99%, 95%, 90% level of significance. The table represents the GARCH coefficients along with DCC coefficients which are represented in the (a) and (b) columns of the table. The DCC (1,1) model fits for all the countries under study except for France. The last column represents the Ljung-Box statistic for at 8 lags, which is the lowest common lag at which the null of no correlation can not be rejected.

α_1, β_1 explain the GARCH coefficients for stock index while α_2, β_2 are the GARCH coefficients for EPU, these coefficients capture the volatility clustering in the two variables. The results show that these parameters are significant and capture the volatility between the variables significant. From the results we also see that $\alpha + \beta < 1$ for both stock and index and

EPU which ensures that the volatility process is stable and shows persistence.

In order for DCC model to fully explain the interdependency between the two variables (stock returns and EPU) (a) and (b) have to be significant. Column (a) represents the stock index and column (b) represents EPU however these coefficient only explain the significance of the consolidated interdependency relation. The nature of the relation as per the time varying correlation coefficients is explained in the graphs.

The time varying conditional correlation coefficients are represented in figures 12 through figure 15. Among the fourteen countries included in the study, only France produced insignificant results. From the pool of thirteen countries we see that Ireland has peculiarly different results such that apart from the negative dip at the end of 2008 the correlation remains positive between 2000-2018.

For Canada and Australia the correlation remains negative till the mid of 2016 after which it starts to grow positive. However for the rest of the ten countries including Brazil, Chile, Germany , Greece, Italy, Japan, Korea, Mexico and Russia show consistently negative conditional correlation.

If we look at the major trends we see that the correlation pattern shows an extreme negative trend and downward pattern at the end of 2008. Since the stock markets showed a negative returns we see that economic policy uncertainty did correctly capture the behaviour. Further individual trends are described below with the graphs.

Graphic Results

Graph (a) of Figure 12 represents the correlation between EPU and stock returns in Australia. The results show that the correlation remained negative between February 2000 and January 2018. However this correlation exhibits a period of brief aberration between June 2016 and June 2017.

During this period the correlation becomes positive, which means that EPU affects stock returns positively. The lowest dip in Australian economy occurred at the end 2006 when provisions regarding the openness of Australian economy were being formulated. Sharp negative dips in correlation are also evident in 2008-2009 around the time of financial crises.

The positive correlation between EPU and index returns for Australia and Canada align with the theoretical findings of Pastor and Veronesi (2012) according to which higher uncertainty can lead to higher stock prices.

Graph (b) for Brazil shows that the extreme negative correlation was observed between 2008-2011. The sharp dip in 2008 is the response to the global financial crises. The correlation is least negative during 2017.

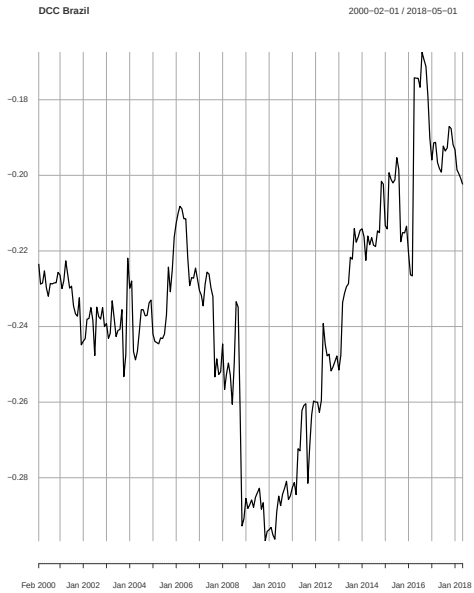
Graph (c) displays the correlation between EPU and index returns for Canada. The correlation remains negative between February 2000 until February 2016 after which it remains positive until January 2018. The

lowest dip is depicted during 2009 which shows the negative impact of high levels of economic policy uncertainty on stock market returns. Again the theoretically underpinning comes from Pastor and Veronesi (2012).

Graph (d) displays the time varying correlation for Chile. The two lowest dips occur at the end of 2008 and the end of 2011. The latter occurred due the impact of major earth quake that occurred in Chile.



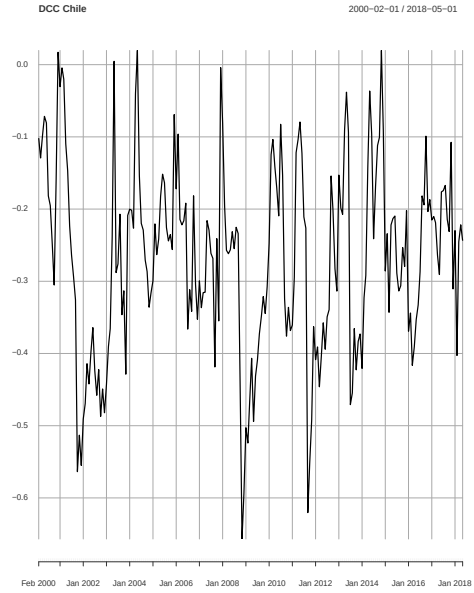
(a) Australia



(b) Brazil



(c) Canada



(d) Chile

Figure 12: Dynamic Conditional Correlation Graphs

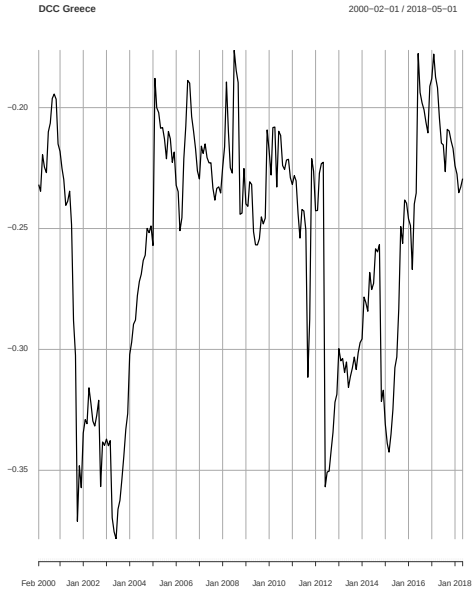
Figure 13, shows graphs for Germany, Greece, Ireland and Italy. The historical correlation between policy uncertainty and stock markets remains negative for Germany and Greece between 2000 - 2018. There is a sharp dip in the correlation pattern in all four graphs including Germany, Greece, Ireland and Italy at the end of 2008.

In addition we see a common negativity pattern for Germany, Greece and Italy and UK at the end of 2001, which occurs between the adoption of Euro and it being floated as a legal tender. The second common feature among Germany, Greece and Italy during the Greek debt crisis between 2011-2013. The individual sharp dip for Greece also occurs in 2015 around the time of snap elections.

For Ireland correlation shows a positive behaviour apart from the major global financial crises between late 2008 till 2010. However even while positive the correlation are very small in magnitude.



(a) Germany



(b) Greece



(c) Ireland



(d) Italy

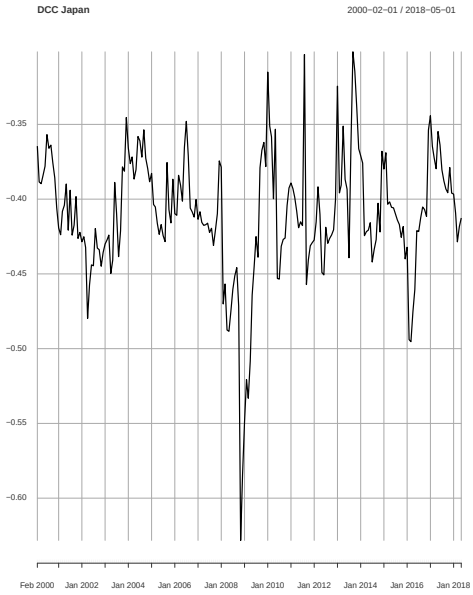
Figure 13: Dynamic Conditional Correlation Graphs

The graphs in figure 14, represent the correlation for Japan, Korea, Mexico and Russia. For Japan the major dips occurred in 2009 and 2016. The two years represent global financial crisis and the earthquake in Japan. In case of Mexico the dips respond to the Argentine economic crises in 2001 which occurred due to devaluation pressure on peso and over night deposit freeze fear among the public. And a shrinkage in the Mexican economy. The graph also shows a negative dip during US financial crises.

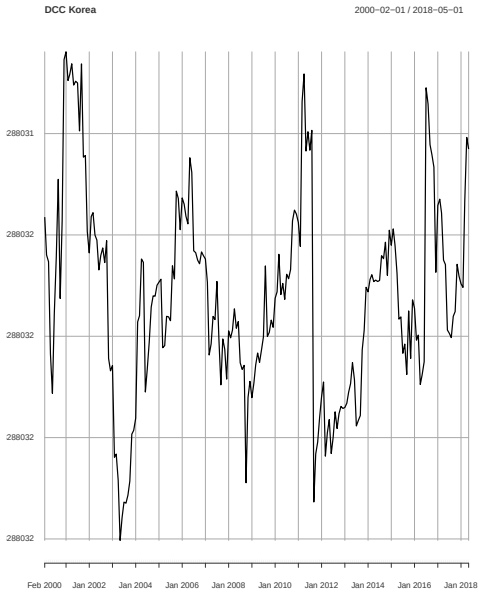
For Russia the major negative behaviour begins form 2008 and continues till 2012. In 2008 Russia faced economic crisis as well as the aftermath of the war with Georgia. This was also combined with the soaring oil prices. In case of Korea major dips occur in early 2003 due to the economy being under distress. It also responded to the 2008 global economic crises.

Figure 15 shows the correlation for UK. The figure shows sharp dips in 2001 and 2008 followed by 2016. These represent the major events

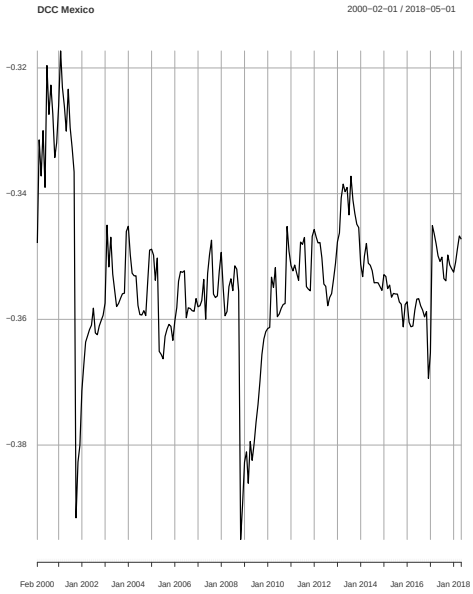
including the inception of Euro, the global financial crises and Brexit.



(a) Japan



(b) Korea

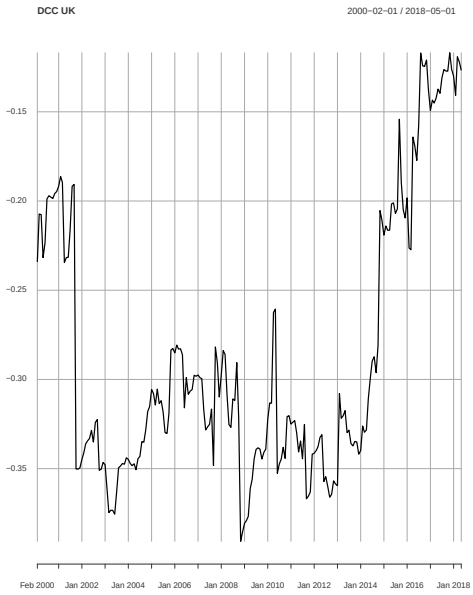


(c) Mexico



(d) Russia

Figure 14: Dynamic Conditional Correlation Graphs



(a) UK

Figure 15: Dynamic Conditional Correlation Graphs

5.7 Conclusion

The focus of this chapter is to study the inter-dependency between stock indices and the economic policy uncertainty index. This allows us to study the historical time varying conditional correlation between the two variables of interest. The dependency coefficients in the bivariate dynamic conditional correlation are significant showing that over time stock markets returns have been significantly impacted by economic policy un-

certainty. Intuitively, if we see the logic behind achieving significant relation is that investors align their believes according to the information that appears in news articles. By construction stock indexes are based on the daily average price of the stocks then consolidated on monthly average based on arithmetic means. On the other hand monthly EPU index is based on the information that occurs in newspapers on a daily basis.

The results are interesting in a way that they ensure that investors align their believes according to the news that disperses through newspapers and then make informed decisions. However studying a sample of fourteen countries we see that under two cases; Australia and Canada we see that after the end of 2016 the correlations turns briefly positive and then negative again. An interesting question would be to study the cause of this brief aberration.

However for all other countries our results show that policy uncertainty negatively impacts stock markets returns. Another important aspect of

the correlations graphs is the timely peaks and dips, which means during times of high uncertainty as gauged by the Baker, Bloom and Davis (2016) index stock indices show an increased negative behaviour.

These results hold significance because investing across OECD markets concurrently without checking the level and correlation with economic policy uncertainty may lead towards losing money. Also, it is evident that high levels of policy uncertainty reduce diversification benefits for portfolio investors.

The correlation behaviour of Ireland, Canada and Australia is specifically appealing since Ireland shows a constant positive correlation apart from two major dips. Further Canada and Australia show positive correlation beginning from 2016. This could open new avenues of research.

5.8 Appendix

Correlation Coefficient:

The residuals if the univariate models are decomposed into $D_t R_t D_t$ matrix where D_t is a diagonal of time varying conditional standard deviations from univariate GARCH. DCC(1,1) model specification:

$$R_t = diag\{Q\}^{\frac{1}{2}} Q_t diag\{Q\}^{\frac{1}{2}}$$

$$Q_t = (1-\alpha-\beta)\bar{Q} + \alpha\varepsilon_{t-1}\varepsilon_{t-1}^T + \beta Q_{t-1}$$

$$\rho_{ij,t} = \frac{q_{ij,t}}{q_{ii,t}q_{jj,t}}, i = j = 1,2,...,n, i \neq j$$

where R_t is a represents time varying correlation correlation between EPU and stock index, $\bar{Q}$ is the unconditional correlation coefficient. It is calculated through moment estimator.

6 Calibrating the Nelson - Siegel - Svensson Model

6.1 Introduction

The relation between interest rates and term to maturity serves a key role in finance and economics. The systematic representation of this relationship is known as term structure of interest rates. Yield curves are used as economic forecasting tools based on their ability to provide information regarding real economic activity, inflation and other key economic variables Piazzesi (2010). Zero coupon rates and forward rates are among the fundamental tools in finance and macro-economics Maciel et al. (2012) as they are used for various purposes such as testing the effects of changes in monetary policy, testing market efficiency and pricing of financial instruments. Forward rates, obtained through forward rate curves are used in pricing financial assets. They also reveal information regarding inflation and market expectations about the economies future. Yield curves were primarily constructed to represent the relationship between nominal interest rates of default-free zero-coupon bonds and time to maturity.

Apart from typical yield curves which are based on the yield and maturities of government bonds (risk free), yield curves can also be constructed for groups of bonds with similar ratings such as Euro Central Bank's AAA and AA rated bonds from the constituting 19 central banks. Hence from macro perspective yield curves are vital for monetary policy dissipation and from micro perspective, they are used by investors to make investment decisions based on expected returns.

Monetary policy dissipation is the process of transmission of monetary policy after settled by the Central Bank. The main transmission channel of monetary policy is the official interest rates settled by the Central Banks. These interest rates are the rates at which central banks lend money to commercial banks which further lend money to private and business borrowers. The slope of the yield curve tells the rate at which the central bank will issue debt, from there commercial banks and other economic agents can take a view of short and long term interest rates.

Due to the vitality of yield curves they have been widely studied in the literature, some of the major contributions include McCulloch (1971), McCulloch and Kwon (1993) for fitting the yield curve using cubic splines, Vasicek and Fong (1982) using exponential spline, Cox et al. (1985) for studying univariate affine term structure models **?** and Svensson (1994), for parsimonious modeling of the yield curve using, Duffee (2002) for making major advancement in affine term structure models, Piazzesi (2005) for adding macro factors to enhance the predictability of yield curves, Pooter (2007) for studying the extensions of Nelson-Svennson -Seigel framework, Diebold and Li (2006) for introducing dynamic yield curve modeling.

Despite the vital role that yield curves play, yield curves are not directly observed. Yield curves are approximated therefore it is essential to use techniques which are accurate and give robust results. The aim of this chapter is to calibrate Nelson-Siegel (NS) and Nelson-Seigel-Svennson (NSS) yield curves yield curves using differential evolution (DE) which

is a global optimization procedure.

NS and NSS models of term structure are parametric, parsimonious models of interest rate modeling. They are used by Central Banks and are known as practitioners model since, practitioners require models that are flexible, computationally easy to fit, well specified and realistic. The parametric approach is efficient to cover all information as it produces curves which take up all the realistic shapes i.e. upward sloping, flat, humped.

However NS and NSS curves are non-convex therefore rigorous optimization methods are required to obtain optimal solutions. Most optimization techniques such as gradient search can stop at a local minima, before reaching the global maximum. Diebold and Li (2006) suggested keeping the exponential decay factor in the Nelson-Svennson-Siegel factor at a fixed value so that the rest of the model could be solved using simple least squares. However this method proposed the difficulty in

finding a suitable fixed value for the decay factor.

6.1.1 Aim of the Chapter

In this chapter I use differential evolution (henceforth DE), introduced in Storn and Price (1997), to fit NS and NSS curves. DE is a global optimization technique to solve problems involving multiple local minima. What makes differential evolution unique is its high accuracy, robustness and ease of implementation Maciel et al. (2012). Differential Evolution is arguably one of the most powerful and versatile evolutionary optimizers for the continuous parameter spaces in recent times, Das et al. (2016). Differential evolution is a population based stochastic search technique used to find globally optimum solution in continuous space. However the empirics of using differential evolution have not been widely studied therefore by using German Bundes Bank data this chapter adds to the empirical robustness of global optimization techniques in modeling yield curves.

This study is based on fitting German Government yield curves using differential evolution method (144 monthly yield curves, in total). When compared to non-linear optimization, the results show that parameters obtained thorough differential evolution have lower standard deviations. Results show that the lambda or the exponential decay parameter shows erratic behavior, therefore handling this model using a fixed exponential decay factor to calibrate the entire function gives spurious results. Therefore Diebold and Li (2006) method can not handle this parameter problem significantly.

This chapter focuses on German data because the Bundes Bank uses NSS model to fit their yield curves. Economically Bundes bank is the main player in the Euro zone. NSS is the main methodology used by Bundes Bank therefore any improvement will add to the practical benefit of yield curve modeling. These bonds are very popular because of their liquidity and rating which increases their frequency of trade and the availability of data. There is also a general understanding that parametric methods

do well in developed bond markets and spline work better in developing bond markets, (2016)Kaushanskiy and Lapshin (2016).

Yield curves for the US have been studied in detail (Gilli et al. (2010), Maciel et al. (2016)). Another reason for US yield curves not being a subject of interest is the trading of instruments called, Separate Trading of Registered Interest and Principal of Securities (STRIPS) since 2007. STRIPS are zero-coupon securities issued by brokerage firms and based on receipts for Treasury securities. This provides yields of bonds of varying maturities and allows ease of construction of the yield curve for the US.

Through robust empirical testing, the results show that parameters obtained through differential evolution on average have low standard deviation when compared to those obtained by using non-linear least square method. In order to check the robustness of the results I use root mean square error which comes out lower for differential evolution over time.

Finally, I present Morgan-Granger-Newbold (1977)[8] test which is used to compare the forecasting power of two competing models. The results show that the parameters obtained through differential evolution have superior forecasting power for both Nelson Siegel and Nelson-Svennson-Siegel curves when compared with non-linear least square method.

The aim of this chapter is to empirically explain the superior fitting properties of global optimization (differential evolution) methodology and compare it with non-linear optimization to show that the errors obtained through the former method are significantly small and robust.

6.2 Background

Broadly term structure has two outcomes: an indication of where the interest rate is going and the perception of risk. These outcomes are important for monetary policy decisions and financial stability analysis (ECB bulletin 2008). Nelson-Seigel and Nelson-Seigel-Svennson models have

[8]Granger and Newbold (1977) developed this test for equal forecast accuracy by enhancing the orthogonalization conditions of the previous test introduced in Morgan (1939). The combined test is called the Morgan - Granger - Newbold test.

the ability to calculate the current interest rates and to make future forecasts Pooter (2007). 9/13 central banks use NSS method to report their zero coupon yield curves (BIS report). Yield curves provide good and useful information regarding bond prices which in turn indicate participants future expectations about markets/economy. Due to the inadequacy of the available data of pure discount bonds there stems a need to have an estimation methodology to derive the zero coupon yield curves from the observed data.

6.2.1 Yield Curves and their Uses

Central banks fit yield curves in order to get a view of market expectations of monetary policy, economic activity and inflation expectations over short, medium and long term horizons, however fitting long term maturities is extremely essential to maintain accuracy in forecasting. Yield curves which are a graphical representation of the term structure of interest rates are also used to represent the future of the economy at a glance, therefore central banks fit them on daily basis. Another vital use of yield

curves is to manage currency unions such as the Euro zone; through constructing yield curves for overnight index swaps and repo rates.

6.2.2 Understanding the Nelson-Svensson-Siegel Yield Curves

Parsimonious models (NS-NSS) are derived from Laguerre functions, which allow the parametric estimation of the curve. These parameters control the level, slope and curvature of the curve and have specific economic interpretation. Steep curve shows that the economy is moving fast, however a flat one shows slow economy. NS-NSS models are neither no-arbitrage nor no equilibrium in nature.

6.2.3 Benefits of Nelson-Svensson-Siegel Yield Curves

NS and NSS models have a great appeal due to several reasons such as; ease of estimation, ease of fitting smooth curves which give us the advantage of finding yields for all maturities, the parametric factors can be interpreted easily (slope, hump and interpolation factors), they are parsimonious in nature which makes replication easy.

But despite the attractive appeal of the parsimonious nature of the NSS models they have technical issues since the functional form is non-convex and poses difficulty in numerical estimation in estimating a global solution. The parsimonious family of models is derived from Laguerre function which gives rise to non-convexity and multiple local minima optimization problem. Thus superior modeling and forecasting techniques enhance the accuracy of the decisions of the parties involved. In order to handle this issue I use a specific global optimization routine introduced in Storn and Price (1997).

6.2.4 Commonly Used Methodologies for Nelson-Svensson-Siegel Yield Curves

The two main approaches to fit yield curves include 1) spline based interpolations 2) parametric approach.

Spline based approach is mathematical methodology which breaks the polynomial function to interpolate these missing points and produce data

points which help to construct a smooth curve. Spline based interpolation is a method used to interpolate missing values between two data points.It is used to approximate yield curves such that it enables to calculate the yields of maturities that are not traded on the market.

Parametric approach is an umbrella term used for optimization algorithms such that approximate the parameters of the yield curve function.

6.3 Literature Review

6.3.1 Methodology: Splines

Having noted the broad scale usage and importance of yield curves the basic shortcoming is that yield curves are not explicitly observed, since bonds of all maturities are neither issued nor traded at all times, McCulloch (1971) developed a methodology based on splines to fit yield curves. Splines are mathematical functions that help in interpolation between given data points. Spline based methods are popular in yield curve modeling since their polynomial based structure allows to take up differ-

ent shapes (humped, upward and downward sloping). Use of quadratic and cubic splines lead to misleading shapes of the yield curves therefore Vasicek and Fong (1982) reiterated the model for US T-Bills using exponential splines to present the superior fit of the overall curve. However the use of splines to fit forward yield curves requires specific weights for short and long maturities, settling these weights has been a major debate in the ongoing literature. However only recently Kaushanskiy and Lapshin (2016) introduced an automatic smoothing technique which does not require choosing weights manually.

6.3.2 Methodology: Parametric Form

Comparative to spline based approach is the Nelson-Seigel and Svensson yield curves. In the original Nelson-Seigel (1987) paper the derivation of the curve results in a parametric form for forward curves. This structure also shows long term convergence. The functional form of the NS-S framework assures that the yield curve only takes up designated shapes however this is not assured by the spline approach. In the past literature

yield curves have been fitted to US-T Bills, using grid search to solve the optimization problem. However their single hump model was then studied for Swedish government bonds in Svensson (1994) which then enhanced the single humped model by a double humped model on the bases of better predictability of future rates. Pooter (2007) studied various extensions of the NSS model and concluded that the original three factor model has the ability to capture the behavior of the yield curves. Extra parameter addition is not required.

Björk and Christensen (1999) studied if the parametric forward rate models comply with the underlying no-arbitrage interest rate models. They checked the original three factor Nelson Seigel model against the Heath Jarrow, Hull and White and Ho-Lee models. The implications of their study were that Nelson-Seigel model does not ensure the absence of arbitrage opportunities. These findings have been tested statistically in Coroneo et al. (2011), using US T-Bill data, and their results show that the parameters derived under arbitrage and no-arbitrage assumptions are

not statistically different at 95% confidence intervals. Christensen et al. (2011) gave an account for the theoretically arbitrage free version of Nelson Seigel model. They concluded that the arbitrage free Nelson Seigel has a strong theoretically underpinning and outperforms affine models, however the application of these is not a topic of our present research.

The most widely used methods to fit the NS-S models include linear regressions such as those in the original papers, followed by Diebold and Li (2006) method, even though other methods can give similar parameters but we need a method which gives superior interpolation/fit, for purposes such as refitting.

Ioannides (2003), compared different methods of yield curve modeling for Mexico and revealed that parsimonious models such as the Nelson-Seigel framework fit the data much better than the spline methods. Csajbok et al. (1998), conducted an in-depth study for the appropriate method of yield curve approximations for Hungary and concluded that parsimo-

nious models give better results and in terms of yield curve modeling and giving forward rates.

Nelson-Seigel model has proved to be a powerful forecast model when compared to other models including VAR and the random walk as studied in Diebold and Li (2006). Fabozzi et al. (2005) also show that this method has good statistical and economic forecast ability. NSS models work very well for long term horizons Velásquez Giraldo and Restrepo-Tobón (2015)). Parametric models are preferred because they are good for forecasting, predictability and fit the humped and exponential-S shapes very well.

6.3.3 Differential Evolution

Various methods that have been employed to model yield curves include exponential splines, non-linear regressions, piecewise polynomials and gradient search. Spline based methods use a number of approximations functions based on which the yield curve can take shapes that do not com-

ply with the underlying economic theory. Direct search or gradient based search methodologies are forced to explore just a small area around the initial value. These techniques are also hard and tricky.

Storn and Price (1997), introduced differential evolution as a vector based global optimization heuristic, with superior convergence properties when tested against other methods including Nelder Mead and annealing. Gämperle et al. (2002), the results showed that Nelder Mead and annealing are highly sensitive to starting values which makes differential evolution a superior method in terms of accuracy.

A broad study of non-linear optimization algorithms was carried out in Manousopoulos and Michalopoulos (2015), they tested three categories of algorithms (direct search, gradient based and global optimization) and deduced that only global optimization techniques can handle multiple minima issues. Global optimization, which is the functionality of DE is important in finance and economics. Gilli et al. (2010) used differen-

tial evolution on Fama and Bliss smoothed data for the US economy and showed that DE provides better convergence as oppose other non-linear methods. Maciel et al. (2016), give a comparison of genetic algorithm, non-linear least squares and differential evolution algorithm to estimate US yield curves. Their results prove that differential evolution provides better results.

Differential evolution is used to solve real valued functions in continuous space function. Differential evolution uses iterative method by running several vectors simultaneously to reach a global optima, this makes it a superior parameter configurations method which helps in escaping local minima issues. Non-linear problems are solved through optimization, however the most important concept in optimization is reaching a global maximum (convex problems have an explicit maxima, however the NS-S curves are non linear which makes them non-convex). DE provides ease of use and implementation as control variables are easy to choose. It also provides consistent convergence to the same values in consecutive trials.

Further it fulfills all the requirements of the stochastic optimization techniques and obtains one global maxima.

Differential evolution also gives solutions that fit the data very well, allowing accurate model fitting and forecasting Gilli et al. (2010). An evolutionary algorithm that aims at solving non-convex optimization problems and enables us to calculate all the parameters in one run. The parameters need to be bounded and the optimization runs within these ranges to optimize. It is used to find the solution in a pool of solutions. It is a type of meta-heuristic used to obtain the global optimum of a problem.

6.4 Theoretical Framework

Term structure of interest rate represents the nominal interest rates of zero-coupon default free government securities over a range of maturities. Each point on the yield curve is associated with a yield at a specific maturity. The term structure is used synonymous to three concepts here: discount function, zero coupon yield, instantaneous forward rate.

Here I describe the important concepts that are used in constructing the yield curve. I begin with the price of the bond which is the present value of its deterministic future cash flows including the redemption value:

$$\begin{aligned} P &= \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_m}{(1+r)^m} + \frac{R_m}{(1+i)^m} \\ P &= C\sum_{i=1}^{m} \delta(\tau_i) + R\delta(\tau_m) \end{aligned} \tag{22}$$

Where $P_{t\tau}$ is the price of a discount bond of τ period maturity at time t. By a discount bond I mean to represent the present value of £1, receivable τ periods ahead. C is the periodic coupon payment at time $\tau_i, i = 1, ..., m,$, r is the instantaneous spot rate, R is the final redemption value at τ_m and $\delta(\tau)$ the discount function.

For a zero coupon bond (with no timely coupons at all) issued by the government (default free in nature) the discount function will become:

$$\delta(\tau) = e^{-\tau y_t(\tau)} \tag{23}$$

From this discount curve we obtain the instantaneous forward rate curve which is the ratio of the derivative of the discount function from equation (2) and the discount function itself:

$$r(\tau) = \frac{-\delta'(\tau)}{\delta(\tau)} \tag{24}$$

The mean forward rate in a specific maturity interval $[\tau_1, \tau_2]$ is the average of $r(\tau)$:

$$f(\tau_1, \tau_2) = \frac{1}{\tau_2 - \tau_1} \int_{\tau_2}^{\tau_1} r(t)dt \tag{25}$$

yield curve is the average forward rate curve:

$$y(\tau) = \frac{1}{\tau} \int_0^{\tau} r(t)dt = \frac{1}{\tau} \int_0^{\tau} \frac{-\delta'(\tau)}{\delta(\tau)} dt = \frac{-ln(\delta(\tau))}{\tau} \tag{26}$$

6.5 The Nelson - Siegel - Svensson Functions

According to NS the yield curve is monotonic and humped therefore a single functional form can explain the behavior of its evolution. Parsimonious models of interest rates have been widely used after regression and

polynomial spline functions, where the concentration is on the discount function. The discount function approach is based on the estimation of the parameters that govern the linear bases function used in estimating splines. Within the Nelson - Seigel - Svennson structure a direct functional form for the forward rate is presented. Here I introduce the Nelson and Siegel (1987) and Svensson (1994). The yield to maturity is the average of the forward rate, such that:

$$R(m) = 1/m \int_0^m r(x)dx, \tag{27}$$

The original model indicates that the yield at a point in time can be explained as

$$y(\tau) = \beta_1 + \beta_2 \Big[\frac{1 - exp(\tau/\lambda)}{\tau/\lambda}\Big] + \beta_3 \Big[\frac{1 - exp(\tau/\lambda)}{\tau/\lambda} - exp(-\tau/\lambda)\Big] \tag{28}$$

The NSS adds second hump to the process such as:

$$y(\tau) = \beta_1 + \beta_2\Big[\frac{1-exp(\tau/\lambda_1)}{\tau/\lambda_1}\Big] + \beta_3\Big[\frac{1-exp(\tau/\lambda_1)}{\tau/\lambda_1} - exp(-\tau/\lambda_1)\Big] + \beta_4\Big[\frac{1-exp(\tau/\lambda_2)}{\tau/\lambda_2} - exp(-\tau/\lambda_2)\Big] \tag{29}$$

The first thing to be understood is that a given yield curve is fitted for a given maturity (time period) and it represents the yields of all the maturities for that time in point. In order to fit the Nelson-Seigel curve for a given cross section we need to estimate four parameters: β_{1t}, β_{2t}, β_{3t}, λ_t. However for the extended version we need to calculate two additional parameters including β_{4t}, λ_{2t}.

β_{1t}, β_{2t}, β_{3t}, β_{4t} are interpreted as the latent factors with respective loadings. However β_1 carries a loading of 1 (constant), often known as long run yield level since it is a constant and does not decay to zero. β_2 has a loading of $\frac{1-exp(\tau/\lambda)}{\tau/\lambda}$ which makes it a weighted function of time to maturity. β_3 is also weighted by a function of τ and has a loading

$\frac{1-exp(_\tau/\lambda)}{\tau/\lambda} - exp(-\tau/\lambda)$, this is the medium term factor.

Diebold and Li (2006), explained the dynamic NS model and their interpretations for the three factor model as the level, slope and curvature factors. Where β_{1t} governs the long term level, and increases all yields equally. The slope/ steepness is governed by β_2 which is defined as the ten year yield minus the three months yield. Where as (β_3) governs the and curvature is defined as the twice the 2 years yield minus ten years yield and three months yield.

Small values of τ show a rapid decay while large values show a slower decay. which helps in fitting curves over a longer period of maturity, but they do not follow extreme curvature. The true relation of the maturity and the yield curve might not be evident since there are so many non-linearities in the real world even if the curve is not the shape we want.

These interpretations are presented in the literature.

- The parameter λ_1 is the exponential factors which governs decay of the curve. Small values of this factor produce slow decay while large values produce fast decay. This behavior can be seen while experimenting with different values of λ. However this behavior can be used to fit curves at short and long maturities. λ_1 gives the first hump to the model while λ_2 gives the second hump to the curve.

- β_1, β_2, β_3, β_4, are latent factors that describe the curve. Where β_{1t} is a constant, according to the mathematical restrictions, this factor cannot reach zero as λ the term to maturity increases. Therefore this factor can be viewed as the long term interest rate. It has a unit factor loading.

- β_2 is understood as the short term factor as its loading $\frac{1-exp^{-\tau\lambda_1}}{\tau\lambda_1}$ starts from 1 and decays to zero.

- β_3 has a loading of $\frac{1-exp^{-\tau\lambda_1}}{\tau\lambda_1}$, this factor starts at zero and then decays to zero therefore it is understood as the medium term factor.

- β_4 has a loading of the $\frac{1-exp^{-\tau\lambda_1}}{\tau\lambda_2} - exp\frac{-\tau}{\lambda_2}$, this factor adds a second

hump to the yield curve.

- The restrictions include $\beta > 0$, $\beta_1 + \beta_2 > 0$ and $\lambda > 0$, $\lambda > 0$ and $\lambda_1, \lambda_2 > 0$.

Shapes of the yield curves

The most common shapes of the yield curves include upward sloping, downward sloping, humped and inverted humped, these shapes comply with the underlying economic theories. The three main theories that explain the behavior of yield curves include:

- **Liquidity Preference Theory:** The liquidity preference theory was developed by Keynes (1964) in his book The General Theory of Employment, Interest and Money (1936). It is an off shoot of the pure expectations theory which indicates that the investors demand a term premia over the holding period. Explaining the cost of capital being invested to be higher at future time periods. This states the intuition behind longer term yields being higher than shorter yields.

- **Preferred Habitat Theory:** It is also referred as the preference theory, was proposed by Culbertson (1957) and Modigliani and Sutch (1966). It explains individual preference, and choice of investment. As investors want to invest in one type of maturity and need substantial risk premia to a shift to a different maturity.

- **Pure Expectations Theory:** This theory was proposed by Mishkin (1990). It asserts that the term structure depends upon the expectations of the investors while price of the bond is determined by the investors expectations of future interest rate only. Forward rates are expected future rates, much of it states that since investors expect higher forward rate the curve is upward sloping. However even if short rates are expected to fall curves are still upward sloping since investors demand a premium on their investments.

Problem

The aim here is to estimate parameters by minimizing the difference between observed rates and model rates. The optimization problem is stated as :

$$\min_{\beta,\lambda} \sum (y - y^M)^2 \tag{30}$$

Where, y: fitted yield and y_M: market observed yield, β: slope parameter, λ: curvature parameter.

While fitting the yield curve slope and curvature parameters are chosen such that the difference between the observed and fitted yield is minimized.

6.6 Methodology

Differential Evolution: Step by Step

Differential evolution is an iterative method of solving the optimization problem. It includes four steps: 1) initialization, 2) mutation, 3) crossover

and 4) selection. Step 2) - 4) are iterated until the maximum termination criteria is met.

Terminologies explained; P: population, it contains all possible candidates/values for the optimized solution. Donor vector: vector generated by differential mutation operator. Target Vector: A parent individual chosen from the current generation is called a target vector. Trial vector an offspring generated by combining donor and the target.

Step1: Initialization An optimization problem consisting of n parameters is represented by a n dimensional vector $\mathbf{x}_{i,G}$ such that:

$$\mathbf{x}_{i,G} = [x_{1,i,G}, x_{2,i,G}, \ldots, x_{n,i,G}], \qquad i = 1, 2, \ldots, N \tag{31}$$

n = number of parameters to be optimized, i = size of the population, G = generation number.

In case of NS and NSS models the $\mathbf{x}_{i,G}$ vector of parameters is repre-

sented as:

$$\mathbf{x}_{i,G} = \theta_i = (\beta_{1t,i}, \beta_{2t,i}, \beta_{3t,i}, \lambda_{t,i},) \tag{32}$$

$$\mathbf{x}_{i,G} = \theta_i = (\beta_{1t,i}, \beta_{2t,i}, \beta_{3t,i}, \lambda_{1t,i}, \lambda_{2t,i},) \tag{33}$$

The set of vectors $\mathbf{x}_{i,G}$, $i = 1,2,\ldots N$ together constitute to a population P, of N individuals. The initialization starts at G=0, where the individual components are chosen randomly within in the given ranges. The population generation methodology is as following:

Each chosen parameter is guarded by a lower and upper bounds, which is coded as $x_{j,min}$, $x_{j,max}$, between the boundaries and each value is chosen as the following formula:

$$x_{j,i,0} = x_{j,min} + \varepsilon_{i,j}.(x_{j,max} - x_{j,min}) \tag{34}$$

where $j = 1,2,\ldots,$ N and $\varepsilon_{i,j}$ is a uniformly distributed random number lying between 0 and 1. The random errors are always chosen from a normal distribution in order to avoid creating any bias in the generated

population.

At this stage we generate a population of possible solutions by defining the ranges within which the true parameters should exist (genetic algorithms like DE do not require ranges however to give the parameters of yield curve economic meaning we give them a boundary). The initial population is created using a trial vector, NP,(NP represents the size of the entire generated population, this generation number the bounds/initial values of this population are given as input to the system) with D dimensional parameter (each D-dimensional vector contains the generated population for independent parameter i.e. NS model has four D-dimensional vectors, while NSS has six D-dimensional vector) vectors such that they contain the probable/candidate set of solution parameters.

Step 2: Mutation This stage is described as the process of random perturbation in each element of the initialized vector to create a donor/mutant vector $v_{i,G}$. This process requires three vectors $x_{r_1^i}$, $x_{r_2^i}$, $x_{r_3^i}$, (the subscripts

are used to identify each member of the population) the subscripts are mutually exclusive integers randomly chosen in [1, N] and distinct from i. The mutation works as follows:

$$v_{i,G} = x_{r_1^i,G} + F.(x_{r_2^i,G} - x_{r_3^i,G}) \tag{35}$$

where F is the mutation scale factor. Different papers use different values usually between [0.4,1]. Mutation expands the search space and increases the robustness of the answer.

Step 3 : Crossover Here a crossover vector is developed for each pair of the generated mutant (donor), $v_{i,G}$, and its corresponding target vector $x_{i,G}$ to generate a new trial vector $u_{i,G} = [u_{1,i,G}, u_{2,i,G}, \cdot, u_{n,i,G}]$. Cr is the crossover parameter, within the range [0,1] and tells the probability of crossover which tells us the probability of creating trial vectors from mutant vectors. The cross over should be kept between [0.3, 0.9] according to Gämperle et al. (2002), according to Ronkkonen et al. (2005) [0, 0.2]

for separable functions and [0.9, 1] otherwise.

Step 4 : Selection It determines whether the target or the trial vector survives to the next generation $G = G + 1$

$$x_{i,G+1} = \begin{cases} u_{i,G}, & \text{if} f(u_{i,G} \leq f(x_{i,G}) \\ \\ x_{i,G} & \text{if } f(u_{i,G}) > f(x_{i,G}) \end{cases} \tag{36}$$

The iterative process stop when the maximum number of generations is achieved.

Control Parameters:

The optimization has been studied in Gimeno and Nave (2009), Manousopoulos and Michalopoulos (2009), Gilli et al. (2010). The parameters are cross-checked with the existing literature.

Control parameters is a list of parameters that are used as input to the code. NP: is the measure of the size of the population. It is set to 200. F:

scaling factor, for controlling the difference vector. It is set to 0.9. CR: is the cross over rate. It is set to 0.99. These parameters are chosen on the bases of the parameters chosen in the past literature, Storn and Price (1997), Gilli et al. (2010), Maciel et al. (2012).

Pseudo Code

Begin

G = 0

Generate initial population NP

while G $<$ G_{max} **do**

for i = 1 to N

generate a donor vector $\rightarrow \mathbf{v}_{i,G}$

generate a trial vector $\rightarrow \mathbf{u}_{i,G}$

if $f(\mathbf{u}_{i,G}) \leq f(\mathbf{x}_{i,G})$ **then**

$x_{j,i,G+1} = x_{j,i,G}$

else

$x_{j,i,G+1} = x_{j,i,G}$

end if

end for

G = G+1

end while

G determines the generation number of the population. In the first step a population of size NP is generated, where N is the number of parameters and P is the permutation number. In the next step a donor vector ($v_{i,G}$) is created. This vector is the weighted difference of two randomly selected vector from the population. The trial vector ($u_{i,G}$) is generated by the donor vector and the target vector. Then the target vector is compared to the trial vector and the one with lowest functional form ($f(x_{i,G})$) is chosen for the next generation. The code reiterates until the lowest functional form is obtained within the lower and upper bound limits set in the parameters.

6.7 Data

We use the expected monthly yields of the German Treasury Bonds, provided by Thomson Reuters database. Our data spans between 11/1/2005 - 11/1/2017. We include maturities of 3M, 6M, 1Y, 2Y, 3Y, 5Y, 6Y, 10Y, 20Y, 30Y.

Comparative Methods

In the original paper Nelson Seigel (1987), used grid search to estimate the parameters $\theta_t = \{\beta_{1t}, \beta_{2t}, \beta_{3t}, \lambda_t\}$ with a fixed value of λ. Diebold and Li (2006), improvised this into a dynamic Nelson Seigel process. They also computed the parameters by fixing a lambda value, however in order to carry out a meaningful estimation of the betas the correlation between the factor loadings has to be considered. This makes Diebold and Li (2006) method technical as it is hard and time consuming to find a value of lambda which which minimizes the correlation and produces significant betas at the same time.

Non-Linear Least Square

Since the NS and NSS equations are formulated as Laguerre function therefore it can be solved using non-linear norms. These norms can be solved without fixing the values for lambda, by using respective optimization functions. Manousopoulos and Michalopoulos (2009), provide an extensive account of the non-linear methods of optimization. We use basic non-linear nlminb.

The parameter settings are as following:

$\beta_{1t} = \frac{1}{M}\sum_{k=1}^{M} yk, \beta_2 = y_s - \beta_1, \beta_3 = 0, \lambda = 1$

1. β_{1t}: is set to the average yield.
2. $y_s - \beta_1$: the value of β_2 is set such that the the average yield us subtracted from the $y_k - 1$
3. β_3: is set to zero.
4. λ: is set to 1.

6.8 Results

Data Description

Figure 16, exhibits the yields for German government bonds. The yields on y axis are very small, therefore in order to make the graph readable the values have been multiples by 100. Number 10 on the y-axis mean 0.01%. The different colors denote different maturities.

Figure 16: Bundes Bank Data

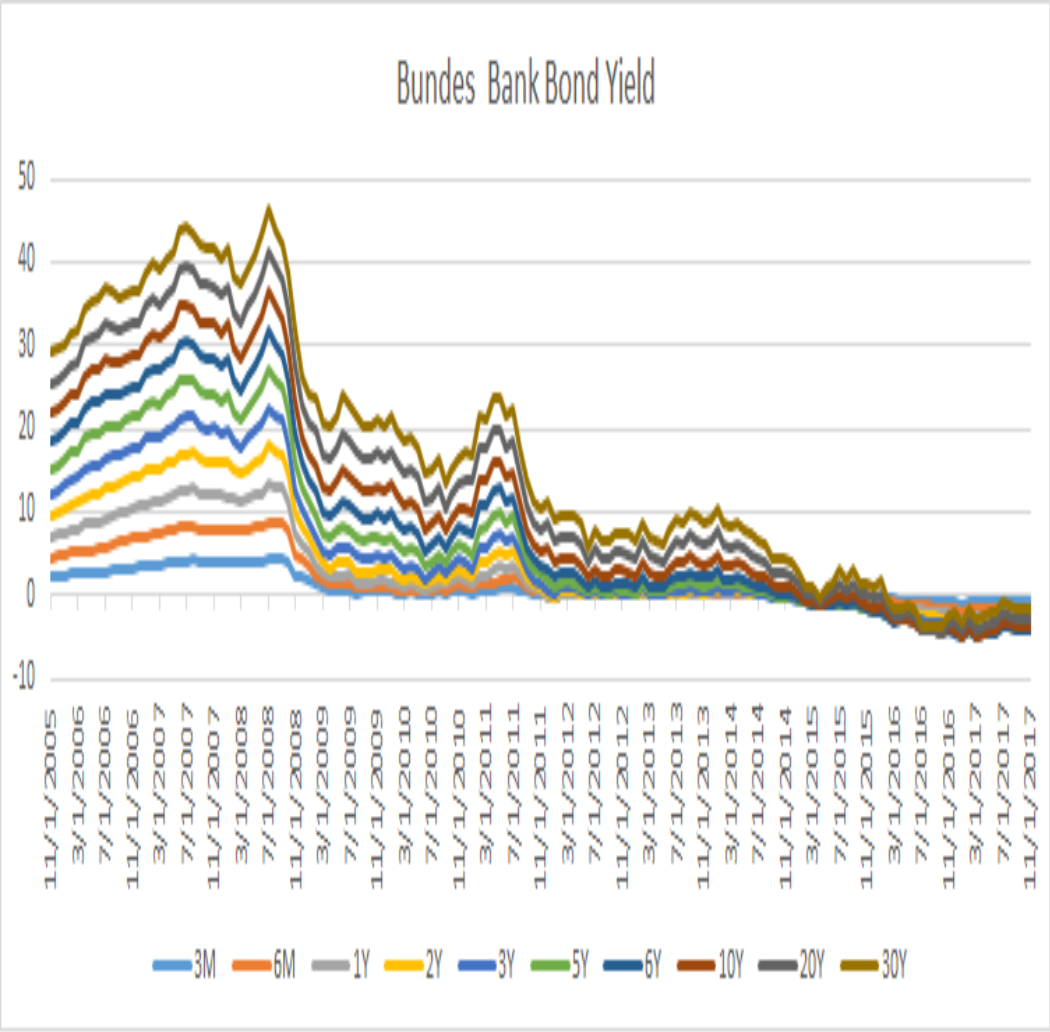


Table 21: Descriptive Statistics

Maturity	Mean	St. Dev	min	max	Skewness	Kurtosis	JB	ρ_{1m}	ρ_{12m}	ρ_{36m}
3 Month	0.89	1.62	-0.98	4.33	0.98	-0.56	25.1867	0.988	0.694	0.063
6 Month	0.96	1.63	-0.92	4.43	0.95	-0.62	24.1969	0.988	0.699	0.081
1 Year	1.05	1.67	-0.86	4.66	0.9	-0.7	22.5039	0.987	0.708	0.110
2 Years	1.13	1.64	-0.82	4.59	0.74	-0.9	18.0622	0.986	0.737	0.161
3 Years	1.24	1.64	-0.8	4.6	0.61	-1.05	15.6114	0.985	0.754	0.193
5 Years	1.56	1.6	-0.56	4.64	0.36	-1.3	12.995	0.984	0.774	0.243
6 Years	1.71	1.58	-0.53	4.63	0.25	-1.38	12.669	0.983	0.782	0.258
10 Years	2.21	1.43	-0.13	4.61	-0.02	-1.41	11.6445	0.982	0.783	0.259
20 Years	2.77	1.38	0.18	4.94	-0.25	-1.31	11.5451	0.980	0.775	0.241
30 Years	2.82	1.29	0.36	4.87	-0.21	-1.28	10.6846	0.978	0.767	0.238

The average yield for all maturities remains positive. However the minimum values for all yields with the exception of the longest maturities i.e. 20 years and 30 years remains negative. The highest yield is earned on 20Y maturity. The measures of kurtosis does not confirm that the distribution of the yields is non-normal. The auto correlation of 1 month and 12 month remain high however these decrease with the increase of time period. The auto correlation becomes weakest for 3 and 6 month maturities since the yields of shorter maturities show erratic behavior.

Parameters

The parameters for NS and the NSS model are presented using data for German government bond yields. Table 23 and Table 24 provide an estimation of the parameters. First I optimize and find parameters for every cross section and then find the average values of the parameters. Since the curves are fitted on daily bases I do not expect large standard deviations. However the results show that the standard deviations of the parameter estimates obtained by the non-linear least squares are erroneously large.

Nelson-Seigel Model

Differential Evolution

Table 22: NS: Differential Evolution

Factor	Mean	Std. dev.	$\hat{\rho}(1)$	$\hat{\rho}(12)$	$\hat{\rho}(30)$	ADF
β_1	3.021406004	1.152237	0.895	0.643	0.182	-3.3815
β_2	-2.088069267	0.9343029	0.808	0.432	-0.097	-1.9223
β_3	-1.176591604	3.660246	0.633	0.427	-0.141	-2.1522
λ	3.729970175	2.831878	0.434	0.271	-0.163	-2.6316

The results were fitted for daily data which give us 143 individual sets of parameters. In order to make them more meaningful I use standard deviation as a measure of comparison. In the first step I calculate the parameters for the observed data. Then I recalculate the yields using parameters resulting from DE, then I use the difference between observed and calculated yields to measure the accuracy of my results as compared to other methodologies. For each cross-section I repeat the simulation ten times to increase the robustness of the results. I also present the root mean square errors in graphical format.

Non-Linear Least Square

Table 23: NS: Non-linear least squares

Factor	Mean	Std. dev.	$\hat{\rho}(1)$	$\hat{\rho}(12)$	$\hat{\rho}(30)$	ADF
β_1	2.187831433	39.13712	0.898	0.647	0.345	-3.98
β_2	-5.706459707	41.5945	0.682	0.296	0.146	-2.7705
β_3	9.639745136	41.15005	0.629	0.383	0.198	-4.3605
λ	2.191799352	13.11176	0.652	0.126	-0.185	-2.302

The results obtained from gradient search are reported in table 24. When compared to DE the standard deviations of the results above are much higher.

Diebold and Li Method

Table 24: NS: Dibold and Li

Factor	Mean	Std. dev.	$\hat{\rho}(1)$	$\hat{\rho}(12)$	$\hat{\rho}(30)$	ADF
beta 1	2.489647	1.42651	0.98	0.779	0.401	0.07406
beta 2	-1.255343	0.5625349	0.882	0.306	-0.018	-2.6807
beta 3	-3.845781	2.497197	0.969	0.432	-0.289	-2.0416

For Dibold and Li (2006) the results are obtained using regression (table 25). Although the standard deviation is not high however keeping lambda (curvature) component fixed does not seem an appropriate option.

Nelson-Siegel-Svensson Model

The aim is to obtain a better fit for the two humped model, since numerical difficulties in fitting this model are often listed therefore it is essential to solve it using DE. This model is an extension of the Nelson Siegel model, it adds an additional hump to improve in-sample fit which results in superior out of sample fit. The second hump also provides better fit for long term maturities.

Differential Evolution

Table 25: NSS: Differential Evolution

Factor	Mean	Std. dev.	$\hat{\rho}(1)$	$\hat{\rho}(12)$	$\hat{\rho}(30)$	ADF
β_0	2.925852	1.2795723	0.965	0.717	0.336	-3.6398
β_1	-1.995919	0.9225568	0.900	0.269	-0.326	-2.7136
β_2	-6.596781	0.7462504	0.751	0.363	-0.149	-2.2709
β_3	4.622580	1.1566433	0.768	0.382	-0.160	-2.1004
τ_1	2.138272	1.4832625	0.836	0.507	0.007	-1.7234
τ_2	3.677279	1.4146413	0.819	0.472	-0.038	-1.8242

Non-Linear Least Squares

Table 26: NSS: Non-linear least squares

Factor	Mean	Std. dev.	$\hat{\rho}(1)$	$\hat{\rho}(12)$	$\hat{\rho}(30)$	ADF
β_0	3.0719910	1.160698	0.964	0.691	0.272	-3.8942
β_1	-3.4050905	4.250270	0.330	0.405	-0.035	-5.2218
β_2	-3.2983986	4.045845	0.217	0.420	-0.016	-3.8864
β_3	-0.7239271	3.369251	0.776	0.322	-0.069	-2.6625
τ_1	1.4596179	1.019411	0.839	0.496	-0.080	-1.6608
τ_2	3.7213578	1.233046	0.671	0.267	-0.101	-2.4284

Table 26 and Table 27 exhibit the parameters for NSS model obtained by both Differential Evolution and Non-Linear Least Squares. The results exhibit lower standard deviations for parameters obtained through DE as compared to those obtained through NLLS. The correlation among parameters using DE is higher which makes interpolation of forward curves more intuitive and efficient.

6.9 Robustness Checks

Root mean square error

$$\sqrt{\frac{1}{m}\Sigma_{i=1}^{m}(y^{M}(\tau_i)-y(\tau_i))} \tag{37}$$

where: $y^M(\tau_i$ is the parameter from market observed yield i.e. parameters obtained from Bundes Bank dataset. $y(\tau_i))$ is the parameter obtained from fitting the curve through DE or NLLS.

Equation 37, is used to calculate the root mean square error for the parameters obtained through differential evolution and non-linear least squares. The results are presented in figure 17 and figure 18.

Figure 17: Comparison of the Root Mean Square Errors for NS model

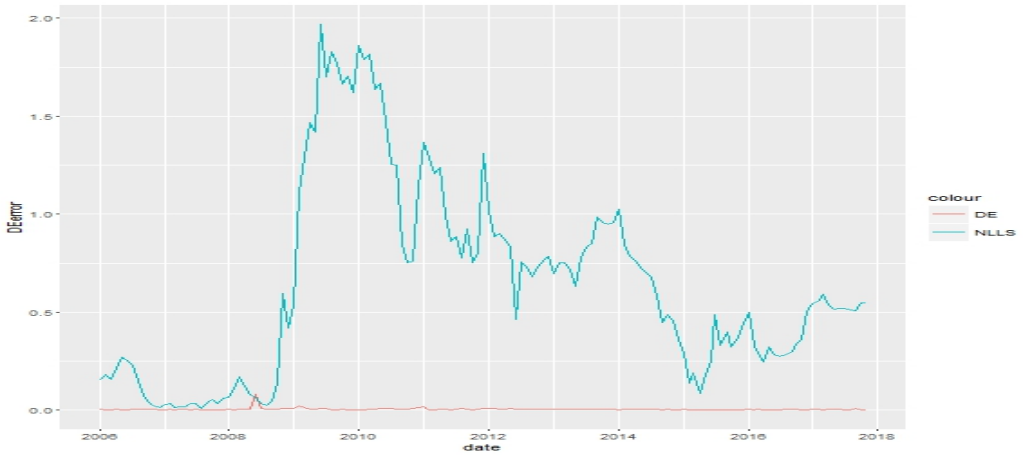
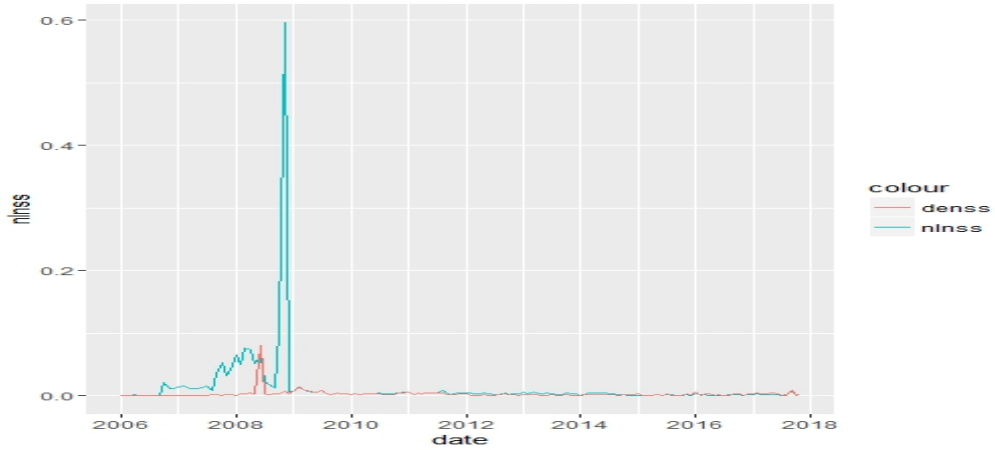


Figure 18: Comparison of the Root Mean Square Errors for NSS model



Figures 17 and 18 represent the root mean square errors of the two comparative methods; differential evolution (red line) and non-linear least squares (blue line). The root mean square errors have been calculated using equation 37.

Figure 17 represents the errors for Nelson Siegel model. It is shown that throughout the observation period which is between 2005-2017 the errors produced by differential evolution are lower and more more stable than non-linear least squares. Figure 18 represents the errors for Nelson-Svensson-Siegel. The graph shows that differential evolution consistently

produces lower errors.

Comparatively Nelson-Siegel has four and Nelson-Svensson-Siegel has six parameters, however differential evolution has produced lower error consistently for both the models.

Forecast Testing

The Morgan-Granger-Newbold (MGN) statistic is used to compare the forecast ability of two parallel methods of parameter estimation. This statistic is chosen because the model is non-nested and this test has the ability to differentiate between the forecasting power of two parallel methods. The specifications of the test are:

Actual values: $\{y_t : t = 1,2,3,\ldots, \mathrm{T}\}$ versus the forecast values from two methods: $\{\hat{y}_{t1} : t = 1,2,3,\ldots, \mathrm{T}\}$ and $\{\hat{y}_{t2} : t = 1,2,3,\ldots, \mathrm{T}\}$.

y represents the market yields for each cross-section while $\hat{y}$ are the val-

ues obtained from DE and NLLS respectively. The forecast error is given as: e $= \hat{y}_{ti} - y_t$ for $i = 1,2$ and the loss differential between the two forecasts is calculated as $d_t = e_{1t} - e_{2t}$. According to the test two methods have equal forecast power if and only if the differential between the losses of the two functions is zero at all times. Under the null I assume that the results obtained from the two methods have equal forecasting power, however rejection of the null confirms that there is significant difference in the forecasting power.

$H_o : E(D_t) = 0$ for all t

$H_a : E(D_t) = \mu \neq 0$

The results between DE and NLLS have the following specification:

Differential Evolution

Table 27: MGN Statistic

	n	r_s	t	df	p-value
NS-DE	143	0.3346	4.22	141	0.0000022
NSS-DE	143	0.3944	5.1	141	5e-7

By rejecting the null for both the models i.e. NS and NSS, the results show that differential evolution has superior forecast-ability.

6.10 Conclusion

The results show that Dibold and Li (2006) method is inappropriate since λ the parameter of curvature does not remain fix and this assumption does not confirm to the data.

In case of Nelson-Siegel and Nelson-Svennson-Siegel both models show that parameters obtained through differential evolution which is global optimization routine have lower standard deviation from the mean values. Further using RMSE as a statistic to check the accuracy of the non-linear least square in comparison to differential evolution both figure 13 and figure 14 show that the errors obtained from non-linear method show a

chaotic behaviour while those obtained from differential evolution show a persistent behaviour.

The aim of this chapter is to test the appropriateness of differential evolution as an optimization routine to fit non-convex yield curves.

7 Elasticity of Real Interest Rate

7.1 Introduction

Interest rates form the backbone of the modern economy. They explain the opportunity cost of capital and play a key role in investment and savings decision. Therefore modelling interest rate plays an essential role in various aspects of finance and economics. However the interest rate quoted in most cases is nominal interest rate, which means that this rate does not cover for inflationary pressures on the economy. In the presence of inflation, rates can be bifurcated in real and nominal terms.

This chapter answers a narrow but important question by calibrating canonical models of real interest rate for the US economy, based on T bill yields and survey based ex-ante inflation forecasts. Using Generalized Methods of Moments technique the results show that under the seven canonical models considered the real interest rate in the US does not show mean reversion between January 1978 and May 2017. However the results show

that the elasticity component which is represented by the index of the diffusion factor is significant in all the seven models. These results are novel and in line with the behaviour depicted by the real interest rate as real interest rate in the US has shown constant decline in the last three decades without mean reversion. The volatility component is important since it can be used in policy making, forecasting, incorporating the consumers expectations.

The study suggests that Brennon and Schwartz model with a unit elasticity component can explain the behaviour of real interest rate.

Nominal interest rates have an important role on both sides; government and the general public. Central banks use the nominal rate to uphold pressures of inflation[9]. But when policy makers need to see how the monetary policy effects the real economy they need to break down the nominal rate into its components. Nominal rates are used to make savings and in-

[9]For example see Hetzel (2004) for a discussion on how inflation was thought to be a hydra-headed monster until central banks used interest rate as an effective tool to control inflation

vestments decisions by individuals because that is the information they receive from their financial service providers (banks for savings, bond return). Therefore it is one of the key factors used in decision making.

Real interest rate is a crucial determinant of investments and savings Rose (1988). The importance of real interest rate is like understanding the gains of delayed consumption in real terms. Although nominal rates are readily available consumers have a perception of inflation, which keeps them aware of their true earnings. Therefore real interest rate is vital from the investors point of view to explain the real value of the money that they receive. Real interest rates climbed from 1970 until 1980 in the United States and the European Countries, showing significant international linkagesCumby and Mishkin (1986), however falling long term trends of about 450 basis points have been witnessed around the world beginning from the 1980's Rachel and Smith (2015). On one side real interest rate is of utmost importance since it is the rate upon which, economic agents base their savings, investments and portfolio decisions Gar-

cia et al. (1991) while on the other side its importance is depicted by its ability to measure the economic cost of financing investments and the tightness of monetary policy Haubrich et al. (2012).

Nominal interest rate has been widely studied Vasicek (1977), Cox et al. (1985), Fama and Gibbons (1982), Fama (1990) and its dynamics have been deeply explored. Past literature has focused on studying the aspects of model specification, term structure and the relationship between nominal interest rate with other economic variables including model calibration, shedding light on elasticity of interest ratesChan et al. (1992). The underlying processes that govern nominal interest rate processes are further used in pricing financial instruments (derivatives). There exists empirical and theoretical consensus to its existing models and the methodologies employed.

The dynamics of real interest rate have not been deeply explored. The theoretical aspect of real interest rate were introduced in Fisher (1930).

The idea explained in his work was based on the observation that the value of money changes with time. Where the difference that caused the decrease in value being named as inflation. According to Fisher's theory, in a well functioning economy where the rate of inflation can be fully anticipated the real rate remains constant. Which means that the interest rates observed now can predict future inflation. This relation has been studied in Dothan (1978), Mishkin (1990), Cumby and Mishkin (1986). Although real interest rate has been the focus of many empirical studies, but much of the concentration in the earlier literature has been on testing market's efficiency in forecasting inflation using Fisher's hypothesis. Further research has worked on questions related to inflation forecasting and term structure of real interest rates.

Empirical research before Fama (1975)[10] rejected the existence of the Fisher's effect in the US economy. However Fama (1975) proved this relation for the US economy during 1953-1971 and real interest rates

[10]See Richard Roll (1973) for details

thus remained constant. In response to this studies focus on the methods and improvements in inflation forecast. More work has been done on probing the sources of what may bring about changes in real rates since the initial work has been done to check Fisher's hypothesis. However recent studies have focused on the components of nominal interest rate: real interest rate, expected inflation and inflation risk premia (Ang, Bekaert & Wei(2008)Ang et al. (2008)), (Haubrich, Pennacchi, & Ritchken(2012))Haubrich et al. (2012), (Grishchenko & Huang (2013)Grishchenko and Huang (2013)), Khramov(2013)Vadim (2013). An intuition for the change in real interest rate is the ex-ante forecast of inflation is short term, this change in inflation expectation causes a change in nominal interest rates which then causes a change in real interest rates.

Based on the current literature and the importance of real interest rate my aim in this chapter is to calibrate canonical models of interest rates. This concept is based on the premise that real interest rate is not a static variable and its movement through time depicts properties that can be used in

policy making, forecasting and understanding important economic concepts. Such testing has been done for nominal interest rates based on well established models. These generic models take the form of a partial differential equation, consisting of drift and diffusion components. The diffusion component is restricted by varying degrees Vasicek (1977) Chan et al. (1992) Brennan and Schwartz (1980) Cox et al. (1985) Fama (1975). The solutions to these partial differential equations are used in pricing bonds, options and various other financial derivatives. Another source of recognition for these models is their ability to gauge the movements of the underlying variable such as the interest rate itself.

The magnitude of the diffusion component, plays a significant role since it explains the relationship between the volatility and the level of interest rate. The phenomena is used in explaining many issues, including the effect of expectations on the power of the central banks policy, change in the real value of investments, and any corrective actions that might be required. Changes in the real interest rate directly influence only the con-

sumption and labour supply of savers. The negative relationship between consumption growth and ex-ante real interest rates has a number of important implications for both asset pricing and monetary policy.

The rest of the chapter is structured as follows: review of the literature, explanation of survey based inflation data, models, methodology, results and conclusion.

7.2 Literature Review

In the review of literature I seek to discuss three main aspects related to the topic; first I discuss the real interest rate and the literature that tests the Fisher's theorem, second I discuss literature which analyses the possible causes for the failure of the existence of this theory in empirical testing lastly I discuss models and the econometric techniques of the empirical test.

7.2.1 Fisher's Theorem

The theoretical implications of real rate of interest were discussed by Irving Fisher (1930). He related ideas of consumption, delayed consumption and the compensation for delayed consumption by linking them to the time value of money. He then went on to value the gains obtained from delayed consumption as interest rate. However the time value of these gains (in monetary terms) lead to the concept of the real and nominal interest rate, due to the change in the amount of commodity return of money.

Based on Fisher's hypothesis which states that in a well functioning economy agents can forecast inflation keeping real returns unvaried, theoretically real interest rate is assumed to remain constant. The theory proposed by Fisher has been widely tested by probing the efficiency of interest rate in predicting future rates of inflation. Moreover the existing literature also expands on to answer questions related to the time series

behaviour of ex-ante real rates, testing market efficiency and a discussion of the econometric issues.

7.2.2 Empirical Evidence: Fisher's Theorem

The empirical testing of the Fisher effect is carried out on the premise that interest rate at one point in time can forecast future inflation. Roll (1972), studied this relation in the commodity market using regression analysis utilizing the wholesale price index and nominal interest rates in the US but failed to prove the existence of Fisher's effect. His work was followed by the landmark research by Fisher (1975), which focused on checking the efficiency in the US market between 1953-1971 using monthly T-Bill and the CPI data. The results proved that there exists a relation between nominal rates and inflation, proving that real interest remained constant for the period under test. However these findings vary from other empirical literature.

According to Fisher (1930) real and nominal rates remain constant how-

ever the difference between the two types of interest rates is caused by the single component of inflation, given perfect hindsight. The consensus among economist is that real interest rate does not remain constant since the relation between current interest rates and future inflation can can not be proved significant((Mishkin (1990), Fama (1990), Garcia et al. (1991), Ang and Piazzesi (2003), Haubrich et al. (2012)).

Hamilton (1985), concentrated on forecasting market expectations of inflation, using past inflation data along with nominal interest rate at one point in time. They modelled expectations as a VaR process. Deducing that lower order VaR could significantly forecast market expectations of inflation. Mishkin (1990), probed the behaviour of ex-ante real interest rates. Their work sheds light on the movement of real interest rate, its behaviour and cross border links. Seeing if real interest rate had cross border impact. This study concluded that the real rate in the US significantly affects the real rates abroad. As opposed to earlier studies they used moving average to calculate the forecast errors in real rates. They

sought a considerable relation between the rising real rates between US and the UK. Rose (1988), dealt with further econometric issues of forecasting inflation. They concentrated on the non-stationary behaviour of nominal rates and thus modelled the forecasts as a unit-root process. This resulted in superior forecast results for the US data.

Mishkin (1990), determined the predictive power of nominal interest rate through models of term structure. Their results showed that maturities at different time periods predicted inflation at varying degrees. However they deduced that the path of future inflation, could be predicted using the slope of term structure models. Garcia et al. (1991), probed the US ex-post real interest rate data from 1961-1986 and studied the behaviour of using regime switching technique. Their results show that, in each time sample, real interest rate show random behaviour around a certain mean and this mean value along with the variance changes with the changing regime. Their results confirm the presence of ARCH effects in real rates.

7.2.3 What causes real interest rate to change?

This earlier set of literature agrees that markets are not perfect and there exists changes in real interest rate. However different views exist as to what causes the change in real rates.

Piazzesi (2005), modelled term structure as a jump process, according to the dates of open market operations in the US. The main idea was to see if these jumps could enhance the forecast ability of inflation using nominal rates in a continuous time environment. However a similar scenario in a discrete environment was also tested. The results produced using the parameters obtained through the discrete environment gave more efficient fit of the term structure curve. Their results deduced that market participants adjusted their expectations according to the date of the Federal Open Market Operation. Therefore dates of the open market operation independently could not be used to explain the causes of change in real rates.

Ang et al. (2008) utilize a regime switching behaviour to study the term structure of real and nominal rates along with inflation in the US. According to their results, the term structure for the US economy shows a slight hump at 1-year maturity and shows greater variations at the short end as opposed to the long end, which means that the real rates become stable in the long run. This flatness in the long term real rates was also accompanied by its negative correlation with both expected and unexpected inflation.

7.2.4 Drivers of real interest rate

The main technicality in studying the real rate of interest is the fact that it is not directly observed. Consumer price index (CPI) is the most widely used proxy of inflation (which makes one component of real interest rate). However ex-ante inflation expectations are measured using two main methods i.e. the market price of inflation protection through indices and the other is inflation surveys. In order to examine the accuracy of

the various measures of inflation Ang and Piazzesi (2003) compared the forecast ability of four alternative methods of inflation expectation using the US data and deduced that inflation expectation surveys outperform other competing methods.

Analysis of the drivers of real and nominal rates have been studied in Haubrich et al. (2012) using a four factor model. They also conduct forecasts of the term structure curve using three different proxies of inflation. A comparison of TIPS, inflation surveys, inflation rate swaps and deduce that the forecasts based on survey infatuation data has the least amount of bias. However the overall analysis of the term structure of real interest rates, expected inflation and inflation risk premia deduced that the short end of the curve is the most volatile.

Secular drivers of the global real interest rate have been studied in Rachel and Smith (2015). They explain that the reason behind this decline (450 bases points over the past 30 yeas), could be the decrease in global neu-

tral rates. A combined finding of the literature is that the real interest rate does not remain constant. However forecasting inflation expectations is very difficult Hamilton (1985).

Term structure of inflation expectation is studied in (2012)Chernov and Mueller (2012), using survey based inflation data, from the US. Stressing on the hidden factors of affecting nominal interest rate, this is an extension of the ideas studied earlier, as to what causes changes in the real rates. They use data from multiple forecasts and multiple horizons, hidden factors affect factors that determine the rate of inflation, in conjunction to the yield curve they use macro factors. They explain that survey based methods have strong predictive power.

The ex-ante measures of inflation are useful because they tell us how much we will earn for our delayed consumption. On the other hand TIPS as a measure of inflation has liquidity and data duration issues. However Ang et al. (2006) show that the survey method is more superior for

inflation expectation of the US.

7.2.5 Empirical issues in modeling real interest rate

Interest rates have been modelled using models of instantaneous interest rates which are based on diffusion processes (stochastic partial differential equations). A diffusion model consists of a drift and a diffusion term. These equations help in explaining the mean reverting and elasticity behaviour of interest rates.

The concept of diffusion was used to model key economic indicators. Models of instantaneous short term interest rate form the backbone of many complex pricing models for options, bonds and other financial instruments. Studying the underlying process has thus been a vital question in both finance and economics. Nominal interest rate has been modelled uni-variate stochastic processes in the continuous time. These models are broadly categorized as canonical models Such models differ on the bases of drift and diffusion structures.

Merton et al. (1973) introduced an additive drift and diffusion term stochastic model to study nominal rates. This model is used as the underlying model of the movement of stock prices. Brennan and Schwartz (1980), studied the behaviour of convertible bonds, by studying the underlying process governing the behaviour of the interest rate in a mean reverting model and the diffusion term is interacted with the interest rate itself, this model shows unit elasticity of interest rate.

Term structure of interest rate has been studied using these continuous models, including Vasicek (1977) and Cox et al. (1985) processes. The Vasicek or the elastic random walk model is based on the Gauss-Markov assumption where values are assumed to be normally distributed. Under the Cox-Ingersoll-Ross(CIR) model the values are assumed to follow the Chi-sq distribution. Although both processes have mean reverting drift components, the former allows the values to become negative since the diffusion term in unbounded. Under the CIR model the drift component is

defined by a square root term which limits values within positive boundaries. Mean reversion has attractive economic application, as it explains the movement of the economy toward mean levels.

The log normal model introduced in Dothan (1978) models interest rate as the geometric Brownian motion. This model assumes that there is no drift and the behaviour of the interest rate is described solely by the stochastic diffusion. Like the CIR model this model also restricts interest rates as strictly positive based on log normal property of the model.

In terms of application nominal interest rates have been calibrated in Chan et al. (1992) (CKLS), they parameterized the canonical models with restrictions on volatility for the US, using GMM methodology and found that nominal interest rates had a highly elastic behaviour in the US during, between 1964 - 1989. Under the CKLS model the elasticity is fixed at 1.5.

7.3 Inflation: Survey Details

Measuring real interest rate is a cumbersome task since it is not directly observed. The unobserved component of inflation makes it a challenging task. In this part I have discussed literature that focuses on the various sources of inflation data. Inflation expectations have played an important role in assessing monetary policy and the business cycle.

7.3.1 Realized Inflation

Realized/Ex-Post inflation is represented through various forms of price indices, among which Consumer Price Index and the Retail Price Index are most widely used. However measuring ex-ante inflation poses many problems since it is not directly observed, but holds great importance including consumers/firm decisions regarding consumption, saving and investments among others. Since ex-ante inflation is not directly observed, some of the methods used to estimate it include regressions based on Fisher's theorem, J curve modelling, term structure modelling of index bonds, regressions based on instrumental variables and other paramet-

ric and non-parametric models. There are two main ways of measuring inflation expectations; survey based and market based. Surveys in the US include those conducted by the body of Professional Forecasters and those conducted on households such as Michigan Household Survey of Inflation Expectations and The Livingston Survey.

7.3.2 Ex-Ante measures of inflation

The Livingston Survey began in 1946 by the late columnist Joseph Livingston. It is the oldest continuous survey of economists' expectations. It summarizes the forecasts of economists from industry, government, banking, and academia. However it is only conducted on quarterly bases. The second survey is the Survey of Professional Forecasters, it is the oldest quarterly survey of macroeconomic forecasts in the United States. This survey began in 1968 and was conducted by the American Statistical Association and the National Bureau of Economic Research. Followed by the Survey of Consumers conducted by the University of Michigan.

University of Michigan inflation expectation survey is a survey based on consumers expectations about future inflation. The surveys are conducted by the research centre at the University of Michigan, under the supervision of the chief economist Richard Curtin. The surveys were initiated in 1946, these surveys stress upon consumers spending and consumption behaviour, to determine the course of the economy. The index of consumer survey is one of the survey compiled on the bases of the data collected every month. The Index of Consumer Expectations focuses on three areas: how consumers view prospects for their own financial situation, how they view prospects for the general economy over the near term, and their view of prospects for the economy over the long term.

The Index of Consumer Expectations, produced by the Surveys of Consumers, is included in the Leading Indicator Composite Index published by the U.S. Department of Commerce, Bureau of Economic Analysis. This data is used in the understand and produce forecasts of the US economy. Index of consumer expectation is chosen to be in the list of leading

indexes on the bases of six significant characteristics including; economic significance, statistical adequacy, consistency of timing at business cycle peaks and troughs, conformity to business expansions and contractions, smoothness, and prompt availability.

7.4 Michigan Inflation Survey

7.4.1 Procedure

The survey is conducted on monthly bases, where each survey contains 50 core questions. All questions are directed towards separate aspects of consumer attitude and expectations. The sampling cohorts are statistically designed to be representative of all American households excluding those in Alaska and Hawaii. Each month, a minimum of 500 interviews are conducted by telephone from the Ann Harbor facility.

7.4.2 Questionnaire

The questionnaire is divided into two parts: core questions and specific questions. The core questions are focused towards areas of personal fi-

nances which include questions on nominal family income and any expected changes, business conditions where respondents are asked about their expectations of the business conditions in the future, and buying conditions.

Specific questions focus on items such as inflation, unemployment, interest rates, confidence in government economic policies, supplement the more general assessments. Respondents are also asked to evaluate the present market conditions for large household durables, vehicles and houses.

The surveys are detailed in the sense that not only are the respondents asked to give a response but they are also asked the reason for their response. Investments in house, savings and other things are important household decisions and have great impact on the economy overall. The follow-up questions are useful in keeping tract of consumer decisions and direction in future and in understanding the reasons on which consumers

base their decisions. The rationale gives great help in understanding the way consumers base their decisions. And compare inflation expectation and forecast. I use inflation surveys because it provides a direct source of inflation expectations. Expectations of inflation play a major role in the macro-economics of the country as in a number of ways. One of them is the high wage expectation if workers expect high levels of inflation. Also the expectation today will affect tomorrow's decision. The believes and expectations of the less qualified agents, who are the consumers is important for the governments and the central banks. Knowing what factors are significant in forming inflation expectation can help in controlling the macros of the economy.

The resource centre runs periodic checks to probe the difference between expected rates and prime rates. In this study I have chosen data based on MICH survey because it incorporates, perceptions on spending and saving.

7.4.3 Critique

The debate on the usefulness of surveys, began in the 1940s, when studies were conducted to gauge if sentiments were able to revive recessions and then moved on to test the relationship between income, consumption and inflation expectations. Some studies also focused on probing if sentiments had greater information content as compared to other macro variables such as stock prices.

Previous notable studies on the rationality of surveyed expectations using the aggregated Michigan data include ((PRE 2009 crises) Keane and Runkle (1990), Maddala, Fisher and Lahiri (1981), Gramlich (1983), Batchelor (1986), Keane and Runkle (1990). However some recent studies have focused on the variables that help in formulating inflation expectations. General factors that affect inflation expectations have been studied in Souleles, (2004). Using the MICH survey they checked the rationality of consumer sentiments and decisions. Their results show that expec-

tations are biased yet efficient however demographics such as spending, pay, income play an important role. The forecasting errors are however correlated with demographics.

Studies that examine Michigan Survey mostly analyse the Michigan question that allows only discrete, qualitative responses about the future path of inflation (up/down/no change). To use this question quantitatively, the studies typically made strong assumptions to derive a continuous-valued expectations time-series from the Michigan data. Aggregate test results show that even in the existence of bias, rationality does not require that people's expectations be on target over the course of period under study.

Studies prove that the demographics are significant and have strong impact. Inflation expectations hold prime importance to Central Banks and macroeconomists since their goal of inflation targeting is affected by the evolution of inflation expectations Ehrmann et al. (2014). A procedure of determining which variables are more strongly affect the process of

inflation expectations is thus important. Ehrmann et al. (2014), studied the micro level data from the Michigan Survey, identifying the variables that had the greatest impact.

Inflation expectations are also shaped by the inflation that consumers actually experience, inflation expectations are shaped much more by the inflation rate of consumption baskets that relate to the respective socio-economic group to which the individual belongs than by the overall inflation indices, at least for low-education and low-income consumers (Pfajfar and Santoro, 2009; Menz and Poppitz, 2013)

The robustness of the variables variables shows that respondents with current difficulty have or at least expect future difficulty, their comparison shows that consumer expectations show upward bias. This survey shows that beyond well establish features the respondents current financial conditions.

Gali and Gertler(1999) Galı and Gertler (1999), study a structural model of inflation based on New Keynesian model. They allowed backward looking price setting to see if the price setting had an implication in forecasting inflation instead of using output gap. Using Phillip's Curve, they conclude that this method gives a good first approximation of price setting. Short run inflation dynamics are a much debated topic. Their estimates show that almost 60-80 % firms show forward looking behaviour in price setting. Therefore output gap is not a good method to gauge inflation as Philip's curve itself is based on theories regarding backward and the forward looking elements.

Wolfers et al. (2003), studied the gaps in the respondents on the survey results. They realised that there exists a difference in respondents expectations and the expectations do vary with dispersion. They linked these variation to major macro economic variables and found a significant relationship between the variations and these variables and deduced that inflation expectation is an important factor in inflation process. Based on

these three surveys, results have shown that more sophisticated groups make more sophisticated decisions however this disagreement varies over time. In this model, economic agents update their expectations only periodically because of the costs of collecting and processing information. Their study revealed that correspondents make informed and meaningful choices.

Adam and Padula (2009)Adam and Padula (2003), study the New Keynesian model and its ability to capture the dynamics of inflation in the US. They use survey of professional forecasters as a proxy of inflation and compare it to other market based sources , their results deduce that NKPC identification and forecasting based on survey data gives superior results as compared to those obtained by other sources.

Inflation surveys are carried out by all major economies including UK, US, Australia, Canada, India and countries in the Euro-Zone. The prior literature discusses the rationality and effectiveness of surveys as to ex-

plain the strengths of surveys in general and MICH in particular. Inflation expectations are viewed as a key determinant of inflation (Bernanke et al. (2005).

7.5 Data, Methodology and Models

7.5.1 Real Interest Rate

Ex-ante real interest rate is a measure of the true value of money which is not directly observable. Lets begin with nominal returns:

$$R_t = \frac{X_{(t)} - X_{(t-1)}}{X_{(t-1)}} \tag{38}$$

Where R_t is the nominal return X_t is the price of the bond at maturity at time(t), from time (t-1). For the real rate of return would be:

$$R_t = \frac{X_{(t)}\pi_t - X_{(t-1)}\pi_{(t-1)}}{X_{(t-1)}\pi_{(t-1)}} \tag{39}$$

$$\tilde{r_t} = R_t + \tilde{\Delta_t} \tag{40}$$

The end of period return on a bond will be the nominal return plus the change in purchasing power. The nominal yield on a bond can be represented as:

$$\begin{aligned} i_t^n &= i_{n,t}^r + \pi_{n,t}^e \\ &= i_{n,t}^r + E_t(\pi_{t+n,n}) + \phi_{t,n} \\ E_t(\pi_{t+n,n}) &= \frac{1}{n} E_t(\pi_{t+1} + ... + \pi_{t+n}) \end{aligned} \tag{41}$$

where $E_t(\pi_{t+n,n})$ is the expected inflation from t to t + n.

According to Fisher's equation, nominal interest rate is the sum of

$$i_r = i_t - \pi_t \tag{42}$$

where:

- i_r = The expected real interest rate at time t, for time period t to j is the expected nominal rate of return on the bond the real return
- i_t = Is the nominal interest rate on a j period bond

- π_t = the expectation at time t of the inflation at time t + j

The ex-post real interest can be written as:

$$eprr = i_r - \pi_t - \pi' = i_r - \varepsilon \tag{43}$$

where ε is the inflation forecast error. Further, the connection between nominal interest rates and inflation is explained as:

$$R_t = r_t + E_t(\pi_{t+1}) + Cov_t(m_{t+1}, \pi_{t+1}) - \frac{1}{2} Var_t(\pi_{t+1}) \tag{44}$$

where R_t is the nominal interest rate, r_t is the real interest rate, π_{t+1} is inflation in the period $t+1$ and $m+1$ is the log for the real stochastic discount factor. The third and the fourth terms include the inflation risk premium. For shorter horizons as shown in Ang et al. (2008). Therefore canonical Fisher equation holds in the short term

$$r_t = R_t - E(\pi_{t+1}) \tag{45}$$

7.5.2 Discrete Time Diffusion Model

The parameter estimation problem that is to be addressed is a general one dimensional, time homogeneous stochastic differential equation:

$$dX_t = \mu(X_t;\theta)dt + \sigma(X_t;\theta)dW_t \tag{46}$$

where θ is the parameter to be estimated from a discrete set of observation at known times and μ and σ are known functions of state.

The continuous time model can be represented as the following discrete time analogue:

$$r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{rt+1} \tag{47}$$

$$E_t[\varepsilon^2_{rt+1}] = \sigma^2 r_t^{2\gamma} \tag{48}$$

where r_t is the real interest rate, ε_{rt+1} is the i.i.d shock with variance $\sigma^2 r_t^{2\gamma}$. Where α represents drift, β is the mean reversal, σ is the variance level while γ is the elasticity of the interest rate volatility.

7.5.3 Methodology and Data

The Generalized Method of Moments (GMM) developed by Hansen (1985) relies on the existence of the moments of the underlying process. Solving continuous time problems can be complex, since the exact solution does not exist in most cases except for Cox-Ingersoll-Ross and Ornstein-Uhlenbeck processes. GMM allows us to calculate all the models in a uniform framework considering the absence of explicit solutions. It also allows us to obtain parameter sets without knowing the exact underlying probability. Some of the other well-known benefits of GMM are: it does not require the process remains normally distributed, which is a constraint for handling interest rates processes, parameters obtained through this process are consistent with heteroskedastic errors, it also allows the existence of serial correlation. This method has been used to test the elasticity of nominal interest rates in the US by Chan et al. (1992)

The discretized version of the continuous model:

$$r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{rt+1} \tag{49}$$

$$E_t[\varepsilon^2_{rt+1}] = \sigma^2 r_t^{2\gamma} \tag{50}$$

Diffusion models are characterised by the Brownian motion which drives the uncertainty in the model. Under general framework, the dynamics of the short rate can be described by the stochastic differential equation:

$$dr = (\alpha + \beta r)dt + \sigma r^{\gamma} dW \tag{51}$$

where dW is the increment from a standard Brownian motion. Chan, Karolyi, Longstaff, and Sanders (1992) note that this equation encompasses a number of models used in the literature. In particular, where T=0.5, the stochastic differential equation describes the square root process used by Cox, Ingersoll, and Ross (1985). For estimation purposes,

the stochastic differential Eq. (1) is usually discretized as in Chan et al.:

$$\Delta r_t = r_t - r_{t-1} = \alpha + \beta r_{t-1}\eta_t \tag{52}$$

where $E[\eta_t|\phi_{t-1}] = 0$ and $E[\eta_t^2|\phi_{t-1}] = \sigma^2 r_{t-1}^{2\gamma}$, and ϕ_{t-1} is the agents' information set at time t - 1. Mean reversion can be captured by setting $\beta < 0$ and leptokurtosis by introducing conditional heteroskedaticity (setting $\gamma > 0$). This discretization serves to approximate the true process. In some special cases, for example the constant elasticity of variance (CEV) process, the square root process, and the constant volatility process, the continuous time likelihood can be estimated directly so that discretization is unnecessary. The data begins from 01-01-1978 and end in 01-05-2017.

7.5.4 Data

For the short term nominal interest rate I use 3 months-Treasury Bill interest rate, form the weekly H-15 release. For inflation expectations I use the forecasts produced by University of Michigan Inflation Expectations Survey (MICH). The graph above shows that in the period under

Figure 19: US Real Interest Rate



study real interest rates show have been both negative and positive. Beginning from 1978 real rates in the US remained negative until the very end of 1981 and after that they remained positive before becoming negative again for a brief period of time between 1993-1994. The negative behavior was is again evident between 2001-2006. The final segment of negative rates began in 2008 and continue till 2017.

7.5.5 Canonical Models of Interest Rates

Models 1-7, are canonical models of instantaneous interest rates governed by stochastic partial differential equations. The first component of the equation is called drift and the second component is called the stochastic volatility component. X stands for interest rate and dX refers to change in interest rate. β is the mean of interest rate where dt represents the change in mean with time, σ is the variance of interest rate and dW represents the Wiener process which adds random factor to the model.

1. Merton(1973):

$$dX = \beta dt + \sigma dW \tag{53}$$

   Merton model has non mean reverting drift represented by β.

2. Vasicek (1977):

$$dX = \alpha(\beta - X)dt + \sigma dW \tag{54}$$

Vasicek model has a mean reversing drift $\alpha(\beta - X)dt$ where α is the rate of mean reversion to β which is the mean level.

3. Dothan Model (1978):

$$dX = \sigma(X)dW \tag{55}$$

Dothon model only has a stochastic drift factor represented by σ.

4. Cox-Ingersoll-Ross (CIR-SR) (1985):

$$dX = \alpha(\beta - X)dt + \sigma\sqrt{(}X)dW \tag{56}$$

CIR model has a mean reverting drift represented by $\alpha(\beta - X)dt$. Where the diffusion component includes the square root of interest rate with the σ term.

5. Geometric Brownian Motion (GBM) Model:

$$dX = \beta(X)dt + \sigma(X)dW \tag{57}$$

GBM model has multiplicative drift and diffusion components.

6. Brennon & Schwartz Model (1980):

$$dX = (\alpha(X) + \beta)dt + \sigma(X)dW \tag{58}$$

In Brennon & Schwartz model α the rate of mean reversion is a multiplicative factor of X, the interest rate.

7. Constant Elasticity of Interest Rate Model (1992):

$$dX = \alpha(X)dt + \sigma_t^{\gamma}(X)dW \tag{59}$$

This model has a non-mean reverting drift and a stochastic diffusion component. The γ component is restricted to represents the elasticity component in the model.

7.6 Results

Variables	N	Mean	SD	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6
r_t	470	0.121343	0.3515	0.98	0.95	0.93	0.91	0.90	0.88
$r_{t+1} - r_t$	469	-0.0001	0.07	0.01	-0.05	-0.05	-0.12	0.004	-0.03

This table shows the means, standard deviation and the monthly auto-correlations of the monthly returns of the Us-T bills. The results show that the observations are significantly correlated and therefore can be significantly modeled using GMM.

Table 28: Model Calibration Results

Model	α	β	σ^2	γ	χ^2	d.f.
Merton	1.267	0.0	2.578***	0	4.085	2
	(0.336)	-	(4.903)	-	-	
Vasicek	4.291	-1.501	2.921***	0	0.819	1
	(2.254)	(-2.432)	(4.933)			
CIR-SR	3.525	-1.325	3.319**	0.5	0.876	1
	(2.026)	(-2.137)	(-4.949)			
Dothan	0.0	0.0	0.109	1	2.603	3
			(5.156)			
GBM	0.0	-0.022	0.107**	1	2.606	2
		(-0.195)	(4.628)			
Brennan-Schwarz	5.779	-1.059	0.109**	1	0.049	1
	(1.653)	(-1.684)	(4.664)			
CIR-VR	0.0	0.0	0.003**	1.5	3.212	3
			(5.020)			

The results in this table follow from equations 56-62. The parameters are estimated using GMM (appendix 8.1). χ^2 exhibits the goodness of fit of the model and degrees of freedom are the parameter restriction imposed according to model specification. T-statistics are presented in parenthesis such that *,**,*** indicate significance at 10%, 5% and 1%.

The aim here was to test the significance of the parameters of seven models such that under the null $\theta = 0$ each model has an independent drift and diffusion component. Vasicek, Cox-Ingersoll-Ross, Brennon-Schwartz models have mean reverting drift components with the β indicating the significance of mean reversion. Among the three models none of the models have a significant β which means that real interest rate does not show mean reversion. The alpha component which is the mean or average level shows high values but insignificant t-values, however the volatility component represented by σ^2 is significant in all the models. The χ^2 explains the goodness of fit of the model. A large value explains that the model is misspecifiedNewey and McFadden (1994). According to the test results none of the model gives us an abnormally high χ^2 value.

The γ values show the elasticity components which varies in degree. One of the main highlighted features which aligns with the behaviour of real interest rates such that real interest rates have shown consistently falling behaviour with no mean reversion. The results how that Brennon and

Schwartz model with a unit elasticity factor explains the elasticity of real interest rate in the US between 1975 - 2017.

The results are based on the χ^2 values of the overall model. Brennon-Schwartz model is chosen on the basis of lowest χ^2 value. Although real interest rate does not show mean reversion it does show unit elasticity which is evident from the significant volatility coefficient σ^2. This means that real interest rate does not show simple ad hoc behaviour it rather shows responsiveness to the overall volatility.

The volatility factor being held by a power of 1 (which is the index of sigma in Brennon and Schwartz equation) implies that real interest rates can be both positive and negative. The closest model to Brennon and Schwartz with the next lowest χ^2 value is Cox-Ingersoll-Ross but intuitively and practically this model does not conform to the historical behaviour of real interest rates since it has a square root volatility term which restricts interest rate to remain strictly positive.

This study therefore concludes that real interest rates in the US show unit elasticity between 1978-2017.

7.7 Appendix: Generalized Method of Moments

The GMM methodology has been used to estimate the parameters of stochastic differential equations. Based on moment conditions,this methodology does not impose restrictions of serial correlation and conditional heteroskedasticity. Introduced in Hansen (1982), the methodology derives the moment conditions based on the the first order Euler- Maruyama discretization of the SDES. The number of moment conditions should be as much as the number of parameters to be identified. The Euler-Maruyama scheme of the SDE allows the generation to follow:

$$X_{t+1} \sim N(X_t + \mu(X_t;\theta)dt, \sigma^2(X_t;\theta)dt)$$

In Hansen GMM approach I use the underlying principal of over identifying restrictions on a system of moment conditions. Let θ to be the vector of elements α, β, σ^2, γ. Given $\varepsilon_{t+1} = r_{t+1} - r_t - \alpha - \beta r_t$

the vector $f_t(\theta)$

$$\left\{ \begin{array}{r} \varepsilon_{t+1} \\ \varepsilon_{t+1} r_t \\ \varepsilon_{t+1}^2 - \sigma^2 r_t^{2\gamma} \\ (\varepsilon_{t+1}^2 - \sigma^2 r_t^{2\gamma}) r_t \end{array} \right\}$$

Under the GMM procedure the papuk $f_t(\theta)$is replaced by sample moments. where

$$g_T(\theta) = \frac{1}{T} \sum_{t=1}^{T} f_t(\theta)$$

and then choosing parameters that would minimize the weight matrix and the quadratic form

$$J_T(\theta) = g_T'(\theta) W_T(\theta) g_T(\theta),$$

where W_T is a positive-definite symmetric weighting matrix. the weighting matrix is the long run covariance matrix.

8 Conclusion

8.1 Summary, Strength and Weaknesses of the Thesis

This thesis answers five questions about financial markets in the OECD region, Euro area and the United States. Through the first three chapters it is empirically proved that economic policy uncertainty is a robust and significant factor in the functioning of financial markets. It affects portfolio optimization strategies as well as broad market indexes. Further it also adds towards the volatility in commodity futures prices.

Findings in chapter 3 confirm the impact of economic policy uncertainty on momentum anomaly in the London Stock Exchange. Stock markets formulate a significant part of the economy therefore these findings are useful from a policy makers' point of view. The results highlight the importance of maintaining steadiness in political and economic environment in order to avoid turbulence in financial markets. The results prove that when policy uncertainty is low, stocks with past higher returns con-

tinue to do well and investors keep on reaping higher returns. However when policy uncertainty is high activity in the stock markets is slowed down and momentum is no longer evident. These findings are novel for London Stock Exchange.

Findings in chapter 4, add to the literature on commodity markets by studying the impact of economic policy uncertainty on silver, palladium, platinum, brent oil and aluminium. Previous studied only focused on gold therefore making the findings of this chapter novel. It is important to cover these commodities as global economic policy uncertainty can affect the appetite and investment decisions of fund managers as well as consumers around the world. Gold futures have been widely studied however by using GARCH-MIDAS present study proves that global economic policy uncertainty causes volatility in silver, palladium and brent oil futures. However global economic policy does not significantly effect the long term volatility in platinum and aluminium futures. These novel findings are important from investors prospective such that they help in

identifying platinum and aluminium as safe havens for investment.

Findings in chapter 5 confirm the correlation between economic policy uncertainty and stock indexes in OECD countries. The results for Australia and Canada prove that high policy uncertainty can have positive correlation with index returns. This is in line with Pastor and Veronesi (2012) theoretical model, which proves that higher news based uncertainty can have a positive impact on index returns. From a policy point of view it is vital to study both the negative and positive impacts of high uncertainty as organized exchanges can be positively effected by high levels of economic policy uncertainty. To the bets of my knowledge this is the only study which reports these results.

Chapter 6 handles the econometric issues related to non-convex yield curve models. The optimization heuristic applied proves higher accuracy and back tracking of parameters. Since NS-NSS family of yield curves are widely used therefore superior modeling techniques enhance the ac-

curacy of results which further increase the accuracy of the policies that are formulated by policy makers, specially Central Banks. The current literature is focused on US only, however this chapter is based on Germany making it novel in nature.

In chapter 7 the elasticity behaviour of real interest rates is studied and the results prove that real interest rate is perfectly elastic to the level of volatility. It is an important finding for policy makers such that these results can aide in inflation targeting and monetary policy implications. The results provide intuitively appealing explanation, such that real interest rates can become negative. This contributes towards the existing theoretical and empirical literature on interest rates.

8.2 Limitations of the Thesis

In chapter 3, the impact of policy uncertainty on momentum returns has been tested in the light of macro variables only. However firm fundamental factors have also proved significant indicators of momentum in

past literature, therefore in a separate study firm specific factors could be added along with economic policy uncertainty to increase the horizon of the study.

In chapter 4, the impact of policy uncertainty on commodity futures returns should be studied in light of trading volumes to increase the robustness of the overall model. A major gap in the literature is to address reasons for atypical results in platinum and aluminium futures this could be answered using trading volumes in a multi dimensional model.

In chapter 5, dynamic conditional correlation between economic policy uncertainty and stock market indexes is studied, however the results are not tested using external shocks. Therefore the absence of external shocks such as the oil price shock poses a limitation to this study.

In chapter 6, the results are purely based on optimizing Nelson-Svensson and Nelson-Svensson-Siegel curves. However the results do not rule out arbitrage opportunities where as this is an important underlying assump-

tion in financial models. Therefore the results are limited to being non-arbitrage and may not be appropriate for building more complex models.

In chapter 7 real interest rate is studied as a uni-variate stochastic differential equation, which makes the econometric scope quite limited. However studying it as part of a more complex econometric framework that would allow inflation and interest rates to be modelled simultaneously could provide more robust results. Since survey based inflation data is now available for a large number of countries therefore it can also be expanded to formulate cross border comparisons.

The aim of this thesis was to answer a few unanswered question in the domain of economic policy uncertainty and financial markets, working along interest rate also became a part of the overall research.

8.3 Conclusion

This paper fills in a narrow gap in the existing literature by parameterizing real interest rates for the US economy. The empirical results of this paper allow us to confirm the non-mean reverting behaviour of real interest rates and the fact that real rates can be negative. The results also help in explaining agents perception of future inflation. Given that agents perception of future inflation is high agents will choose to consume rather than save, which is a typical feature of the US economy.

These results are useful in policy making such that they enable policy makers in understanding the elasticity of real rates. Since real interest rats are perfectly elastic with change in volatility, and volatility is being driven by changes in inflation perception policy makers may make policies which will send positive signals regarding inflation to the agents.

The results also confirm the significance of survey based inflation mea-

sures in empirical testing. Further, these results can be used in inflation targeting. The results are also useful in settling monetary policy since they determine the responsiveness of real interest rates to the overall level of volatility.

Further work could include using multidimensional stochastic differential equations in modeling real interest rates, which would allow studying the time varying behaviour of inflation along with real interest rate. It would add towards building a more sophisticate model for real interest rate modeling. This study is limited to the US, however a similar study including all the countries with survey based inflation data could be carried out to make geographical comparisons.

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