Charles University

Faculty of Social Sciences
Institute of Economic Studies

MASTER'S THESIS

Low Interest Rates and Asset Price Fluctuations: Empirical Evidence

Author: **Bc. Bano Ali**

Supervisor: **Prof. Roman Horváth, PhD.**

Academic Year: **2017/2018**

Declaration of Authorship

The author hereby declares that she compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

The author grants to Charles University permission to reproduce and to distribute copies of this thesis document in whole or in part.

Prague, January 4, 2018

Signature

Acknowledgments

I would like to express my gratitude to my supervisor, Prof. Roman Horváth, PhD., who provided me with valuable suggestions and ideas for research. His willingness to share his experience helped me in all the time of writing of this thesis. I am also grateful to doc. PhDr. Tomáš Havránek PhD. for his helpful suggestions and comments on vector autoregressive modelling. Last but not least, a special gratitude belongs to my family for their support during my university studies.

Abstract

The thesis focuses on estimating the effect of expansionary monetary policy concerning asset prices, specifically house and stock prices as they are of primary importance in financial markets. A structural vector autoregressive model is used including data for the Euro Area, the United Kingdom, and the United States from 2007 to 2017. Moreover, instead of short-term nominal interest rate, the shadow policy rate is used to measure the stance of both conventional and unconventional monetary policy. It is useful when policy rates of central banks are at or near zero as it neglects the zero-lower bound. Using both impulse response functions and forecast error variance decomposition, results suggest that higher interest rates are indeed associated with lower asset prices. That is confirmed by including two different estimates of shadow rates into the model and observing the effect for two specific types of assets. More precisely, house prices react almost immediately showing the most substantial decrease for the United Kingdom, while stock prices slightly increase at first and decrease afterward with similar size of the effect for all areas under consideration. Finally, the discussion of how the monetary authority should react to asset price fluctuations is provided, summarizing the vast amount of literature on the topic about 'lean vs. clean' debate. In conclusion, after the crisis, there is strong support for the argument that monetary authority should consider the development of asset markets as the center viewpoint of the macroeconomic analysis.

JEL Classification	C32, E43, E44, E52, E58, G12
Keywords	asset prices, monetary policy, shadow rate, financial crisis, negative interest rates, zero-lower bound

Author's e-mail	banoali1311@gmail.com
Supervisor's e-mail	roman.horvath@fsv.cuni.cz

Abstrakt

Práce se zaměřuje na význam expanzivní měnové politiky související s cenami aktiv, konkrétně cenami nemovitostí a akcií, jako nejdůležitějšími aktivy na finančních trzích. Model strukturální vektorové autoregrese je využit k vyhodnocení dat zaměřujících se na Eurozónu, Velkou Británii a Spojené státy americké od roku 2007 do 2017. Navíc jsou nominální krátkodobé úrokové sazby nahrazeny stínovými sazbami, které jsou vhodnějším prostředkem na vyhodnocení jak konvenčních, tak nekonvenčních nástrojů měnové politiky. Jejich použití je žádoucí v případě, že se hodnota nominální úrokové sazby v ekonomice blíží nebo je rovna nule, jelikož nulová dolní mez pro úrokové sazby není v tomto případě brána v potaz. Výsledky analyzované pomocí funkcí impulzní odezvy spolu s variační dekompozicí naznačují, že vysoké úrokové míry jsou asociovány s nízkými cenami aktiv. Tyto výsledky jsou potvrzeny použitím dvou různých stínových sazeb a dvou různých typů aktiv zahrnutých v modelu. V případě cen nemovitostí je reakce v podstatě okamžitá s největším poklesem cen u Velké Británie. Ceny akcií se téměř vždy nejdříve nepatrně zvýšily a až poté následoval jejich pokles, jehož výše je srovnatelná napříč oblastmi. Na závěr, diskuze ohledně reakce monetární autority na změny v cenách aktiv shrnuje rozsáhlé množství literatury na téma 'lean vs. clean'. Následky finanční krize poukazují na poznatek, že by centrální banky měly nahlížet na trh akcií jako na centrální bod při makroekonomických analýzách.

Klasifikace JEL	C32, E43, E44, E52, E58, G12
Klíčová slova	ceny aktiv, monetární politika, stínové sazby, finanční krize, negativní úrokové sazby, nulová dolní mez

E-mail autora	`banoali1311@gmail.com`
E-mail vedoucího práce	`roman.horvath@fsv.cuni.cz`

Contents

List of Tables

List of Figures

Acronyms

BoE Bank of England

BoJ Bank of Japan

EA Euro Area

ECB European Central Bank

FED Federal Reserve System

FEVD Forecast Error Variance Decomposition

FRED Federal Reserve Bank of St. Louis

GATSM Gaussian Affine Term Structure Model

GDP Gross Domestic Product

HP House Prices

IRF Impulse Response Function

OECD Organisation for Economic Co-operation and Development

SP Share Prices

SRTSM Shadow Rate Term Structure Model

SVAR Structural Vector Autoregressive Model

UK United Kingdom

US United States

VAR Vector Autoregressive Model

ZLB Zero-Lower Bound

Master’s Thesis Proposal

Author	Bc. Bano Ali
Supervisor	Prof. Roman Horváth, PhD.
Proposed topic	Low Interest Rates and Asset Price Fluctuations: Empirical Evidence

Motivation In relation to recent economic crisis starting in 2007, the expansionary monetary policy has been implemented by many central banks around the world as a remedy for disastrous consequences of this crisis. The main aim of this policy was to prevent deflation and reach the inflation target as well. Historically, this action has been made several times in order to relieve the economy after crisis. However, from the last case, interest rates have been almost on the zero lower bound. Some central banks have decreased them even to the negative rates. During the last few years, this issue has been receiving much attention as many economists have tried to observe the impact of this policy in relation to prices in various markets, more precisely the relationship between low interest rates and the price bubbles.

To mention few studies observing this relationship, Bordo and Landon-Lane (2013) was trying to observe The Effects of Expansionary Monetary Policy on Asset Price Booms using panel data of 18 OECD countries in period 1920-2011. Their results show that the policy of low interest rates has positive impact on multiple asset prices. Another study proposed by Gali and Gambetti (2014) observes The Effects of Monetary Policy on Stock Market. They estimated the response of stock prices to exogenous monetary policy shock using a vector-autoregressive model on USA data in period 1960-2011, showing that stock markets prices increase persistently in response to an exogenous tightening of monetary policy. Both of them vary considerably.

The objective of this diploma thesis is to observe the relationship between expansionary monetary policy and asset price bubbles while using a vector-autoregressive model for panel data and moreover, the shadow rate will be used instead of a short-term interest rate controlled by central bank. The thesis will focus on United States, United Kingdom and Eurozone.

Hypotheses

Hypothesis #1: Expansionary monetary policy indeed has a positive impact on asset prices.

Hypothesis #2: The impact is observable in prices of various assets.

Hypothesis #3: The choice of shadow rate does not matter for the estimated effect of monetary policy on asset prices.

Hypothesis #4: Monetary authority should/not react to these movements in prices.

Methodology To study the effects of expansionary monetary policy, the vector-autoregressive model is estimated on monthly panel data since 2004 for United States, United Kingdom and Eurozone (European Central Bank), namely on GDP, the consumer price index, the commodity price index, real estate prices and a stock price index of each area (S&P 500, FTSE 100, EURO STOXX 50). In addition, for measuring the stance of unconventional monetary policy, instead of short-term nominal interest rates controlled by central bank, the shadow rate term structure model proposed by Black (1995) is employed. It neglects the presence of zero-lower bound and can be therefore both positive and negative.

For the hypothesis no. 1 and no. 2, the sign of coefficient and the significance on monetary policy stance indicator will be tested to see if it has an expected significant and negative impact on asset prices.

To check the hypothesis no. 3, differently computed shadow rates will be employed for observing, how the results would change in different environment. This would provide the extent to which it is convenient to use shadow rate instead of other measures of interest rate in the economy.

Finally, the question no. 4 is rather a topic for discussion of several papers, where, if the positive impact of expansionary monetary policy on asset prices will be confirmed, consequent measure of what to do with the asset price bubbles will be suggested.

Expected Contribution In contrast to previous works on this topic, the shadow rate will be used to observe the relationship between expansionary monetary policy and asset price bubbles, which will allow for more precise data neglecting the zero-lower bound. Moreover, this thesis will cover a longer time considering the whole period of the crisis and not just its beginning.

Outline

1. Introduction
2. Literature Review
3. Data Description
4. Methodology
5. Empirical Results
6. Conclusion

Core bibliography

Bernanke, B. & Gertler, M., 2000. Monetary Policy and Asset Price Volatility. NBER Working Paper No. 7559, (February).

Bernanke, B. & Gertler, M., 2001. Should Central Banks Respond to Movements in Asset Prices? The American Economic Review, Vol. 91, No. 2, Papers and Proceedings of the Hundred Thirteenth Annual Meeting of the American Economic Association, (May), pp.253-57.

Black, F., 1995. Interest Rates as Options. The Journal of Finance, 50, No. 5(Dec., 1995), pp.1371-1376.

Bordo, M.D. & Landon-Lane, J., 2013. Does Expansionary Monetary Policy Cause Asset Price Booms; Some Historical and Empirical Evidence. NBER Working Paper No. 19585, (August), pp.4-52.

Buiter, W.H., 2009. Negative Nominal Interest Rates: Three ways to overcome the zero lower bound. The North American Journal of Economics and Finance, Elsevier, vol. 20(3), 20(3) (December), pp.213-38.

Gali, J. & Gambetti, L., 2014. The Effects of Monetary Policy on Stock Market Bubbles: Some Evidence. NBER Working Paper No. 19981, (March), pp.233-57.

Hakkio, C.S. & Kahn, G., 2014. Evaluating monetary policy at the zero lower bound. Economic Review, 2014(Q II), pp.5-32.

Hamilton, J.D. & Wu, J.C., 2011. The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment. Journal of Money, Credit and Banking, Blackwell Publishing, 44(02), pp.3-46.

Christensen, J.H.E. & Rudebusch, G.D., 2013. Estimating Shadow-Rate Term Structure. Federal Reserve Bank of San Francisco.

McCallum, B.T., 2000. Theoretical Analysis Regarding a Zero Lower Bound on Nominal Interest Rates. NBER Working Paper No. 7677.

Mishkin, F.S., 2011. Monetary Policy Strategy: Lessons from the Crisis. 6th ECB Central Banking Conference, 18-19 November 2010.

Posen, A.S., 2006. Why Central Banks Should Not Burst Bubbles. Institute for International Economics, (January).

Posen, A.S., 2010. Do we know what we need to know in order to lean against the wind?, Washington.

Robinson, T. & Stone, A., 2005. Monetary Policy, Asset-Price Bubbles and the Zero Lower Bound. NBER Working Paper No. 11105.

Wright, J.H., 2011. What does Monetary Policy do to Long-Term Interest Rates at the Zero Lower Bound? Economic Journal, 122(2012), pp.F447-F466.

Wu, J.C. & Xia, F.D., 2015. Measuring the Macroeconomic Impact of Monetary. Journal of Money, Credit and Banking, Vol. 48, No. 2?3, 2016(March-April), pp.254-91.

Author

Supervisor

Chapter 1

Introduction

The outbreak of the recent economic crisis in $2007 - 2009$ has been associated with an implementation of expansionary monetary policy with nominal short-term interest rates reaching the zero-lower bound. Some central banks, e.g., ECB, BoJ or Swedish Riksbank, have decreased them even to negative values through unconventional monetary policy tools to prevent deflation and stimulate economic activity during the crisis. Essentially, that disapproves common intuition that nominal rates cannot go below zero. It assumes that there is always a possibility to switch from deposits to cash defined as an asset with zero yield. Consequently, it limits the capability of central banks to stimulate economic growth further.

Traditional view considers the expansionary monetary policy as a subject inflating the asset prices such as of stocks, bonds, and real estate, caused by lower costs of borrowing. This issue has been receiving much attention[1] as to observe the link between the low-interest rate policy and asset prices, where an upward pressure on the latter can create significant asset price booms and subsequent bubbles. A burst of these bubbles can have disastrous consequences leading to a severe banking crisis and prolonged recessions (Reinhart & Rogoff 2009).

As a result, there should be a clear answer about the relationship between these two variables to prevent potential busts. Also, before the crisis, there

[1]Bordo & Landon-Lane (2013), Gali & Gambetti (2013), or Huber & Punzi (2016) are few of those recently observing this topic.

was a consensus, that central banks should not react to asset price fluctuations and focus mainly on guaranteeing low inflation and unemployment (Mishkin 2008; Posen 2006). Many economists also oppose that firstly, the asset price bubbles are hard to identify and secondly, aggressive response to asset price fluctuations can cause significant harm to the economy (Posen 2006; Bernanke & Gertler 2001). Nonetheless, after the crisis, they have been confronted with opposite viewpoint suggesting that central banks should consider the development of asset markets the center point of macroeconomic analysis(Mishkin 2011; Wesselbaum & Luik 2016).

The main aim of this thesis is to estimate if the expansionary monetary policy indeed leads to increase in the asset prices - specifically, stock and house prices. Since there has been an extensive amount of literature observing this topic, the main contribution of the thesis is to use the shadow policy rates instead of short-term nominal interest rates controlled by central banks to observe the impact of interest rate on asset prices. This approach was firstly proposed by Black (1995) to use it in an environment with interest rates at or near zero and to measure the deviations from Taylor rule. It neglects the presence of zero-lower bound and can be therefore both positive and negative, reflecting central banks' additive easing through unconventional tools. Consequently, it will allow for more precise data neglecting the zero-lower bound. Primarily, the estimates of shadow rate computed by Wu & Xia (2016) are used to estimate the effect.

There are four hypotheses of primary interest: at first, whether expansionary monetary policy indeed has a positive impact on asset prices. At second, this impact should be observable in various assets to be sure, that interest rates do not influence only specific part of asset market. There are two asset prices employed in the model - house and stock prices. Apparently, the choice of these specific assets is motivated by their importance in financial markets. The third hypothesis explores if the choice of shadow rate matters for the estimated effect of monetary policy on asset prices mentioned above. For this, another estimate of shadow rate computed by Krippner (2013) is included. Last but not least, the fourth hypothesis observes if monetary authority should react to the asset price fluctuations.

To study these effects, the structural vector autoregressive is employed. As to cover the whole period of the global financial crisis, the effect will be estimated on data from 2007 to 2017. Eventually, to be able to confirm the effect and potential differences across economies, there are three areas considered to measure the impact - the Euro Area, the United States, and the United Kingdom.

The thesis is divided into two major parts: the first one is focused on the qualitative analysis of the relationship between interest rates and asset prices, while the second once provides quantitative analysis of it. More specifically, Chapter 2 contains a literature review of the topic included in the model. Chapter 3 discusses different approaches to the shadow rate term structure. Furthermore, Chapter 4 and 5 describe the data and methodology used for the quantitative analysis. It is followed by Chapter 6 with observed empirical results of the baseline model and its different specifications to check for robustness, suggesting that there indeed is a positive relationship between the low-interest rates and asset prices. In Chapter 7, the discussion on the reaction of monetary policy on possible asset price fluctuations is provided to show different points of view on this question prior and post the crisis in 2007-2009. Finally, Chapter 8 concludes the overall results and possible future extensions of the observed question.

Chapter 2

Literature Review

There has been an extensive amount of studies observing an impact of monetary policy on asset prices during the period of financial crisis in 2008-2009. Before it, central banks were using the inflation-targeting approach to bring inflation under control. This approach, however, does not respond to changes in asset prices, unless they signal changes in expected inflation (Bernanke & Gertler 2000). Nevertheless, the recent crisis has driven the attention on the reaction of asset prices to monetary policy. This section provides a brief overview of the relevant literature.

The main transmission mechanism of the monetary policy concerning adjustments in asset prices - asset price channel - is considered to come through changes in official interest rates as they influence financial conditions and market expectations in the economy. These adjustments can occur in a fundamental component of a price, but it can also be of a non-fundamental character leading to a creation of bubble component in the asset price. Thus, it is crucial to estimate the responsiveness of asset prices to monetary policy.

On the other side, the impact of these two variables works in both directions. Asset prices are also considered in the setting of monetary policy besides targeting only output and inflation. Consequently, they further affect other variables in the economy. Taylor (1993) has proposed a model, where federal funds rate is a linear function of inflation and output gap. Chen (2012) constructed a model based on Taylor's rule with an addition of variables for asset prices. She concludes that monetary policy also responds to asset prices as according to her observation 10% increase in stock market results in the rise of federal funds rate by 0.062%, which she finds as a considerable impact. A question if the monetary policy should further react to asset price bubbles in the market is also one of the topics of this thesis and will be discussed later.

Essentially, the relationship between interest rate and asset prices is considered to be negative - expansionary monetary policy has a positive impact on asset prices. There might be several explanations for it. Naturally, the present value of such an asset is higher when discounted by the lower interest rate. Furthermore, it is attractive to buy assets such as houses. Reduced borrowing costs with consequent lower mortgage interest payments also enhance the demand for this asset.

Rigobon & Sack (2002) observe the response of asset prices and market interest rates to changes in monetary policy resulting in the negative impact of short-term interest rate on stock prices and significant positive impact on market interest rates. Furthermore, Lawrence *et al.* (2010) explores the relationship between monetary policy and booms and finds out that inflation is low in stock market booms and credit growth is high. He concludes that interest rate targeting rule as a function of expected future inflation may destabilize asset markets and the broader economy. This destabilization comes from targeting interest rate in the boom while using inflation forecast in opposite direction than it would naturally develop without any monetary authority. As a consequence, the real interest rate is far from its natural value.[1]

Bernanke & Kuttner (2004) analyze the impact of changes in the federal funds rate on equity prices using event-study approach for period 1989-2002, finding a consistent and robust response of the stock market to unexpected monetary policy actions. More precisely, according to their results, a surprise 25-basis-point cut in federal funds rate leads to about a 1 percent increase in stock prices. They, however, emphasize that the role of the monetary policy surprises in the overall variability of stock prices is still minimal. The stock prices are mainly affected by expected future excess returns or expected future dividends, but not directly through effects on the real interest rate.

In contrast, Shiller (2007) argues that the volatility in stock prices and real estate prices did not relate to movements in long-term interest rates. He instead

[1] He defines 'the natural interest rate' as the socially optimal interest rate.

suggests focussing on changes in popular economic models as both long-term interests, and asset prices react to changes in the public's ways of thinking about the economy. Mostly, these models are viewed by rational expectations theorists as generally reconciled by population and only some genuinely exogenous factors can make a change in the economy. Nevertheless, these frameworks are regularly changed, and therefore, sufficient explanation cannot be provided just by a behavior of exogenous factor (Shiller 2007, pg. 111).

House prices have been a matter of discussion because of its immense role regarding the financial crisis in 2007. Many studies have tried to explain their relationship with monetary policy, most of them with similar results.

Bjornland & Jacobsen (2009) have studied the role of house prices in the monetary transmission mechanism in Norway, Sweden, and the UK. They use SVAR model for 1983-2006. Overall, they find out that a monetary policy shock raising interest rate by one percentage point leads to falling in house prices by $3-5\%$. Apart from that, interest rate reacts systematically to house price shocks.

That is in accordance with Rahal (2016). He studies housing market response to unconventional monetary policy shocks in the form of an increase of central bank total assets and monetary base. Panel VAR model for eight OECD countries has been employed showing a positive, persistent response of house prices with peaks between one and two years after a policy shock.

His results are relatively consistent across countries, while Musso *et al.* (2010) show the difference in the role of the housing market in the macroeconomics in the US and Euro Area. Essentially, they observe effects of three different structural shocks, indicating many similarities between the areas concerned from the qualitative point of view. Nevertheless, their evidence from SVAR model indicates stronger transmission of monetary policy shocks in the US. In addition, there is stronger and more persistent positive effect of housing demand shocks on real variables, particularly on consumption. On the other hand, credit supply shocks more significantly Euro Area.

Surprisingly, the relationship between monetary policy and long-term interest rates affecting various bond yields. Wright (2011) has proposed an approach using the tools of identification through heteroscedasticity and high-frequency event-study analysis. His estimates show the negative effects of stimulative monetary policy shocks on both long-term Treasury and corporate bond yields. While being statistically significant, the effects fade away fast over the subsequent months.

Equivalently, Beckworth *et al.* (2012) observe this relationship using VAR model with long-run identifying restrictions for 1964-2007 in the US. They find out that both short-term and long-term interest rates are similarly responsive to the monetary policy shocks for the overall sample period. In spite of it, while short-term interest rates indicate similar results for both pre- and post-1979 sub-periods, for long-term interest rates, results are remarkably different in these sub-periods They explain it by the change in the Federal Reserve's inflation-fighting credibility after 1979. Gertler & Karadi (2014) obtained similar results after combining traditional VAR model with the high-frequency identification of monetary policy shocks.

Certainly, there have been several studies observing the relationship between monetary policy and asset prices, however, in opposite way. As the purpose of this thesis is to explain if low-interest rates cause asset prices to go high, some studies also propose the idea of using interest rates to slow down booms rather than potentially causing them.

Gerlach & Assenmacher (2008) study the responses of residential property and equity prices by about 0.375% in one or two years which is about three times more the effect on real GDP. Thus, interest rates would have to increase substantially to slow down asset price movements which would consequently decrease GDP. They also conclude, that is is not possible to use monetary policy to stabilize both residential property and equity prices because of different times for each of them to return to their initial level.

Several studies have already focused on whether expansionary monetary policy creates bubbles in prices of assets, but as compared to observing the effect of monetary policy on real variables, the scale of empirical studies on this topic is relatively smaller. Moreover, they vary considerably. Bordo & Landon-Lane (2013) observe 18 OECD countries from 1920 to 2011 estimating the impact of the loose monetary policy. They define it as interest rate below the target rate or having a growth rate of money above the target growth rate, and further, the impact of low inflation and bank credit on the house, stock, and commodity prices. This approach seeks for periods of asset price boom, which is defined as a sustained expansion in asset prices ending in a significant correction. The sustained expansion is considered as a period of economic growth higher than usual based on previous cycles which must last at least two years and average at least 5% per year for real house and commodity prices and 10% per year for real stock prices. Furthermore, the price correction must be of a value greater than 25 % of the expansion in price occurred during the expansion (Bordo & Landon-Lane 2013, pg. 20, 21).Their results show a significant contribution of loose monetary policy to the creation of booms in prices of assets mentioned earlier even across different sub-periods of the data. Nevertheless, they do not provide any evidence of magnitudes of the effects of each of these three control variables on asset prices; therefore, it is not clear, how they affect each other.

On the contrary, Gali & Gambetti (2013) use data only for the U.S. for period 1960-2011 when observing the response of stock prices to exogenous monetary policy shocks. The structural vector-autoregressive model with time-varying coefficients is used for this purpose. They recognize two components of asset prices - a 'fundamental' component, defined as the present discounted value of future dividends, and a 'bubble' component. Their results indicate a persistent increase of stock market prices in response to an exogenous tightening of monetary policy, particularly in short-run. This conclusion is contradictory to the conventional view. It says that using tight monetary policy may reduce the fundamental component, but on the other side, the bubble component increases, which makes monetary policy ineffective during periods of bubbles.

Several studies have already proposed the idea of using shadow rate to analyze the relationship between unconventional monetary policy and asset markets.

Huber & Punzi (2016) observe the housing market in the United States, the United Kingdom, Japan and the Euro Area for period 1980-2014. They use a time-varying parameter VAR model, similarly to Gali & Gambetti (2013), while including the shadow interest rate estimated by Krippner (2013). Their findings suggest that 25 basis point increase in the shadow rate leads to decrease in housing prices, residential investment, consumption, consumer price index and mortgage lending. Moreover, tightening monetary policy shocks have significantly more substantial effects in the US. Nevertheless, they do not specify the reason for it. Regarding the impact of financial crisis on housing markets, they find out that unconventional monetary policy was successful in dampening the consequences, particularly in the US.

Alessi & Kerssenfischer (2016) criticize a small scale VAR model because of its inability to handle a broader set of macroeconomic variables. Instead of VAR, they employ the structural factor model for the Euro area based on 127 variables from 2004 to 2015 splicing Euro Overnight Index Average rate with the shadow rate computed by Wu & Xia (2016). They emphasize the effects of monetary policy shocks on asset prices to be quick and large. SFM suggests roughly 3% decline in stock prices and 1% decline in house prices in reaction to contractionary monetary policy. In latter case, it returns to their previous level within 1-2 years. Their estimates appear to be largely consistent with basic economic theory.

On the other hand, it is necessary to mention that VAR models still produce accurate estimates in case of shocks being fundamental and keeping the number of variables small. As factor models impose a specific framework of structure on the data, they are usually less general than VAR models (Forni & Gambetti 2010). Moreover, this study does not provide any differences of estimates from model computed by normal short-interest rates and the shadow rates, so the effects are hard to assign precisely.

As the above-presented list of related literature indicates, there has been a significant contribution already devoted to this topic. Most of the studies agree that asset prices react negatively to expansionary monetary policy, although they vary considerably about the resulting magnitude of this effect in last crisis. Following text aims to quantify the effect of low-interest rate policy on asset prices, while using shadow rate instead of short-term interest rate. Moreover, it will cover the whole period of Great Recession.

Chapter 3

Shadow Rate Term Structure

In this chapter, two types of shadow-rate term structure models are introduced as this thesis aims to observe the effect of low-interest rate through two differently computed types of shadow rate. The first part introduces the original approach proposed by Black (1995) and followed by Wu & Xia (2016). The second part explains the approach suggested by Krippner (2012).

3.1 The Black Shadow-Rate Model

The idea of shadow rate was firstly proposed by Black (1995), which was based on a general agreement that the nominal short rate cannot be negative. Simply because in case of their negative values, people would not hold an instrument bringing them a negative interest rate. Instead of it, they would hold currency, which therefore is an option. This leads to a conclusion that all negative rates can be replaced with zeros. There comes the idea of zero lower bound for the interest rate. To construct an observable risk-free rate, r_t, shadow rate s_t or 0 is implemented:

$$r_t = \max\{0, s_t\} \tag{3.1}$$

If the shadow rate is greater than ZLB, the short-rate is s_t. Otherwise, it equals 0. Therefore, the nominal short rate is also an option. In simple words, the shadow short rate is a state of the world without the currency option (Black 1995, pg. 1372). Moreover, he defines a 'shadow real rate' as the shadow short-term nominal rate less the expected inflation rate. As both shadow real rate and inflation rate can reach negative values, shadow nominal rate can also be negative.

Similar approach was used by Wu & Xia (2016). Instead of zero in the equation 3.1, they use a lower bound $\underline{r}$. Furthermore, they assume s_t to be an affine function of some state variable X_t:

$$s_t = \delta_0 + \delta_1^{'} X_t \tag{3.2}$$

Defining

$$\hat{a}_n \equiv \delta_0 + \delta_1^{'} \left(\sum_{j=0}^{n-1} \left(\rho^Q\right)^j \right) \mu^Q,$$

$$b_n^{'} \equiv \delta_1^{'} \left(\rho^Q\right)^n$$

The state variables follow a first-order vector autoregressive process under the physical (real world) measure

$$X_t = \mu + \rho X_t + \sum \epsilon_{t+1}, \epsilon_{t+1} \sim N(0, I) \tag{3.3}$$

Furthermore, they describe the log stochastic discount factor with price of risk λ_t as

$$logM_{t+1} = -r_t - \frac{1}{2}\lambda_t^{'}\lambda_t - \lambda_t^{'}\epsilon_{t+1}, \lambda_t = \lambda_0 + \lambda_1 X_t \tag{3.4}$$

implying the dynamics for the factors under the risk neutral measure(Q) to be also first-order vector autoregressive process:

$$X_{t+1} = \mu^Q + \rho^Q X_t + \sum \epsilon_{t+1}^Q, \epsilon_{t+1} \sim N(0, I) \tag{3.5}$$

The distance between P and Q parameters is as follows:

$$\mu - \mu^Q = \sum \lambda_0$$

$$\rho - \rho^Q = \sum \lambda_0$$

Basically, they propose an analytical approximation for the forward rate in the shadow rate term structure model, defining $f_n, n+1, t$ as the forward rate at time t for a loan starting at t+n and maturing at t+n+1, which is a linear function of yields on risk-free n and n+1 period pure discount bonds Wu

& Xia (2016, p. 256,257). The error associated with their approximation was observed to be very small.

$$f_{n,n+1,t} = (n+1)y_{n+1,t} - ny_{nt} \tag{3.6}$$

Moreover, defining

$$a_n \equiv \hat{a}_n - \delta_1^{'} \left(\sum_{j=0}^{n-1} \left(\rho^Q\right)^j \right) \Sigma \Sigma^{'} \left(\sum_{j=0}^{n-1} \left(\rho^Q\right)^j \right)^{'} \delta_1$$

the forward rate can be approximated by

$$f_{n,n+1,t}^{SRTSM} = \underline{r} + \sigma_N^Q g \left(\frac{a_n + b_n^{'} X_t - \underline{r}}{\sigma_n^Q} \right) \tag{3.7}$$

where $(\sigma_n^Q)^2 \equiv Var_t^Q(s_{t+n})$.

This approach is supposed to be the first to propose the analytical approximation for the forward rate in the SRTSM applicable to discrete-time data directly (Wu & Xia (2016, pg. 257)). Therefore, the numerical value of the error associated with simulation method and numerical integration is probable to be equal to zero. As opposed to Krippner (2012), who proposed a forward rate for the continuous time period. Hence, it is necessary to integrate the forward rate over that period numerically.

To relate this model to the Gaussian Affine Term Structure Models, Wu & Xia (2016) short interest rate with shadow rate at time t. Thereafter, this model becomes from an SRTSM to the GATSM. The forward rate in this model is an affine function of the factors.

$$f_{n,n+1,t}^{GATSM} = a_n + b_n^{'} X_t \tag{3.8}$$

with the terms a_n and b_n the same as in the equation3.7. They also emphasize, that the GATSM is an approximation for the SRTSM when the economy abstains from the ZLB.

In practice, to construct a new policy rate s_t to be able to measure the stance of unconventional monetary policy at the ZLB, Wu & Xia (2016) splice together the effective federal fund rate before 2009 and the estimated shadow federal funds rate since 2009. Their model implies, that before 2009, when the federal fund rate was not at the ZLB and was able to provide the information about the monetary policy effect on the economy, the short rate was equal to the shadow rate. After 2009, it has remained at the ZLB, while the shadow rate became negative.

In summary, the SRTSM is a handy tool how to observe the economy when being at the ZLB. The shadow rate as an analytical approximation for the forward rate in the SRTSM can be used to measure the impact of unconventional monetary policy on the real economy. While observing, if the shadow rate can be used instead of the federal funds rate to measure the macroeconomic impact of monetary policy at the ZLB, Wu & Xia (2016) find, that the shadow rate contains essential information about the economy after it reaches the ZLB. In fact, the effective federal funds rate does not provide such information. They also consider this approximation very close to the real value with the approximation error to be equal just to few basis points. Nevertheless, this model has been criticized due to its potential bias from the correct values of the shadow rate.

3.2 Option-Based Shadow-Rate Models

Krippner (2012) argues that Gaussian affine term structure models are not sustainable to apply in the presence of zero lower bound and physical currency. That is caused by arising of non-zero probabilities of negative interest rates for all maturities on the term structure for any unconstrained Gaussian process for short rate dynamics (Krippner 2012, pg. 1). These models are, however, applied in the real world with an assumption that the probabilities of negative interest rates are small enough to make almost no difference to real-world conditions. Nevertheless, many economies maintain near-zero interest rate policy, which means that in the real world, there is a constraint implied by ZLB, whereas GATSMs assume no constraint and therefore cannot provide accurate information about the term structure.

Krippner agrees with Black's framework of eliminating negative interest rates based previously mentioned the option of physical currency over negative interest rate at each point in time. The drawback of this model is, however, the limited tractability of the models.

An alternative option-based approach suggested by Krippner (2012) is based on two different bond-pricing situations. In one of them, the physical currency is not available, and in the second one, it is. Moreover, in the state with currency, constant nominal value and no transaction costs are assumed. In the no currency situation, the price of a shadow-rate zero-coupon bond is $P(t,\delta)$ and the risk-free shadow rate s_t may be negative. Therefore, it can be traded above par, as the expected return might be negative. On the contrary, in the situation with currency, the price for a zero-coupon bond at time t with a time to maturity δ is $\underline{\mathrm{P}}$(t, δ) without a possibility of receiving negative returns. The physical currency is essentially defined as a bond with a price of one and interest rate of zero (Krippner 2012, pg. 4). In this state, investors have the possibility to either buy the zero-coupon bond and receive one unit of currency or just hold the currency.

To precisely illustrate his idea, firstly single time-step period is considered for the annualized rate of return with continuous compounding:

$$R(t,\delta) = \frac{1}{\delta} log \left[\frac{1}{P(t,\delta)} \right] \tag{3.9}$$

Apparently, if $P(t,\delta) = 1$, $R(t,\delta) = 0$ which is equal to the return offered by the currency. If $P(t,\delta) < 1$, $R(t,\delta) > 0$, an investor will choose to hold the bond rather than currency and in opposite if $P(t,\delta) > 1$, $R(t,\delta) < 0$, which results in preferring to hold the physical currency at $P(t,\delta) = 1$. This shows, why the currency is described as an option, because one has the right, but not the obligation to hold it.

To summarize the decision-making in both states, the investor will decide as follows:

$$\begin{aligned} \underline{P}(t,\delta) &= \min\{1, P(t,\delta)\} \\ &= P(t,\delta) + \min\{1 - P(t,\delta), 0\} \\ &= P(t,\delta) - \max\{P(t,\delta) - 1, 0\} \\ &= P(t,\delta) - C(t,0,\delta) \end{aligned} \tag{3.10}$$

where $C(t,0,\delta)$ is the payoff for a call option expiring immediately with a strike price equal to 0 (Krippner 2012, pg. 4). The ZLB short rate is established as follows:

$$
\begin{aligned}
\underline{R}(t,\delta) &= \frac{1}{\delta} log\left[\frac{1}{P(t,\delta)}\right] \\
&= -\frac{1}{\delta} log\left[P(t,\delta) - C(t,0,\delta)\right] \\
&= -\frac{1}{\delta} log[\min\{1, P(t,\delta)\}] \\
&= \max\left\{-\frac{1}{\delta} log[1], -\frac{1}{\delta} log\left[P(t,\delta)\right]\right\} \\
&= \max\{0, R(t,\delta)\}
\end{aligned}
\tag{3.11}
$$

Investors know that at any point of time in the future, they will be able to choose between holding currency or shadow bonds at their future prevailing market price. To extend this model for multiple time-steps, τ is added as a representation of a future time horizon from time t. $\underline{P}(t+\tau, delta)$ is therefore a contingent quantity as compared to noncontingent quantity $\underline{P}(t, delta)$.

$$
\begin{aligned}
\underline{P}(t+\tau,\delta) &= \min\{1, P(t+\tau,\delta)\} \\
&= 1 + \min\{0, P(t+\tau,\delta) - 1\} \\
&= 1 - \max\{0, 1 - P(t+\tau,\delta)\}
\end{aligned}
\tag{3.12}
$$

Last two terms represent boundary conditions. For the multiple finite-step shadow bond $P(t,\tau)$ maturing at time $t+\tau \rightarrow P(t+\tau, 0)$, the boundary condition is 1. Furthermore, $\max\{0, 1 - P(t+\tau,\delta)\}$ is a boundary condition for a put option $Q(t,\tau,\tau+\delta)$ expiring at time $t+\tau$ with strike price equal to 1. The solution for the ZLB bond price is:

$$
\underline{P}(t,\tau+\delta) = P(t,\tau) - Q(t,\tau,\tau+\delta) \tag{3.13}
$$

Using put-call parity relationship (see Krippner (2012, p. 6)):

$$
P(t,\tau) - Q(t,\tau,\tau+\delta) = P(t,\tau+\delta) - C(t,\tau,\tau+\delta) \tag{3.14}
$$

with a price of ZLB bond

$$
\underline{P}(t,\tau+\delta) = P(t,\tau+\delta) - C(t,\tau,\tau+\delta) \tag{3.15}
$$

The ZLB short rate $\underline{R}(t+\tau,\delta)$ is established as follows:

$$\begin{aligned}
\underline{R}(t+\tau,\delta) &= \frac{1}{\delta}log\left[\frac{1}{\underline{P}(t+\tau,\delta)}\right] \\
&= -\frac{1}{\delta}log[P(t+\tau,\delta) - C(t+\tau,0,\delta)] \\
&= -\frac{1}{\delta}log[\min\{1, P(t+\tau,\delta)\}] \\
&= \max\left\{-\frac{1}{\delta}log[1], -\frac{1}{\delta}log\left[P(t+\tau,\delta)\right]\right\} \\
&= \max\{0, R(t+\tau,\delta)\}
\end{aligned} \tag{3.16}$$

Last step to establish a general ZLB term structure is to change a discrete-time term structure model to continuous time one.

$$\begin{aligned}
\underline{f}(t,\tau) &= -\frac{d}{d\tau}log[\underline{P}(t,\tau)] \\
&= \lim_{\delta\to 0} -\frac{d}{d[\tau+\delta]}log[\underline{P}(t,\tau+\delta)] \\
&= f(t,\tau) + z(t,\tau)
\end{aligned} \tag{3.17}$$

$f(t,\tau)$ represents the shadow forward rate curve. To get the resulting ZLB forward rate, there is also the option effect $z(t,\tau)$ to add.

$$z\left(t,\tau\right) = \lim_{\delta\to 0}\left\{\frac{d}{d[\delta]}\left[\frac{C(t,\tau,\tau+\delta)}{P(t,\tau)}\right]\right\} \tag{3.18}$$

Through the ZLB forward rate $\underline{f}(t,\tau)$, the ZLB interest rate $\underline{r}(t,\tau)$ and the ZLB bond price $\underline{P}(t,\tau)$ can be obtained.

$$\underline{r}(t,\tau) = \frac{1}{\tau}\int_0^\tau \underline{f}(t,\nu)d\nu \tag{3.19}$$

$$\begin{aligned}
\underline{P}(t,\tau) &= exp\left[-\int_0^\tau \underline{f}(t,\nu)d\nu\right] \\
&= exp[-\tau * \underline{r}(t,\tau)]
\end{aligned} \tag{3.20}$$

For the general ZLB term structure, which is well-defined and always non-negative quantity, the following term is obtained:

$$\begin{aligned}\underline{r}(t) &= \lim_{\tau \to 0} \underline{f}(t, \tau) \\ &= f(t, 0) + z(t, 0) \\ &= r(t) + max\{-r(t), 0\} \\ &= max\{r(t), 0\}\end{aligned} \tag{3.21}$$

The general ZLB term structure can also be considered as the sum of the forward rate on the unconstrained shadow bond and add-on correction term in equation 3.18 (Christensen & Rudebusch (2013, p. 7)).

Krippner further explains a framework for imposing a zero lower bound on Gaussian affine term structure models, which is however beyond the scale of explanation in this thesis. His approach eliminates the negative interest rates and adds the optionality of the present and future availability of physical currency to the GATSM term structure. Nevertheless, Christensen & Rudebusch (2013) argue that the observed discount bond prices in equation 3.20 might be different from the bond price in the equation 3.15, which was consequently used to construct the non-negative forward rate in the equation 3.17. Hence, Krippner's framework might not be fully internally consistent in case of being close to ZLB. From the comparison of Krippner's ZLB framework and Black's framework (see Krippner (2012, p. 8,9)), the approximation seems quite good. Large differences in results from both of these frameworks come with longer maturities as for 1-year maturity, they are very close to each other. Apparently, the short rates resulting from using both of the frameworks are also identical. The main differences come through the process of converting the shadow rates from each of the frameworks in to 'real world' short rates in the presence of ZLB.

Chapter 4

Data Description

This chapter describes the variables under observation. Specifically, the first section provides a summary of the recent development of all the crucial variables. The second section concisely describes the data used in a vector autoregressive model illustrated in Chapter 5.

4.1 Recent Evidence

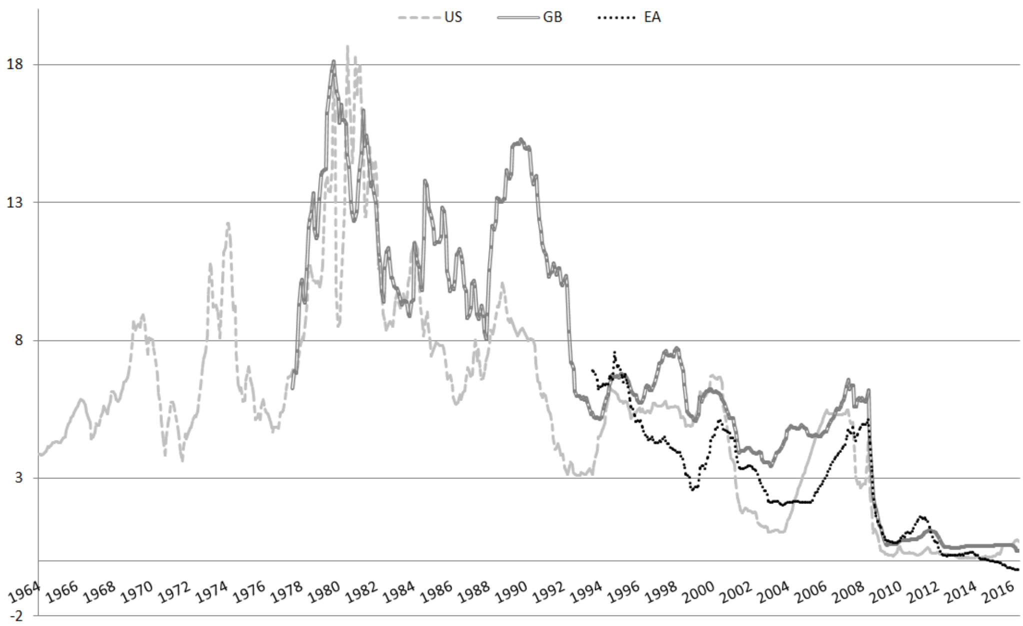
Essentially, a short-term interest rate is the primary instrument of monetary authority to adequately react to different periods of the business cycle in the economy. During an expansion period, there is a tendency to decrease interest rate to support economic activity, and on the other side, it is usually increased during a recession.

Figure 4.1 provides a development of short-term interest rates for the US, the UK and Euro Area. They have varied between 0.11% and 18.65% from 1964 to 2016 in the US, between 0.36% and 18.1% from 1978 to 2016 in the UK, and between -0.31% and 7.58% from 1994 to 2016 for Euro Area. As compared to 1960s, short-term interest rate increased on a large scale in the US as well as in the UK in late 1970s.The main reason for such behavior apart from oil crisis in 1973 was to bring inflation to a standstill. This period is known as Great Inflation. Subsequently, short-term interest rates were much higher than long-term ones. Despite inflation being tamed down in the early

1980s, money supply continued to expand excessively and was considered as one of the leading contributors of stock-market bubble and the housing boom by the end of 20th century and early 2000s.

In the early 1990s, the development of short-term interest rate again follows a sharp increase pattern followed by a small recession in both of the considered countries. Next ten years are considered to be very prosperous with the continuous increase of GDP in the US. Low inflation, as well as low unemployment altogether with rising productivity, lead to substantial technological boom and consequent increase in overall stock prices (see Figure 4.3). This boom ended in 2000 with a burst of the dot-com bubble, which resulted in a loss of $5 trillion in the market value of the companies after the stock market crash.

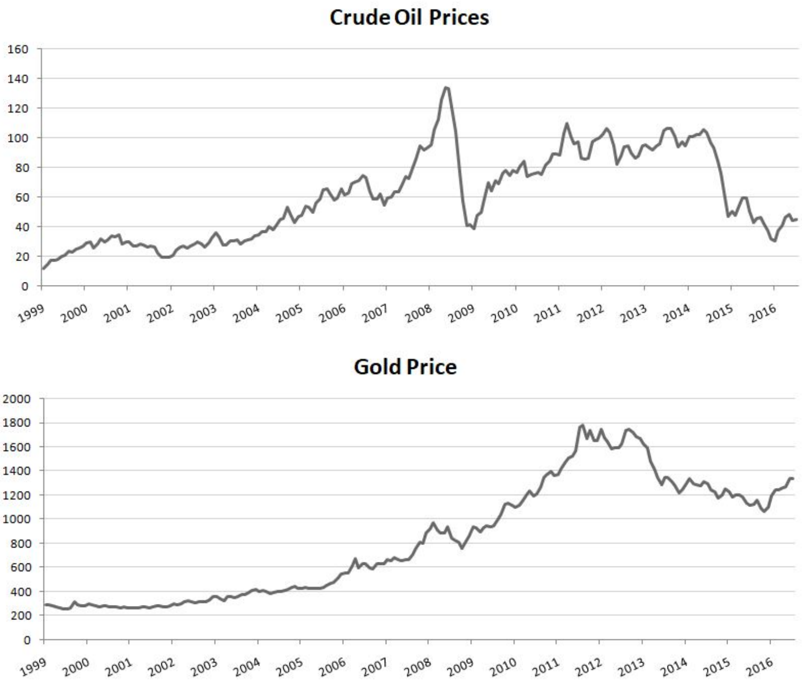
Figure 4.1: Short-term interest rates for the United States, the United Kingdom and the Euro area (in %)



Source: OECD

Recent evidence shows that after 2001, short-term interest rates had been continuously decreasing before they started to increase in 2006 so that economic growth would remain on the sustainable path. In this period, a considerable increase in price was experienced for most of the assets, especially those of housing and stocks, but also oil prices. On the other hand, development of price of gold is substantially different.

Figure 4.2: Crude Oil Prices ($ per barrel) and Gold Fixing Price ($ per troy ounce)



Source: FRED

After Great Recession in 2008-2009, they have been decreasing again, reaching even negative values for Euro Area, and being slightly above zero-lower bound for the US and the UK. Moreover, it does not seem they would rise in near future as central banks declare it is necessary to support investment activity and maintain aggregate demand at levels required to attain other monetary policy goals as price stability and sustainable employment. Another potential danger is deflation and subsequent stagnation of the economy.

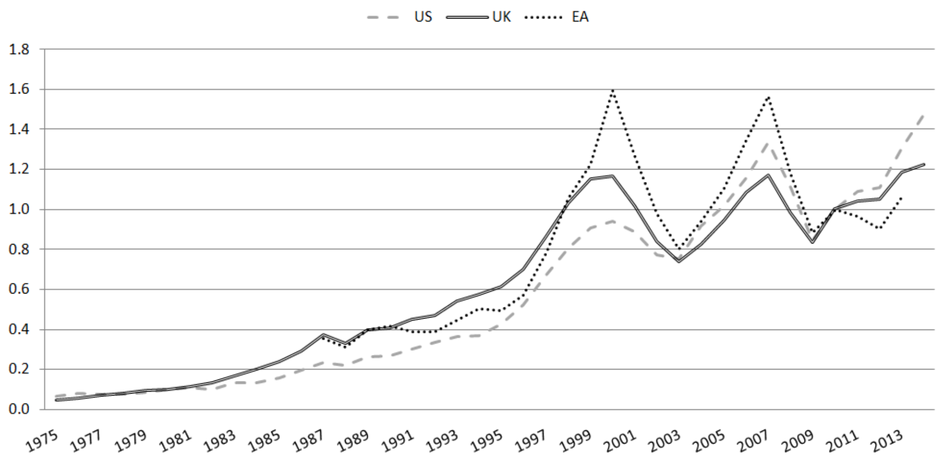
This persistent low-interest rate environment, however, limits the ability of the monetary authority to react to potential harmful shocks adequately. The reason is that at some point, intermittent increase of interest rate may cause a lot of damage to the economy due to high levels of debt and also because of people being accustomed to low interest rate environment. On the other side, the ability of monetary authority to stimulate the economy by cutting down the interest rate is limited by the zero-lower bound as well.

Figure 4.3 shows the total share prices for all shares[1] in the US, the UK from 1975 and from 1987 for the Euro Area till 2014. The share prices were increasing

[1] Calculated from the prices of common shares of companies traded on national or foreign

very slightly during 1975-1995. The consequent steep increase is apparent from 1996 when the equity value on stock markets started to rise rapidly because of the growth of Internet sector - commonly known as a dot-com bubble mentioned earlier. Most of the companies, even outside of the Internet field experienced a massive overvaluation of their shares (e.g., Boo.com, Tiscali). After the bubble burst, the share prices started to fall dramatically in 2000. In 2003, there was a considerable rise again in their value, reaching its peak in 2007. At the end of 2007, the prices decrease largely. Till March 2009, they fell roughly by 50%, experiencing more severe recession than back in 2000.

Figure 4.3: Total Share Prices for All Shares in the US, the UK and the Euro area (2010=1)



Source: FRED

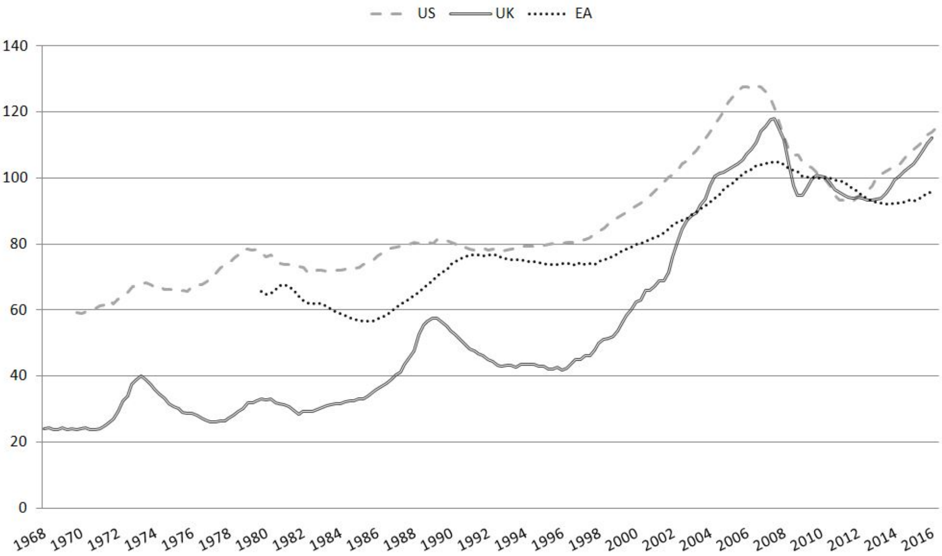
Restabilization of the markets usually leads to searching for other stores of wealth in society. One of them is investments in real-estate. Figure 4.4 shows an evolution of Housing Indicator[2] in the US, the UK, and the Euro Area from 1970, 1968, and 1980, respectively. There is a considerable increase of the indicator in 1971 as many investors turned from stock market to real-estate market. Nevertheless, this boom was tiny compared to the housing bubble in the early 2000s and resulting real-estate crash in 2007. According to NAR (2016), historical housing price data, there was no decrease in home prices from 1968 to 2004 with an average increase of 6.4% per year in the US. In other countries, the increase was even steeper than in the US (i.e., UK, Spain). In 2007, the prices doubled their value from the late 1990s, and after

stock exchanges. A share price index measures how the value of the stocks in the index is changing.

[2]It includes rent prices, real and nominal house prices, and ratios of price to rent and price to income. It is an index with base year 2010.

it, however, real-estate market has experienced a continuous decline till 2012 associated with global economic and financial crisis.

Figure 4.4: Real House Prices for the United States, the United Kingdom and the Euro area (2010=100)



Source: OECD

4.2 Data Description

The econometric analysis below is conducted on monthly data on Real Gross Domestic Product as a measure of economic activity, Harmonized Index of Consumer Prices as the aggregate price level, Shadow Policy Rates as the short-term interest rate, Bloomberg Commodity Index to incorporate the development of international prices, and Economic Policy Uncertainty Index. Essentially, the dataset covers 19 members of European Union using euro as their common currency-Euro zone as a single entity. This is due to the fact that the monetary policy in these countries does not reflect national preferences and is upon the whole group conducted from ECB. Furthermore, the United Kingdom and the United States are included as the world's leading economies to account for a global environment. The choice of these areas, as well as the period considered, was influenced mainly by the availability of data for shadow rates computed by Wu & Xia (2016) and Krippner (2013).

The time dimension of the sample ranges from January 2007 to July 2017 for Euro Area and the UK and to November 2015 for the US. Data before the year 2007 are not used as in the non-ZLB environment, the shadow rates are mostly equal to policy rate (Kuusela & Hännikäinen 2017).

Table 4.1: Description of the variables

Variable	Description	Source
y	Quaterly Gross Domestic Product, per head, logs (expenditure approach, reference year=2010, SA)	OECD (2016)
p	Monthly Harmonized Index of Consumer Prices, logs (reference year=2015)	FRED (2016)
hp	Quaterly Real House Price Index, logs (reference year=2015, SA)	OECD (2016)
sp	Monthly Share Price Index, logs (reference year=2010)	OECD (2016)
sr WX	Monthly Shadow rate - the method of Wu & Xia (2016; 2017)	Wu (2017)
sr LK	Monthly Shadow Short rate - method of Krippner (2013)	RBNZ (2016)
bcom	Monthly Bloomberg Commodity Index, logs	INV (2017)
unctr	Monthly Economic Policy Uncertainty Index, logs	EPU (2017)

Regarding the data manipulation, two series - real GDP and house prices only available at a quarterly frequency have been interpolated with the natural method of cubic spline interpolation. Since using only log-transformation of variables is not sufficient to provide stability in the models, most variables are kept in either month-to-month or year-to-year differences of log-levels except shadow rates being in levels. Table 4.1 lists all variables in the data set along with the applied transformation and its source.

Table 4.2: Descriptive statistics - Euro Area

Statistic	N	Mean	St. Dev.	Min	Max
y	127	10.5	0.02	10.5	10.6
p	127	4.6	0.04	4.5	4.6
hp	127	4.6	0.04	4.5	4.7
sp	127	4.7	0.2	4.2	5.1
sr WX	127	−0.3	2.6	−5.5	4.3
sr LK	118	−0.3	2.8	−7.4	4.4
bcom	127	4.9	0.3	4.3	5.5
unctr	127	5.1	0.4	3.9	6.1

Source: Author's calculations

Table 4.3: Descriptive statistics - United Kingdom

Statistic	N	Mean	St. Dev.	Min	Max
y	127	10.6	0.1	10.4	10.7
p	127	4.5	0.1	4.4	4.6
hp	127	4.6	0.1	4.5	4.8
sp	127	4.7	0.1	4.2	4.9
sr WX	127	−2.0	3.7	−6.5	6.1
sr LK	118	−0.1	3.2	−7.0	5.9
bcom	127	4.9	0.3	4.3	5.5
unctr	127	5.3	0.6	3.4	7.0

Source: Author's calculations

Table 4.4: Descriptive statistics - United States

Statistic	N	Mean	St. Dev.	Min	Max
y	109	10.8	0.1	10.8	10.9
p	109	4.6	0.1	4.4	4.6
hp	109	4.6	0.1	4.5	4.8
sp	109	4.8	0.2	4.2	5.0
sr WX	109	−0.2	2.3	−3.0	5.3
sr LK	109	−1.0	2.8	−5.4	5.3
bcom	109	4.9	0.2	4.3	5.5
unctr	109	4.8	0.3	3.8	5.6

Source: Author's calculations

The shadow policy rates from Wu & Xia (2016) and Krippner (2013) are used instead of short-term interest rates in the Euro Area, the UK, and the US. Principally, the reason behind using shadow rates is to mirror both conventional and unconventional monetary policy tools. The commodity prices are included as strictly exogenous variable as it is not the aim of this thesis to model them. Their role is to display foreign asset price development.

In addition, economic policy uncertainty index to measure policy-related economic uncertainty is included in the period under observation. This index comprises of three types of underlying components. First one quantifies newspaper coverage of policy-related economic uncertainty; the second component represents the number of federal tax code provisions set to expire in future years. The last component shows the disagreement among economic forecasters being a proxy for uncertainty.

An Augmented Dickey-Fuller test and Kwiatkowski-Phillips-Schmidt-Shin test have been performed on the log-levels, month-to-month and year-to-year differences of all variables except shadow rates being in level form. To some extent, the stationarity can be obtained for all variables after first-differencing them, however, not entirely. Neither seasonal differencing has transformed them to be stationary. Nevertheless, as Lütkepohl (2005) suggests, the stability of VAR implies stationarity. Therefore, it is more convenient to satisfy the stability condition as a whole. The results about the stability of each model are discussed in the Chapter 6 within their individual results.

Chapter 5

Methodology

This chapter aims to provide a methodological background for the model used for the empirical analysis. Firstly, a structural vector autoregressive model is introduced as the main model for the estimation. It is followed by the methodology of impulse response functions variance and forecast error variance decomposition.

5.1 Vector Autoregressive Model

VAR models have started to be increasingly popular in recent years. It is a very suitable tool to observe the response of macroeconomic variables to various exogenous shocks in the economy. Therefore, it provides a beneficial and credible way to analyze the impact of policy-making and consequent behavior of the economy, describing and summarizing data, forecasting, and structural inference. The main problem of observing the relationship between macroeconomic variables and the reaction of the behaviour of the economy is endogeneity as there is no clear direction of influence of the variables. VAR model is a convenient solution for this issue as one can include as many endogenous variables as necessary, resulting in the corresponding number of equations.

A VAR model consists of n-variables, which are explained by its own lagged values (of p-th order) and moreover by the current and past values of remaining (n-1) variables (of p-th order). Such model results into consisting n-equations.

All variables enter the model in the same way, and all are treated as endogenous. Nevertheless, it can also include some exogenous variables.

The most straightforward kind of VAR consists of two variables interacting with each other, a so-called bivariate vector autoregressive model. Their current values are affected by current and p-th lagged values. When choosing $p = 1$, it results in VAR of first-order - VAR(1):

$$\begin{aligned} y_t &= b_{10} + b_{12} z_t + \gamma_{11} y_{t-1} + \gamma_{12} z_{t-1} + \epsilon_{yt} \\ z_t &= b_{20} + b_{21} y_t + \gamma_{21} y_{t-1} + \gamma_{22} z_{t-1} + \epsilon_{zt} \end{aligned} \tag{5.1}$$

$$E(\epsilon\epsilon') = \sum\nolimits_{\epsilon} = \begin{bmatrix} \sigma_y^2 & 0 \\ 0 & \sigma_z^2 \end{bmatrix} \tag{5.2}$$

where it holds that y_t and z_t have to be stationary time series, ϵ_{yt} and ϵ_{zt} are white noise disturbances, where $E(\epsilon_{it}) = 0$, and the variance-covariance matrix $E(\epsilon_{yt}, \epsilon_{zt})$ is also equal to zero. Variances of ϵ_{yt} and ϵ_{zt} are σ_y^2 and σ_z^2, respectively. In the structural form of VAR model, there are variables correlated with error terms. Therefore, it is used to sort out contemporaneous links among the various variables.

The model can be written in matrix forms in following way:

$$\begin{aligned} y_t - b_{12} z_t &= b_{10} + \gamma_{11} y_{t-1} + \gamma_{12} z_{t-1} + \epsilon_{yt} \\ z_t - b_{21} y_t &= b_{20} + \gamma_{21} y_{t-1} + \gamma_{22} z_{t-1} + \epsilon_{zt} \end{aligned} \tag{5.3}$$

$$\begin{bmatrix} 1 & -b_{12} \\ -b_{21} & 1 \end{bmatrix} \begin{bmatrix} y_t \\ z_t \end{bmatrix} = \begin{bmatrix} b_{10} \\ b_{20} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix} \begin{bmatrix} y_{t-1} \\ z_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{yt} \\ \epsilon_{zt} \end{bmatrix} \tag{5.4}$$

or simply

$$BX_t = \Gamma_0 + \Gamma_1 X_{t-1} + \epsilon_t$$

where

$$B = \begin{bmatrix} 1 & -b_{12} \\ -b_{21} & 1 \end{bmatrix}, X_t = \begin{bmatrix} y_t \\ z_t \end{bmatrix}, \Gamma_0 = \begin{bmatrix} b_{10} \\ b_{20} \end{bmatrix}, \Gamma_1 = \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix}, \epsilon_t = \begin{bmatrix} \epsilon_{yt} \\ \epsilon_{zt} \end{bmatrix}$$

By multiplying the structural form with B^{-1}, a reduced form of VAR is obtained.

$$X_t = A_0 + A_1 X_{t-1} + e_t \tag{5.5}$$

where $A_0 = B^{-1}\Gamma_0, A_1 = B^{-1}\Gamma_1, e_t = B^{-1}\epsilon_t$. The reduced form VAR considers each variable as a linear function of its own past values and past values of all other variables, and a serially uncorrelated error term. It is employed when analyzing causality and forecasting. Moreover, it can be easily estimated by OLS. It also has the lower number of parameters than structural form, which is therefore considered as not identified.

As can be seen from the equation 5.5, $e_t = B^{-1}\epsilon_t$, which means that residuals are represented by the linear combination of structural residuals.

$$e_t = B^{-1}\epsilon_t = \frac{1}{1 - b_{12}b_{21}} \begin{pmatrix} 1 & b_{12} \\ b_{21} & 1 \end{pmatrix} \begin{pmatrix} \epsilon_{yt} \\ \epsilon_{zt} \end{pmatrix} \tag{5.6}$$

$$e_{1t} = \frac{\epsilon_{yt} + b_{12}\epsilon_{zt}}{1 - b_{12}b_{21}}$$

$$e_{2t} = \frac{\epsilon_{zt} + b_{21}\epsilon_{yt}}{1 - b_{12}b_{21}}$$

If $b_{12} = 0$, then $e_{1t} = \epsilon_{yt}$, $e_{2t} = \epsilon_{zt} + b_{21}\epsilon_{yt}$.

This leads to the case when the variable ordered first has contemporary effect only on its own, but other variables contain contemporary feedback. This scheme is known as a recursive VAR, which tries to identify the structure of the model by constructing the error term in each regression, which would be uncorrelated with the error term in preceding equations. Hence, OLS may be used to estimate each equation and get residuals that are uncorrelated across equations. To attain it, firstly, the reduced form is estimated and followed by a computation of the Cholesky decomposition of the variance-covariance matrix of the residuals.

Assuming that ϵ_{yt} and ϵ_{zt} are white-noise disturbances and their variance is independent from time, both e_{1t} and e_{2t} are supposed to have zero mean.

$$
\begin{aligned}
Var(e_{1t}) &= E\left[\left(\frac{\epsilon_{yt}+b_{12}\epsilon_{zt}}{1-b_{12}b_{21}}\right)^2\right] - \left[E\left(\frac{\epsilon_{yt}+b_{12}\epsilon_{zt}}{1-b_{12}b_{21}}\right)\right]^2 \\
&= \frac{E\left[\epsilon_{yt}^2+2b_{12}\epsilon_{yt}\epsilon_{zt}+b_{12}^2\epsilon_{zt}^2\right]}{(1-b_{12}b_{21})^2} = \frac{\sigma_y^2+2b_{12}\epsilon_{yt}\epsilon_{zt}+b_{12}^2\sigma_z^2}{(1-b_{12}b_{21})^2} \\
&= \frac{\sigma_y^2+b_{12}^2\sigma_z^2}{(1-b_{12}b_{21})^2}
\end{aligned}
$$

Furthermore, the autocorrelations of e_{1t} and e_{1t-i} are zero. The same applies to e_{2t} having zero mean, constant variance and zero autocorrelation. Nevertheless, error terms for reduced form of VAR, e_{1t} and e_{2t} are correlated with each other.

$$
\begin{aligned}
E(e_{1t}e_{2t}) &= E\left[\frac{(\epsilon_{yt}+b_{12}\epsilon_{zt})(\epsilon_{zt}+b_{21}\epsilon_{yt})}{(1-b_{12}b_{21})^2}\right] \\
&= \frac{b_{21}\sigma_y^2+b_{12}\sigma_z^2}{(1-b_{12}b_{21})}
\end{aligned}
\tag{5.7}
$$

As mentioned earlier, structural VAR is used to sort out the contemporaneous links between variables. It cannot be estimated by OLS, which requires the regressors to be uncorrelated with error terms. It also has more parameters than reduced form. Therefore, it requires the economic theory to set identifying assumptions which would particularly establish causal relationships between variables. Moreover, it is not restricted only to the contemporaneous effect of shocks.

Cholesky decomposition is the most common method to identify a structural system. It imposes restrictions on a contemporaneous effect of one variable on the other one. While having n variables, it is necessary to specify $(n^2-n)/2$ restrictions to identify the system. Naturally, they need to correspond to the set-up of the economic model.

In case of b_{12}, there is a contemporaneous effect of y_t on z_t, but to get the effect the other way around, it happens only with one period lag.

It can be derived in following way:

$$
\begin{bmatrix} 1 & 0 \\ -b_{21} & 1 \end{bmatrix} \begin{bmatrix} y_t \\ z_t \end{bmatrix} = \begin{bmatrix} b_{10} \\ b_{20} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix} \begin{bmatrix} y_{t-1} \\ z_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{yt} \\ \epsilon_{zt} \end{bmatrix}
$$

B^{-1} is given by:

$$B^{-1} = \frac{1}{1 - b_{12}b_{21}} \begin{pmatrix} 1 & b_{12} \\ b_{21} & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ b_{21} & 1 \end{pmatrix}$$

Premultiplying structure system:

$$\begin{bmatrix} y_t \\ z_t \end{bmatrix} = \begin{bmatrix} b_{10} \\ b_{10}b_{21} + b_{20} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ b_{21}\gamma_{11} + \gamma_{21} & b_{21}\gamma_{12} + \gamma_{22} \end{bmatrix} \begin{bmatrix} y_{t-1} \\ z_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{yt} \\ \epsilon_{yt} + \epsilon_{zt} \end{bmatrix}$$

Rewriting the equation 5.5 gives:

$$y_t = a_{10} + a_{11}y_{t-1} + a_{12}z_{t-1} + e_{1t}$$
$$z_t = a_{20} + a_{21}y_{t-1} + a_{22}z_{t-1} + e_{2t}$$

OLS can be used to estimate the system's parameters and consequently transformed to structural parameters. For that, following equations need to be solved.

$$a_{10} = b_{10}$$
$$a_{11} = \gamma_{11}$$
$$a_{12} = \gamma_{12}$$
$$a_{20} = b_{10}b_{21} + b_{20}$$
$$a_{21} = b_{21}\gamma_{11} + \gamma_{21}a_{22} \quad = b_{21}\gamma_{12} + \gamma_{22}$$

Moreover,

$$\begin{aligned} Var(e_1) &= Var(\epsilon_{yt}) = \sigma_y^2 \\ Var(e_2) &= Var(b_{21}\epsilon_{yt} + \epsilon_{zt}) = b_{21}^2\epsilon_{yt}^2 + 2b_{21}\epsilon_{zt}\epsilon_{yt} + \epsilon_{zt}^2 = b_{21}\epsilon_{yt}^{2} + \epsilon_{zt}^2 \\ &= b_{21}\sigma_y^2 + \sigma_z^2 \\ Cov(e_1, e_2) &= b_{21}\sigma_y^2 \end{aligned}$$

Equations mentioned above imply that there is an effect of both ϵ_{yt} and ϵ_{zt} on a current value of z_t, but only the shock ϵ_{yt} may affect current value of y_t.

5.2 Lag Length

The crucial step to construct and analyze impulse response functions is to determine the lag order of VAR model. The most common method is to estimate it through various lag length selection criteria with identical lag length for all variables and equations. It should be considered that with a selection of lag length, losing degrees of freedom is part of a process. For n variables and p lags, $n+pn^2$ parameters are to be estimated. Nevertheless, too small lag length leads to misspecification of the model (Liew 2004).

The first five lag order selection criteria to be calculated are:

1. Akaike Information Criterion:
   $AIC_p = -2T[ln(\hat{\sigma}_p^2)] + 2p$
2. Schwartz Information Criterion:
   $SIC_p = ln(\hat{\sigma}_p^2) + [p * ln(T)]/T$
3. Hannan-Quinn Criterion:
   $HQC_p = ln(\hat{\sigma}_p^2) + 2T^{-1}p * ln[ln(T)]$
4. The Final Prediction Error:
   $FPE_p = \hat{\sigma_p^2}(T-p)^{-1}(T+p)$
5. Bayesian Information Criterion:
   $BIC_p = (T-p)ln[(T-p)^{-1}T\sigma_p^2] + T[1 + ln(\sqrt{2\pi})]$
   $p * ln[p^{-1}(\sum_{t=1}^{T} y_t^2 - T\hat{\sigma_p}^2)]$

with $\hat{\sigma}_p^2 = (T-p-1)^{-1}\sum_{i=p}^{T}\hat{\epsilon}_t^2$, $\hat{\epsilon}_t^2$ are the model's residuals and T is the number of observations.

It is cumbersome to decide which criterion should be chosen as none of them is found to consistently perform better than the rest in all cases. Liew (2004) has observed HQC to perform substantially better in case the sample size is larger or equal to 120. AIC and FPE operate better for a small sample size of not more than 60 observations.

Ivanov & Kilian (2005) also find HQC the most accurate criterion except sample sizes of less than 120 observations where SIC is more accurate.

Apart from the test based on information criteria, there is likelihood ratio test for cross-equations defined as:

$$LR = (T - c)(ln|\sum_r| - ln|\sum_u|)$$

where c is the number of parameters in each equation of the unrestricted system, and $\sum_r$, $\sum_u$ are variance/covariance matrices of residuals of the restricted and the unrestricted model, respectively.

This test requires normally distributed errors based on asymptotic theory. Hence, it is typically not very useful for small samples of time series (Sims 1980).

5.3 Impulse Response Functions

The VAR methodology offers the useful instrument to analyze the interactions between the variables of the system - impulse response functions. IRFs are used to track the response of current and future values of system's variables to impulses of the system's shocks. More precisely, impulses of the system's shocks deployed as a one-unit increase in the current value of one of the VAR errors, where it is assumed that this error returns to zero in the subsequent period and all other errors are kept equal to zero. Essentially, this idea purports when the errors are uncorrelated across equations, and thus, impulse responses are commonly used in case of recursive and structural VARs.

To track out the response of time series to various shocks, vector moving average is employed. VAR model with two variables presented in VAR section can be rewritten in a reduced form as a moving average representation in terms of the $\{\epsilon_{yt}\}$ and $\{\epsilon_{zt}\}$.

$$\begin{bmatrix} y_t \\ z_t \end{bmatrix} = \begin{bmatrix} \bar{y}_t \\ \bar{z}_t \end{bmatrix} + \sum_{i=0}^{\infty} \begin{bmatrix} \phi_{11}(i) & \phi_{12}(i) \\ \phi_{21}(i) & \phi_{22}(i) \end{bmatrix} \begin{bmatrix} \epsilon_{y_{t-1}} \\ \epsilon_{z_{t-1}} \end{bmatrix} \tag{5.8}$$

Coefficients ϕ_i are called dynamic multipliers and reveal the required interaction between y_t and z_t. $\phi_{11}(i)$, $\phi_{12}(i)$, $\phi_{21}(i)$, and $\phi_{22}(i)$ represent the effects of unit shocks in the variables of the system within i periods and are called impulse response functions. By the summation of relevant coefficients of IRFs, it is possible to get particular accumulated effects. Furthermore, to visualize the response of one variable to a unit shock (forecast error) in another variable, impulse response functions - coefficients of $\phi_{jk}(i)$ against i are plotted graphically to perceive the dynamic relationships within the system.

To compute IRFs for structural form vector autoregression model, matrix B from equation 5.4, containing the immediate relations between left-hand-side variables must be invertible. Nevertheless, the system is still not identified. As mentioned earlier, it is again necessary to impose additional restrictions as through Cholesky decomposition. That makes the system identified.

Incidentally, impulse response functions contain error because of being constructed using estimated coefficients. Hence, confidence intervals are produced to allow for the sampling uncertainty in the estimation results. Moreover, IRFs depend on the variable ordering as well as any results from VAR. That is caused by the decomposition leading to an asymmetry of the system in errors e_{1t} and e_{2t}.

5.4 Forecast Error Variance Decomposition

Apart from impulse response functions, VAR model estimates can be interpreted by constructing variance decomposition. It examines the properties of the forecast error, where the variance decomposition reveals the proportion of the movement in the dependent variables caused by their own shocks as compared to shocks to the other variables-the relative share of variance each structural shock contributes to the total variance of each variable.

The construction involves a determination of how much of steps ahead forecast error variance for each variable is explained by shocks to each explanatory variable, as stated in (Hermannová 2012, p.47).

Presumably, the same requirement of identification is needed as in case of IRFs as the ordering of variables matters.

Chapter 6

Empirical Results

In this second part of the thesis, the structural vector autoregressive model explained in the previous chapter is employed to estimate the transmission of interest rate and response of the asset prices, stock and house prices, respectively to its changes. It is applied to the Euro Area, the United Kingdom, and the United States, in each separately, to check the first and the second hypothesis. Firstly, the baseline model analysis with shadow rates computed by Wu & Xia (2016) is introduced. Then, the second section comprises different specifications of this model along with the change of the shadow rate - computed by Krippner (2013) to check for robustness of the model and verify the third hypothesis.

6.1 Baseline Model

A structural VAR model with an exogenous variable - SVARX is used as a baseline model of the analysis. The following reduced form model is considered:

$$Y_t = A_0 + A_1 Y_{t-1} + ... + A_p Y_{t-p} + C_0 X_t + C_1 X_{t-1} + ... + C_q X_{t-q} + e_t \quad (6.1)$$

where Y_t is a K-dimensional vector of endogenous variables and X_t is M-dimensional vector of exogenous variables, A is a vector of intercepts, A_i and C_i are $(K \times K)$ and $(M \times M)$ coefficient matrices, and e_t is a K-dimensional vector of errors (Lütkepohl 2005, p. 387). In case of the error term e_t being white noise, a model of this type is often called dynamic simultaneous equations model (SEM) in the econometrics literature.

The structural form of the model looks as following:

$$A \cdot Y_t = A_0^* + A_1^* Y_{t-1} + ... + A_p^* Y_{t-p} + C_0^* X_t + C_1^* X_{t-1} + ... + C_q^* X_{t-q} + B \cdot \epsilon_t \quad (6.2)$$

where A is $(K \times K)$ and represents the contemporaneous relations between the endogenous variables, A_i^* and C_i^* are structural coefficients equal to $A_i = A^{-1}A_i^*$ and $C_i = A^{-1}C_i^*$. They differ from their reduced-form counterparts if $A \neq I$. The reduced form residuals can be retrieved from structural VAR model by $e_t = A^{-1}B\epsilon_t$ Pfaff (2008).

The choice of using the model is closely motivated by Primiceri (2005), Morgese Borys *et al.* (2009), and Gali & Gambetti (2013). To identify original shocks from the reduced model, the application of Cholesky decomposition is proposed. The choice of the variables and their ordering is motivated again by Gali & Gambetti (2013) and furthermore, by Bordo & Landon-Lane (2013). In the baseline model, the set of endogenous variables consists of 4 main ones in the following order: GDP per capita, HICP, the shadow rates computed by Wu & Xia (2016), and share prices, and later house prices. For simplicity, they are both together called asset prices. The set of exogenous variables comprises only Bloomberg Commodity Index. Moreover, all of these data are transformed into year-to-year differences except shadow rate being kept in levels.

Precisely, the A-model similar to Christiano *et al.* (1998) specifies the structural model. It imposes a recursiveness assumption placing the following zero restrictions on A:

$$\text{A}=\begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix}, \text{B}=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

According to this assumption, monetary policy shocks are orthogonal to the information set of the monetary authority. Consequently, it allows identifying the dynamic response of variables under observation to a monetary policy shock.

Apart from other things, these identifying assumptions, imply that individual central bank does not respond contemporaneously to share and house price innovations. Furthermore, the specific ordering of the variables presumes that monetary policy reacts contemporaneously to shocks in economic activity and price level, while the opposite does not hold. On the contrary, both of the asset prices may react immediately to shocks in economic activity and price level, as well as to monetary policy shocks.

The lag length is selected based on information criteria described in the Chapter 5. HQIC and SBIC suggest the lag length 3 or 4 in different specifications of the model. AIC and FPE propose the lag length 9 or 10. As Ivanov & Kilian (2005) recommend for sample sizes smaller than 120, SBIC tends to be more accurate and, for the model to stay parsimonious, the lag length of 4 is chosen for the Euro Area and the United Kingdom, and the lag length of 3 is chosen for the United States.

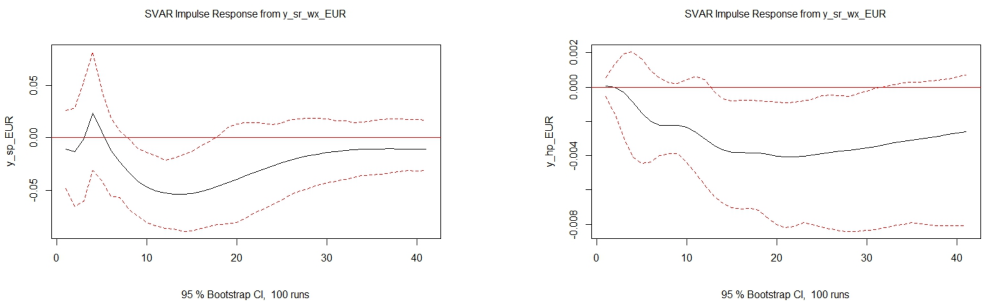
The results presented in the Appendix A shows that the VAR model is stable overall. Apparently, from the Figures A.1-A.6, the parameter stability cannot be rejected by OLS-CUSUM test computing the empirical fluctuation process. Visual inspection of ACF and PACF function shows no significant systematic pattern in residuals and Engel's ARCH test for residual heteroscedasticity shows no ARCH effects. Finally, the Tables A.1-A.3 provides the eigenvalues of the companion form, which are all less than one.

As the interest rate transmission effect on the asset prices is of the primary interest, only impulse response from shadow rates to asset prices are reported graphically. Figure 6.1 presents the results of a contractionary monetary policy shock on share and house prices for the Euro Area - precisely, the impulse response function for a three-year period ahead and associated 95% confidence interval, which was bootstrapped using 100 replications. The estimation is repeated for each sample to obtain non-structural impulse responses. Afterwards, they are identified by imposing the aforementioned identifying assumptions.

The IRF can be interpreted in the following way: one unit shock to interest rate (units are in %) leads to x-unit response of the annual growth rate of the asset price.[1]

[1] To be precise, it is the approximation constructed by taking the difference of logarithms of the asset prices and their lagged values with lag equal to 12.

Figure 6.1: Response of Asset Prices to a 100-bp Increase in the ECB Shadow Policy Rate

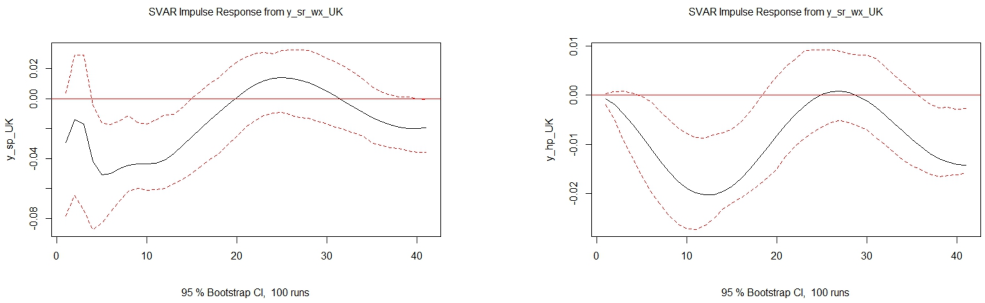


STOCK PRICES HOUSE PRICES

Source: Author's calculations

Considering the effects in the Euro Area, the unexpected increase in the shadow policy rate leads to a 0.05% decrease in the annual growth rate of share prices within about 15 periods. In case of house prices, the effect seems smaller. The increase of 100-bp in the ECB shadow rate results in 0.004% decrease in the annual growth rate of house prices. The policy horizon is also slightly longer. The responses of other variables are presented in the Appendix A. The stock price results are consistent in direction and the duration of reaching the peak effect with those by, e.g., Alessi & Kerssenfischer (2016) or Bordo & Landon-Lane (2013). Nevertheless, in case of the house prices, the results are obtained by former study shows a mere reaction to contractionary monetary shock while considering the structural VAR model, but similar in case of SFM. On the other hand, they are consistent with Huber & Punzi (2016), concluding that increase in the ECB shadow rate generates, along with other effects, a decrease in housing prices.

Figure 6.2: Response of Asset Prices to a 100-bp Increase in the BoE Shadow Policy Rate



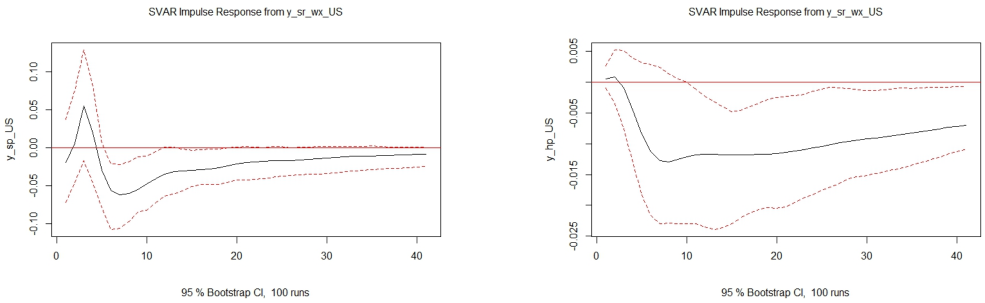
STOCK PRICES HOUSE PRICES

Source: Author's calculations

The results of a contractionary monetary policy on share and house prices for the United Kingdom are presented in Figure 6.2. The unexpected increase in the BoE shadow policy rate leads to the similar results as in case of the Euro Area - leading to decrease of almost -0.06%, while reaching the peak effect much quicker. After about 15 periods, it disappears as the impulse response converges to zero, showing even the slight increase, which is however not statistically significant from zero. Regarding the house prices in the UK, monetary policy tightening leads to 0.02% decrease with reaching the peak after $12-15$ periods. The effect converges to zero in about 25 periods and then decreasing again. That shows the less persistent response in case of the UK as compared to the Euro Area. Huber & Punzi (2016) explain this fact by the implementation of forward guidance policies[2] by ECB with different time periods relative to the UK and the US. Besides, the weaker response in the Euro Area might be explained by the lower integration of individual member states in the EA. These results are again consistent with their ones, showing that the overall magnitudes are higher in case of the UK, particularly in house market, while both being less persistent.

[2] *"If a central bank gives forward guidance, it means it is providing information about its future monetary policy intentions, based on its assessment of the outlook for price stability."* ECB (2017)

Figure 6.3: Response of Asset Prices to a 100-bp Increase in the FED Shadow Policy Rate



STOCK PRICES HOUSE PRICES

Source: Author's calculations

Last but not least, Figure 6.3 shows the effects of monetary policy tightening in the United States. One unit shock to the FED shadow rate leads firstly to an increase of 0.06% in the annual growth rate of share prices, which is however statistically insignificant. Consequently, after about 10 periods, it decreases to 0.07% being statistically significant and converging to zero after about 30 periods. The results for house market show almost immediate decrease reaching its peak of -0.0125 on a monetary policy horizon. Moreover, the response is more persistent than in case of share prices, showing the longer duration of the effect.

Again, the results are consistent with economic intuition. Regarding the asset prices, Gali & Gambetti (2013) and Rigobon & Sack (2002) show similar results for the US, including S&P index and the Nasdaq index in their study. To be more precise, in these studies, the same results are obtained under alternative specification with imposing a contemporaneous interest rate response to stock prices. Nevertheless, this assumption is not included in the model of this thesis and might be a subject of questioning its relevance according to Furlanetto (2008).

In case of house prices, Del Negro & Otrok (2007) obtain similar results regarding the direction of the results, showing the significant and persistent drop in the housing prices after the contractionary monetary policy shock. Nevertheless, they show that the impact has been non-negligible, but fairly small relative to the size of the housing price increase prior to the financial crisis in 2007.

The results for the variance decomposition of asset prices for the Euro Area are presented in Table 6.1. It shows that the variation in the share prices is explained mainly by its own shock, followed by GDP per capita, the ECB shadow policy rate, and the least by HICP. In the initial period, the variation in the share prices explained on its own is 97%. That declines to 87% while being ten periods ahead, while the explanatory power of other variables ranges from 3% to 5%. Until 20 periods ahead, the share prices explain about 56.8% of its own variation, which is followed by GDP per capita of 23.1% and the shadow rate explaining 14.5%. HICP explains about 5.5%.

Considering the house prices in the Euro Area, almost identical results are obtained while observing the explanatory power of the house prices on their own of 97.3%, followed by the shadow policy rate, HICP and lastly by GDP per capita. Over ten periods horizon, house prices explain its own variation with 81.1% and the shadow rate explains 10.5%. Eventually, the results of 20 periods ahead signify that 20.7% is explained by the shadow rate, 9.5% is explained by HICP and 4.1% by GDP per capita.

Table 6.1: Variance Decomposition for the EA

Period	**Variance Decomposition of Share Prices**				**Variance Decomposition of House Prices**			
	GDP	**HICP**	**SR**	**SP**	**GDP**	**HICP**	**SR**	**HP**
1	0.0000	0.0266	0.0031	0.9703	0.0059	0.0207	0.0002	0.9732
2	0.0094	0.0140	0.0038	0.9728	0.0021	0.0195	0.0032	0.9752
3	0.0271	0.0158	0.0031	0.9539	0.0007	0.0226	0.0081	0.9687
4	0.0355	0.0201	0.0085	0.9359	0.0022	0.0267	0.0180	0.9532
5	0.0398	0.0230	0.0081	0.9291	0.0042	0.0317	0.0330	0.9310
6	0.0409	0.0268	0.0089	0.9235	0.0044	0.0377	0.0517	0.9062
7	0.0395	0.0308	0.0128	0.9170	0.0040	0.0446	0.0704	0.8810
8	0.0383	0.0317	0.0212	0.9088	0.0066	0.052	0.0859	0.8548
9	0.0410	0.0310	0.0337	0.8944	0.0101	0.062	0.0970	0.8303
10	0.0518	0.0296	0.0484	0.8702	0.0102	0.0736	0.1051	0.8111
11	0.0723	0.0282	0.0639	0.8357	0.0089	0.0833	0.1124	0.7953
12	0.0996	0.0274	0.0786	0.7944	0.0110	0.0900	0.1213	0.7777
13	0.1287	0.0277	0.0919	0.7517	0.0163	0.0937	0.1326	0.7573
14	0.1555	0.0294	0.1036	0.7114	0.0217	0.0955	0.1458	0.7370
15	0.1781	0.0323	0.1139	0.6756	0.0251	0.0964	0.1593	0.7192
16	0.1962	0.0361	0.1227	0.6450	0.0270	0.0970	0.1718	0.7042
17	0.210	0.0405	0.1300	0.6193	0.0287	0.0972	0.1825	0.6916
18	0.2204	0.0452	0.1361	0.5983	0.0312	0.0970	0.1915	0.6803
19	0.2273	0.0502	0.1411	0.5814	0.0355	0.0961	0.1994	0.6691
20	0.2314	0.0552	0.1452	0.5683	0.0412	0.0946	0.2067	0.6575

Source: Author's calculations

The results of the variance decomposition of asset prices for the United Kingdom are presented in Table 6.2. The variance decomposition of the share prices shows the share prices are again primarily explained by its own shock followed by the BoE shadow policy rate and decidedly less by HICP and GDP per capita. In the initial period, share prices 94% explain its variation, the explanatory power declines to 71.7% by 10 periods ahead of time horizon followed by 16.7% of the shadow rate and 8.6% and 3% of HICP and GDP per capita. By 20 periods ahead of time horizon, the share prices explain only 58.9% of its variance, while almost one fifth is explained by the shadow rate.

Similarly, in case of house prices, in the initial period, 95.7% and 4.3% is explained by their own variation and the shadow policy rate, respectively. The former one declines to 68.5% and the shadow rate increases to 27.7% until 10 periods ahead of time horizon. It reaches 37.7% when explaining the variation in house prices, while they explain 36% on their own, 13.8% is explained by GDP per capita and 12.5% by HICP.

Table 6.2: Variance Decomposition for the UK

Period	**Variance Decomposition of Share Prices**				**Variance Decomposition of House Prices**			
	GDP	**HICP**	**SR**	**SP**	**GDP**	**HICP**	**SR**	**HP**
1	0.0002	0.0345	0.0255	0.9398	0.0003	0.0001	0.0427	0.9569
2	0.0006	0.0408	0.0191	0.9395	0.0009	0.0034	0.0469	0.9488
3	0.0011	0.0772	0.0203	0.9015	0.0014	0.0129	0.0595	0.9262
4	0.0073	0.0816	0.0421	0.8691	0.0006	0.0276	0.0739	0.8979
5	0.0136	0.0780	0.0717	0.8368	0.0016	0.0404	0.0933	0.8648
6	0.0137	0.0782	0.0974	0.8107	0.0053	0.0465	0.1197	0.8285
7	0.0140	0.0824	0.1181	0.7855	0.0095	0.0455	0.1533	0.7917
8	0.0178	0.0857	0.1356	0.7609	0.0113	0.0399	0.1927	0.7562
9	0.0236	0.0863	0.1517	0.7383	0.0103	0.0336	0.2349	0.7212
10	0.0304	0.0856	0.1670	0.7170	0.0089	0.0293	0.2768	0.6850
11	0.0389	0.0844	0.1807	0.6959	0.0096	0.0284	0.3155	0.6466
12	0.0509	0.0833	0.1914	0.6744	0.0135	0.0311	0.3492	0.6062
13	0.0672	0.0822	0.1979	0.6527	0.0211	0.0376	0.3765	0.5649
14	0.0868	0.0810	0.2005	0.6317	0.0324	0.0475	0.3960	0.5242
15	0.1068	0.0798	0.2003	0.6132	0.0474	0.0602	0.4068	0.4856
16	0.1246	0.0787	0.1987	0.5981	0.0656	0.0746	0.4093	0.4505
17	0.1389	0.0779	0.1966	0.5866	0.0856	0.0892	0.4054	0.4199
18	0.1496	0.0775	0.1945	0.5784	0.1053	0.1028	0.3973	0.3945
19	0.1574	0.0774	0.1927	0.5726	0.1231	0.1150	0.3874	0.3745
20	0.1625	0.0775	0.1914	0.5686	0.1378	0.1254	0.3774	0.3595

Source: Author's calculations

Last, but not least, for the United States, the results of the variance decomposition of asset prices can be seen in Table 6.3. The variance decomposition of the share prices is again explained by its own shock followed by HICP, GDP per capita and least is explained by the FED shadow policy rate. In the initial period, share prices almost 100% explain its variation. By 10 periods ahead, it declines quickly to 52.5%, followed by HICP with the explanatory power of 24.5% of the variation and GDP per capita of 13.1%, while the shadow rate explains only about 10%. By 20 periods ahead, it increases by about 2.5%.

Considering the house prices, the results suggest the explanatory power of the shadow rate is even smaller. In the beginning, 96.9% is explained by its own shock followed by GDP per capita explaining 2.7%. The explanatory power of the house prices on itself continues to decline while other variables gain more explanatory power, particularly GDP per capita explaining 23.6% and HICP with 14.2% by 10 periods ahead. The shadow rate explains about 6.8%. Similarly to the share prices, it increases to 11% while being 20 periods ahead.

Table 6.3: Variance Decomposition for the US

Period	Variance Decomposition of Share Prices				Variance Decomposition of House Prices			
	GDP	**HICP**	**SR**	**SP**	**GDP**	**HICP**	**SR**	**HP**
1	0.0017	0.0000	0.0060	0.9923	0.0272	0.0004	0.0037	0.9687
2	0.0033	0.1148	0.0037	0.8782	0.0386	0.0030	0.0021	0.9564
3	0.0178	0.1639	0.0283	0.7899	0.0615	0.0124	0.0027	0.9235
4	0.0469	0.1938	0.0280	0.7313	0.0937	0.0322	0.0141	0.8599
5	0.0692	0.2135	0.0314	0.6859	0.1301	0.0597	0.0299	0.7803
6	0.0724	0.2295	0.0479	0.6502	0.1647	0.0877	0.0434	0.7041
7	0.0678	0.2432	0.0669	0.6221	0.1935	0.1108	0.0528	0.6429
8	0.0746	0.2506	0.0825	0.5923	0.2147	0.1270	0.0589	0.5994
9	0.0995	0.2502	0.0927	0.5576	0.2284	0.1370	0.0635	0.5711
10	0.1312	0.2454	0.0983	0.5251	0.2359	0.1425	0.0676	0.5540
11	0.1553	0.2409	0.1013	0.5025	0.2389	0.1451	0.0720	0.5441
12	0.1662	0.2387	0.1039	0.4912	0.2393	0.1458	0.0766	0.5383
13	0.1678	0.2386	0.1068	0.4868	0.2387	0.1454	0.0814	0.5345
14	0.1665	0.2395	0.1099	0.4841	0.2379	0.1441	0.0863	0.5317
15	0.1660	0.2401	0.1130	0.4809	0.2377	0.1421	0.0910	0.5292
16	0.1664	0.2404	0.1158	0.4775	0.2382	0.1396	0.0954	0.5268
17	0.1663	0.2405	0.1183	0.4749	0.2395	0.1366	0.0994	0.5245
18	0.1655	0.2406	0.1205	0.4734	0.2411	0.1335	0.1032	0.5223
19	0.1648	0.2406	0.1224	0.4722	0.2426	0.1304	0.1067	0.5203
20	0.1648	0.2406	0.1238	0.4708	0.2436	0.1276	0.1101	0.5187

Source: Author's calculations

To sum it up, the findings for the US seem to be more pronounced as compared to the EA and the UK. Subsequently, the EA results seem to be more persistent, which was explained earlier. That is consistent with both studies of Musso *et al.* (2010) and Huber & Punzi (2016) who find an impact of contractionary monetary policy significantly in the US than in the UK and the EA. Nevertheless, their results suggest that the transmission of monetary policy shocks to the housing market is stronger regarding the size of the effect in the US, while the results from the baseline model regarding the house prices show the highest decrease for the UK.

Hence, the first hypothesis stating that expansionary monetary policy has a positive impact on asset prices cannot be rejected. That can be clearly seen in all the models estimated in this chapter. The persistence of the effects however slightly differs across different specifications. Next, the second hypothesis of positive impact is observable in prices of various assets cannot be rejected either. Share and house prices show results of different magnitudes which also vary across different countries. Nevertheless, both of them show a negative response to monetary policy tightening. Thus, low interest rates employed during previous years have not affected only specific markets, but financial sector as a whole.

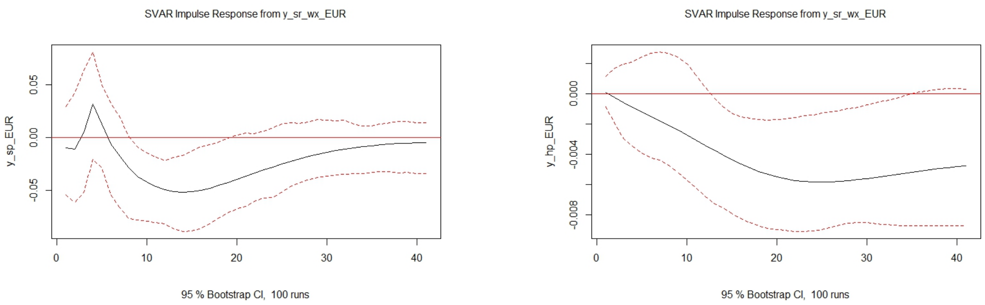
6.2 Different specifications and Robustness checks

Next, to the baseline model with all variables in year-to-year differences except the shadow policy rate, it is necessary to additionally estimate models with a different specification to check for the baseline model robustness. Firstly, the same structural VARX model as the base is estimated while new variable - uncertainty - is added among the endogenous variables, denoted by VARX-U model. It is followed by the estimation of the baseline model with all the variables in month-to-month differences except the shadow rate, denoted by VARX-M model. Finally, to check for the third hypothesis, the shadow rate in the baseline model computed by Wu & Xia (2016) is substituted by the shadow rate computed by Krippner (2013). This model is denoted as VARX-K model.

Figures 6.4-6.6 show the results of the estimation of VARX-U model. As can be clearly seen, all the responses of the asset prices to the unexpected shock in the shadow policy rate are basically the same. The responses of other variables are presented in Figures A.16-A.21, for which some of the responses slightly differ. Nevertheless, most of them accumulate to the same number.

To mention some differences, the response of house prices to the 100-bp increase in the ECB shadow policy rate seems even more substantial than in case of the baseline model reaching a decrease of 0.006% in the annual growth of house prices. In addition, the horizon of reaching the peak is also slightly longer, while the convergence to zero is rather sluggish.

Figure 6.4: Response of Asset Prices to a 100-bp Increase in the ECB Shadow Policy Rate - VARX-U model

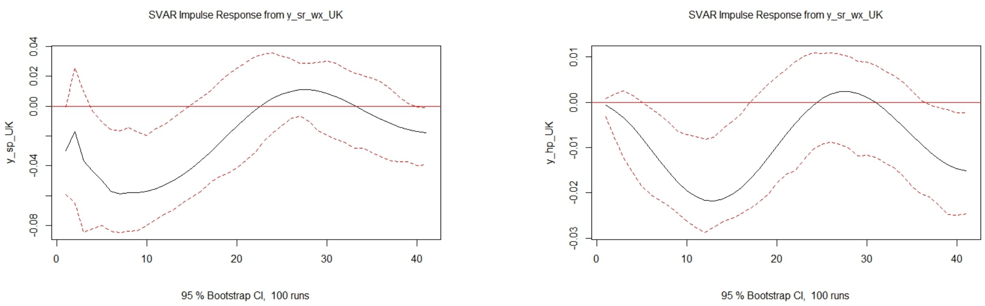


STOCK PRICES HOUSE PRICES

Source: Author's calculations

Unexpected shock in the BoE shadow policy rate again leads to a somewhat higher decrease in the share prices, which can be considered negligible as well as the difference in the house prices response.

Figure 6.5: Response of Asset Prices to a 100-bp Increase in the BoE Shadow Policy Rate - VARX-U model

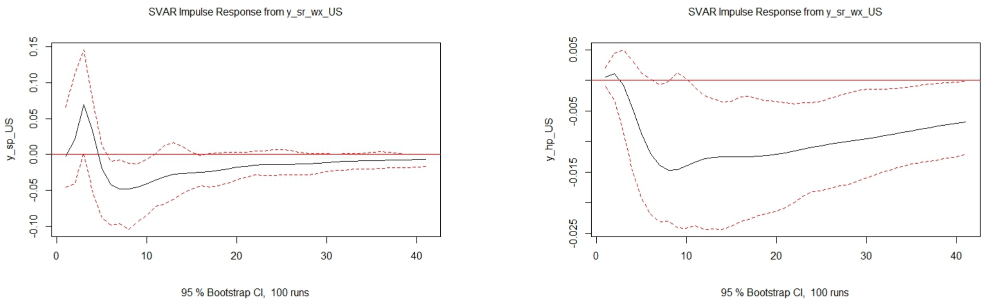


STOCK PRICES HOUSE PRICES

Source: Author's calculations

Regarding the response of share prices to increase in the FED shadow policy rate, the magnitude of change in the share prices seems smaller than in the baseline model reaching about 0.04% decrease in its annual growth rate. In opposite, a decrease in the shadow rate leads to 0.015% decrease in the house price signifying greater reaction as compared to the baseline model.

Figure 6.6: Response of Asset Prices to a 100-bp Increase in the FED Shadow Policy Rate - VARX-U model



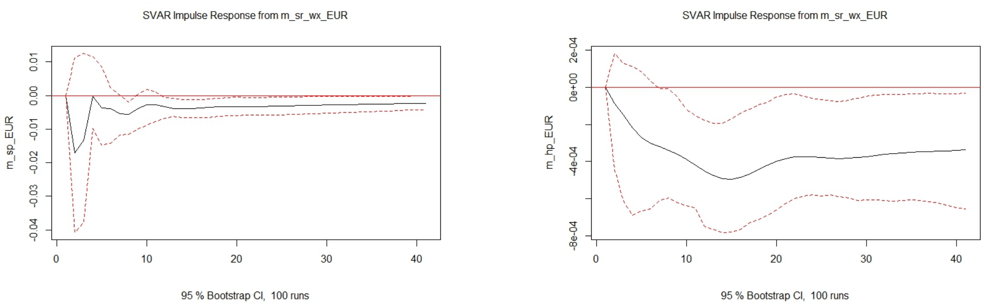
STOCK PRICES HOUSE PRICES

Source: Author's calculations

Interestingly, in all cases, unexpected shock in the shadow rate causes a slight decrease in uncertainty, although it subsequently recovers after few periods. These responses, however, do not seem very persuasive as they are not statistically significant from zero. Therefore, it may suggest there is no explanatory power of uncertainty in the cause of asset price fluctuations, and another specification of the baseline model should be employed.

Therefore, instead of year-to-year differences, monthly differences are employed into the baseline model. Resulting impulse response functions are presented in Figures 6.7-6.9. Regarding the effects in the Euro Area, an unexpected increase in the shadow policy rate leads to an almost immediate decrease of about 0.02

Figure 6.7: Response of Asset Prices to a 100-bp Increase in the ECB Shadow Policy Rate - VARX-M model

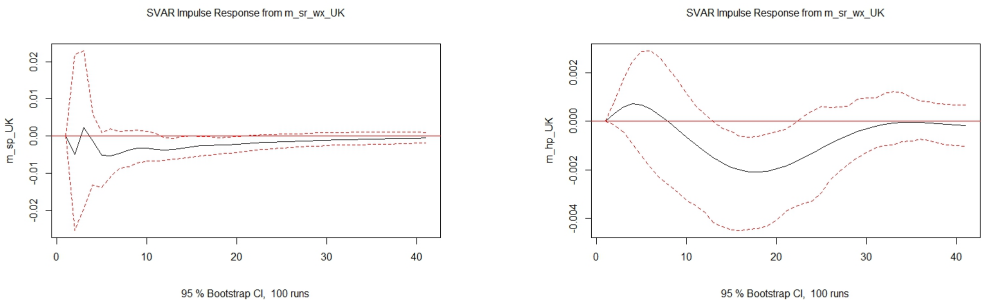


STOCK PRICES HOUSE PRICES

Source: Author's calculations

As far as BoE shadow policy rate is concerned, some fluctuations in share prices are apparent. Nevertheless, the magnitude is much smaller being statistically insignificant and the effects disappear after just a few periods. Regarding house prices, there is a slight increase after the unexpected shock in the shadow rate, followed by a decrease of more than 0.002%.

Figure 6.8: Response of Asset Prices to a 100-bp Increase in the BoE Shadow Policy Rate - VARX-M model

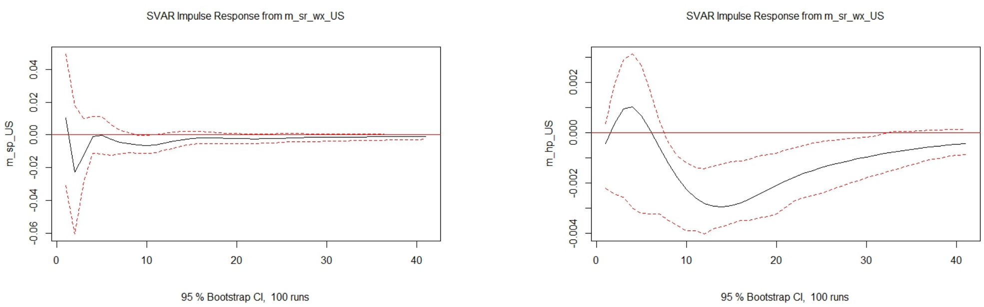


STOCK PRICES HOUSE PRICES

Source: Author's calculations

Finally, the increase in the FED shadow policy rate leads share prices to decrease by about 0.02%, but the effect is again less persistent, dissolving quickly. House prices response acts in accordance with the baseline model, with increase lasting for more extended time in the beginning, followed by decrease of 0.03%. Moreover, it converges to zero faster than in case of year-to-year differences.

Figure 6.9: Response of Asset Prices to a 100-bp Increase in the FED Shadow Policy Rate - VARX-M model



STOCK PRICES HOUSE PRICES

Source: Author's calculations

Overall, the usage of monthly growth rates brings similar results to the baseline model with annual growth rates considering particularly the direction of the responses. Nevertheless, duration of the effects significantly differs being much shorter in case of this model. Probably, it is caused by more stability in the baseline model using annual growth rates. Whereas with month-to-month differences, the volatility might be higher causing the effects to be less significant.

The shadow policy rates principally represent the monetary policy stance when the economy reaches the zero lower bound, and unconventional monetary policy measures are used by central banks. As Bauer & Rudebusch (2013) and Christensen & Rudebusch (2013) pointed out that different models can produce various estimations of the shadow rate, Wu & Xia (2016) confirm, that different models influence the level of the shadow rate. Thus, to remove the uncertainty of the results, it is inevitable to employ another shadow rate estimates and check the robustness of the baseline model outcomes. Correspondingly, in addition to Wu & Xia (2016) estimates, the shadow policy rates computed by Krippner (2013) are employed.

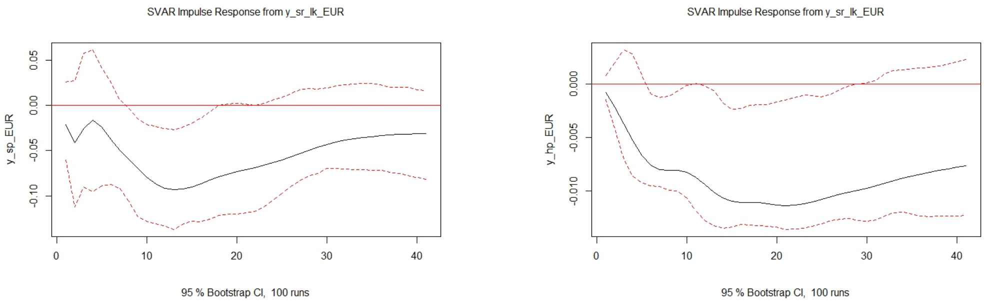
These estimates are based on option-pricing model[3] and apart from the US, the UK and the Euro Area, they are also available for Japan. Unlike the estimates provided by Wu & Xia (2016), they are computed only till October 2016. Moreover, Lombardi & Zhu (2014) also provide their estimates of the shadow rate applying dynamic factor model. Nevertheless, they are computed only for the United States, hence are omitted as they cannot be wholly employed to check for the robustness.

Figure 6.10 presents the responses of the asset prices to the ECB shadow policy rate computed by Krippner (2013). The response of the share prices is very similar in shape to the one of the baseline model. The magnitude still differs, reaching its peak of 0.09% decrease in the annual growth rate of the stock prices in the same horizon. That signifies almost double the effect of the baseline model.

Considering the response of house prices, the effect is even larger, reaching the decrease of 0.012% which is triple the magnitude from the baseline model.

[3]Further information can be found in Chapter 3.

Figure 6.10: Response of Asset Prices to a 100-bp Increase in the ECB Shadow Policy Rate - VARX-K model

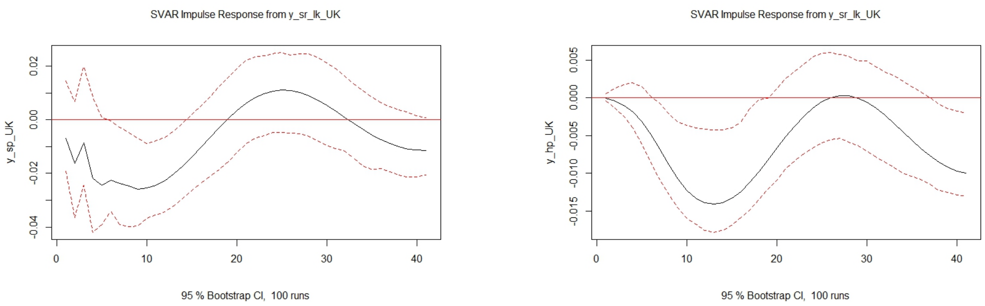


STOCK PRICES HOUSE PRICES

Source: Author's calculations

The responses of asset prices to an unexpected shock in the BoE shadow policy rate are presented in Figure 6.11. In case of the share prices, the shape of IRF is again very similar to one obtained from the baseline model, but the size of the effect is somewhat smaller, about -0.025%. Also, there is more noise in first few periods as compared to the baseline model with a decrease of 0.06%. Regarding the response of house prices, the conclusion is the same as in previous case - the shape of the response is the same while the size of the effect is of 0.014% decrease in the annual growth rate of house prices, which is the difference of about 0.006%.

Figure 6.11: Response of Asset Prices to a 100-bp Increase in the BoE Shadow Policy Rate - VARX-K model



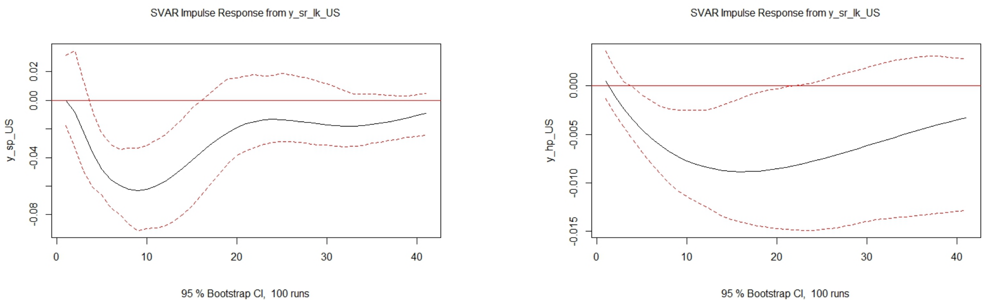
STOCK PRICES HOUSE PRICES

Source: Author's calculations

Last but not least, Figure 6.12 shows the responses of asset prices to the shock in the FED shadow policy rate. The size of the effect is in case of the share prices similar, but there is no increase in the annual growth rate in first few periods as compared to the baseline model. Moreover, the speed of convergence to zero is also rather moderate.

The response of house prices is subtle in the VARX-K model with the lower magnitude in comparison to the baseline model. The peak effect is reached in monetary policy horizon with 0.008% decrease in the annual growth rate of house prices and in addition, the response is smooth.

Figure 6.12: Response of Asset Prices to a 100-bp Increase in the FED Shadow Policy Rate - VARX-K model



STOCK PRICES HOUSE PRICES

Source: Author's calculations

In conclusion, the responses of the asset prices under both shadow policy estimates are in general very similar, despite some minor differences in the size of the effects. These results are in accordance with, e.g., Horváth & Hájek (2017) using different estimates of shadow rates to examine the robustness of the global VAR model to observe the international spillovers unconventional monetary policy of ECB and FED. The responses of other variables presented in Appendix A are also consistent with one another across the different models. Nevertheless, both of the models exhibit prize puzzle.

Sims (1992) explains this phenomenon by the reaction of monetary authority that might know about the upcoming inflationary pressures and use contractionary monetary policy to dampen potential effects. In that case, prices might rise, but by less than without monetary contraction. Consequently, he says that output might fall. The response of GDP per capita estimated in the baseline model (as well as from other models) is in accordance with his interpretation as it decreases as well.

Also, Balke & Emery (1994) provide an alternative explanation, where the monetary authority reacts to supply shocks by raising policy rates. Hence, it might lead to the rise in real interest rates, decreased real output, and increased prices. So, for instance, FED may respond to supply shock by raising federal funds rate, but it is not enough to eliminate the inflationary consequences of the supply shock. Furthermore, they suggest to include variables as a proxy for future inflation and supply shocks. The inclusion of commodity prices does not completely eliminate the price puzzle, which is also apparent from the baseline model. Nonetheless, the spread between ten-year and three-month Treasury rates eliminates the puzzle. Thus, there is a possible future extension of this model to correct the puzzle.

To sum up the size of the effects, both of the asset prices have displayed a more substantial decrease in the annual growth rate of prices considering the Euro Area and the shadow rates computed by Krippner (2013). In opposite, both the United Kingdom and the United States results suggest slightly smaller decrease using the aforementioned estimates of the shadow rates. By any means, given that these two of the shadow rate estimates vary considerably, this comparison provides evidence for robustness of the results.

As a consequence, to answer the third hypothesis if the choice of shadow rate matters for the estimated effect of monetary policy on asset prices, the results suggest that considering the direction of the effect, both estimates have provided very similar results. Nevertheless, the size of the effect might be distinctive while using different estimates of the shadow policy rate.

Chapter 7

Reaction of Monetary Authority

The quantitative analysis provided in the previous chapter shows the evidence of the relationship between low-interest rates and asset price fluctuations in all of the three areas considered. Consequently, it is vital to present a discussion over the response of monetary policy to these asset price changes. Therefore, to answer the fourth hypothesis, a considerable amount of literature is observed, comparing potential measure pre and post financial crisis in 2007, to sum up, potential views on this issue.

As Mishkin (2011) mentions, before the crisis in 2007, monetary policy was considered complete and well defined to fulfill its ultimate objective in terms of stabilizing inflation and economic activity to promote the public good. A monetary-policy framework known as inflation-targeting[1] was highly popular addressing the announcement of medium-term inflation targets as a credible commitment of central banks. That at the same time allows central banks to instantaneously react to the instability of the real economy in the short run. The answer of this approach to what extent should monetary policy react to asset prices is quite straightforward. Once their predictive content for inflation is accounted for, monetary policy should not react further to any fluctuations.

Bernanke & Gertler (2001), finding negligible additional gains from the monetary policy reaction to the level of asset price, run worst-case scenarios to analyze the performance of policy rules. They conduct stochastic simula-

[1] More precisely, the monetary policy strategy is referred to as " flexible inflation targeting" (Svensson 1995), because the communication strategy of central banks with public varied a lot across different countries.

tions of their model to evaluate the expected performance of alternative policy rules while including stock price "bubble" shocks, technology shock and their combination; they still conclude that central banks should not respond to asset prices.

Basically, the same model has been employed by Cecchetti *et al.* (2000). They argue that asset prices can contain relevant information about the evolution of central macroeconomic variables which might be lately revealed by conventional tools to forecast them. Conversely, their conclusion gives strong support to adjusting the policy instruments of central banks in response to its forecast of future asset prices, apart from inflation and output gap. Specifically, they emphasize the achievement of the superior performance of central banks when considering the adjustment to asset prices as well. Moreover, the complexity of identifying asset price misalignments should not be the reason to avoid them and that some asset prices play a significant role while measuring core inflation, particularly house prices, but not equity ones. Eventually, asset prices are essential for the transmission of inflationary impulses (Cecchetti *et al.* 2000, pg. 3).

Apart from other things, Bernanke & Gertler (2001) oppose that a too-aggressive response to stock prices can cause significant harm. Subsequently, these kinds of active debates lead to what is called *the "Lean" vs. "Clean" Debate*; alternatively, if monetary policy is characterized as leaning against the asset price bubbles or cleaning up the consequences of bubble bursts. Mishkin (2011) explains that in the former case, monetary policy is conducted by raising interest rates to slow a bubble's growth to prevent it or mitigate the damage aftermath its burst. The latter suggests not to react anyway and just clean up the damage.

Roubini (2006) presents the arguments in favor of the first one. Primarily, he suggests that optimal monetary policy is characterized by the considerable reaction to asset prices and exogenous asset bubbles. In addition, uncertainty about the existence of bubbles and its potential to have damaging effects are not persuasive arguments to ignore them. He adds that it is not necessary to set high-interest rates to prick the bubbles, but a moderate increase can have sufficient impact and reduce possible economic distortions.

In opposite, Posen (2006) suggests that central banks should not burst the bubbles unless the movements in asset prices directly affect forecasts about inflation and output. He considers bubbles are not that harmful as it is often assumed, if the banking system does not suffer any serious problems or if, after the burst of the bubble, the central bank does not take the action of tightening the monetary policy. Filardo (2001) presents the similar investigation of optimal monetary policy, proposing the response to changes in asset prices generally and price bubbles specifically, if the asset prices play an important role in determining output and inflation. In case of uncertainty to identify bubbles, there is a significant valuable information even in overall asset price movements. The usage of it, however, depends on the central bank's preference for interest rate smoothing and the variability asset prices. Last but not least, the expected costs considerably increase the expected benefits, if there is uncertainty about the macroeconomic role of asset prices and their bubbles.

In general, Mishkin (2008) points out that there are two types of asset price bubbles, where the first type can refer to as an 'irrational exuberance bubble'. Typically driven by overly optimistic expectations, it is far less dangerous for the financial system than the second type[2]. The second type is called 'credit-driven bubble' and may be highly dangerous. Typically, it begins with credit boom caused by either huge expectations about future economic prospects or structural changes in the financial markets. Then, the boom increases prices of some specific assets because of higher demand for them. The rise in their value encourages lending against them and the further increase of their demand and prices. This loop, however, can generate a bubble causing creditors to be less aware of the ability of the borrowers to repay the loans (Mishkin 2008, pg. 4). The consequences after burst are disastrous.

Hence, before the financial crisis in 2007, his suggestion is not to react to asset price bubbles and instead look at the effects of asset prices on employment and inflation as that is the mandate of central banks. Generally, the prevailing view was not to lean against potential bubbles.

This view however suddenly changed after the global financial crisis of 2007 − 2009, completely resetting the science of monetary policy. The primary outcome was the cost of cleaning up after an asset price bubble burst can be very high. Besides the loss of aggregate output, slow growth and high

[2] He gives an example of several technology stocks bubbles in the 1990s and at the beginning of 2000s.

unemployment rates, there is usually a sharp increase in government budget deficits and various fiscal problems.

Therefore, the actions to respond to asset price movements become more supported. Mishkin (2011) newly suggests financial sector to be the center of macroeconomic analysis. Moreover, rather than leaning against potential asset price bubbles, monetary policy should lean only against credit-driven bubbles, which are easier to identify. He concludes there is no question of whether or not, but to which extent should the central banks respond.

Wesselbaum & Luik (2016) empirically investigate whether the FED responds to asset prices using DSGE model. Their findings suggest that if monetary policy can reduce the likelihood of bubbles, the decrease of risk in the asset market is attainable as the fundamental value of the asset becomes more important. Moreover, the costs of cleaning are too high while adverse effects towards the real economy being rather large. Meanwhile, they conclude that the FED reacts to asset price bubbles, but it is at the cost of a lower output level. Since the central bank in their model can correctly identify the potential bubble, they add that central banks should be able to select them as well and consequently limit its effects on the economy.

In opposite, even after the crisis, Posen (2010) argues that it is not easy to readily recognize bubbles, and it is beyond the ability of policymakers to decide, which booms are harmful. Even in case of correct recognition of bubbles, it is ineffective for central banks to act on booms, considering the duration of their action and most of the booms.

In summary, considering all the different views mentioned above, it is difficult to give a clear answer to the fourth hypothesis. It hugely depends on the economic situation and the ability of the central banks to identify and adequately react to financial frictions. Recent global crisis, however, has undoubtedly influenced the opinions of those suggesting no response to asset price fluctuations, which prevailed before 2007. Nowadays, many economists are in favor of the argument of leaning against the wind as to prevent potential bubbles in asset markets to evolve and to subsequently dampen their consequences in case of their burst.

Chapter 8

Conclusion

Since the global financial crisis beginning in 2007, there is a tendency and pressure on central banks worldwide to decrease short-term nominal interest rates to zero. As a consequence, many of them set policy rates even below zero, into the negative territory as one of the unconventional monetary policy tools to dampen the consequences of the crisis. That, however, can lead to significant changes in various asset prices, increasing them to unreal amounts.

This thesis observes the relationship between low-interest rates prevailing in many economies for several years, and asset prices in general. For this purpose, a structural vector autoregressive model is used along with shadow policy rates, which provide more precise estimates of this relationship because of neglecting the zero-lower bound and its ability to go well below zero. Principally, the model considers three areas having observable and crucial predictive value - the Euro Area, the United Kingdom, and the United States.

Besides estimating potential effects of interest rate transmission into asset prices, the thesis provides a short discussion about the possible steps which should be taken by central banks to react in times of asset price bubbles adequately.

Regarding the objective of the thesis, there are four hypotheses of primary interest. Firstly, estimating the direct impact of monetary policy on asset prices, the significant positive effect is found in case of house prices. They react almost immediately and persistently to increase in interest rates with the most substantial decrease for the United Kingdom. In case of the stock prices, all of three areas considered firstly show a slight increase in reaction to interest rate rise. Nonetheless, in just a few periods, it is replaced by the decrease in share prices, resulting in similar effects across the countries. Therefore, regarding the second hypothesis of the impact of low-interest rates on various classes of assets, even though both of the assets show a reaction in a right direction, it would be useful to include more types of assets to confirm the obtained results.

Moreover, employing different specifications of the models leads to a conclusion there is indeed a positive effect on asset prices. Nevertheless, it varies considerably across different specifications of the baseline model, mainly in the persistence of the effects.

Essentially, both of the first two hypothesis are estimated using a shadow policy rate computed by Wu & Xia (2016). Other estimates are provided by Krippner (2013). Many economists pointed out that different models for the estimation of shadow rate can produce results specific for each of them. The third hypothesis, therefore, states, that the choice of shadow rate does not matter for the estimated effect of monetary policy on asset prices. This hypothesis cannot be rejected as employing shadow rates computed by Krippner (2013) results into very similar responses of asset prices. There are however some minor differences in the size of the effects.

Last but not least, after quantitative analysis showing the evidence of low-interest rates positively affecting asset price fluctuations, potential ways of how monetary authority can react to these changes are explained. The general view of monetary policy before the crisis was not to react to any asset price signals and focus only on the economic stability concerning low inflation, low unemployment, and steadily growing output. That has been supported even more by presuming, that asset price bubbles are hard to identify before their burst and any potential reaction can negatively affect the economy. After the crisis, however, unfortunate consequences demonstrated that at least some reaction is necessary from the central banks. Most of the opinions are contemporary in favor of reacting to asset prices as there might be essential signals in their changes regarding the future development of the economies.

In conclusion, the empirical evidence about low-interest rates positively affecting asset prices fluctuations has been provided. In contrast to previous studies, VAR model used to estimate the relationship employs the shadow policy rate which signals the behavior of unconventional monetary policy in an improved way. Moreover, the whole period of the financial crisis is covered to control for all the possible outcomes.

There are several potential extensions of this thesis. Firstly, it would be useful to include more types of various assets into the model to confirm the effect of interest rate transmission into asset prices. In addition, as Balke & Emery (1994) suggest, an inclusion of the spread between long- and short-term interest rates might help to solve the price puzzle. Secondly, time-varying coefficients allow for a possibility that the responses of house and share prices vary over time as suggested by Paul (2017). Therefore, a time-varying VAR along with shadow policy rates may provide more precisely estimated results. Last but not least, it would be appealing to decompose the effect of monetary policy on asset prices into a fundamental part of the price, showing the real value of the asset, and the bubble part. That may help to provide central banks with a model where the bubbles would be identified more easily way.

Bibliography

Alessi, L. & M. Kerssenfischer (2016): "The response of asset prices to monetary policy shocks: stronger than thought." *Working Paper Series 1967*, European Central Bank.

Balke, N. S. & K. M. Emery (1994): "Understanding the price puzzle." *Economic and Financial Policy Review* **(Q IV)**: pp. 15–26.

Bauer, M. & G. Rudebusch (2013): "Monetary policy expectations at the zero lower bound." *Federal Reserve Bank of San Francisco* pp. 1–43.

Beckworth, D., K. P. Moon, & J. H. Toles (2012): "Can monetary policy influence long-term interest rates? it depends." *Economic Inquiry* **50(4)**: pp. 1080–1096.

Bernanke, B. & M. Gertler (2000): "Monetary policy and Asset Price Volatility." *National Bureau of Economic Research* **7559**: pp. 1–74.

Bernanke, B. & K. N. Kuttner (2004): "What Explains the Stock Market's Reaction to Federal Reserve Policy?" *Journal of Finance* pp. 1221–1256.

Bernanke, B. S. & M. Gertler (2001): "Should central banks respond to movements in asset prices?" *American Economic Review* **91(2)**: pp. 253–257.

Bjornland, H. & D. H. Jacobsen (2009): "The role of house prices in the monetary policy transmission mechanism in small open economies." *Norges Bank Working Paper* **2009**: pp. 1–20.

Black, F. (1995): "Interest Rates as Options." *The Journal of Finance* **50(5)**: pp. 1371–1376.

Bordo, M. D. & J. Landon-Lane (2013): "Does Expansionary Monetary Policy Cause Asset Price Booms; Some Historical and Empirical Evidence." *National Bureau of Economic Research* **2013(19585)**: pp. 3–73.

Cecchetti, S., H. Genberg, & J. Lipsky (2000): "Asset prices and central bank policy." *International Centre for Monetary and Banking Studies* **2**.

Chen, S. (2012): *The Role of Asset Prices in Monetary Policy.* Senior thesis, University of California, Berkley.

Christensen, J. H. E. & G. D. Rudebusch (2013): "Estimating Shadow-Rate Term Structure Models with Near-Zero Yields." *Federal Reserve Bank of San Francisco* pp. 1–37.

Christiano, L. J., M. Eichenbaum, & C. L. Evans (1998): "Monetary policy shocks: What have we learned and to what end?" *Working Paper 6400*, National Bureau of Economic Research.

Del Negro, M. & C. Otrok (2007): "99 luftballons: Monetary policy and the house price boom across u.s. states." *Journal of Monetary Economics* **54(7)**: pp. 1962–1985.

ECB (2017): "The european central bank." https://www.ecb.europa.eu/.

EPU (2017): "Economic policy uncertainty." http://www.policyuncertainty.com/.

Filardo, A. J. (2001): "Should monetary policy respond to asset price bubbles? some experimental results." *Federal Reserve Bank of Kansas City* pp. 1–33.

Forni, M. & L. Gambetti (2010): "The dynamic effects of monetary policy: A structural factor model approach." *Journal of Monetary Economics* **57(2)**: pp. 203 – 216.

FRED (2016): "The federal reserve bank of st. louis." https://fred.stlouisfed.org/.

Furlanetto, F. (2008): "Does monetary policy react to asset prices? some international evidence." *Cahiers de recherches economiques du département d'econométrie et d'economie politique (deep)*, Université de Lausanne, Faculté des HEC, DEEP.

Gali, J. & L. Gambetti (2013): "The Effects of Monetary Policy on Stock Market Buubles: Some Evidence." *National Bureau of Economic Research* **2013(19981)**: pp. 1–23.

Gerlach, S. & K. Assenmacher (2008): "Financial structure and the impact of monetary policy on asset prices." *CFS Working Paper Series 2008/30*, Center for Financial Studies (CFS).

Gertler, M. & P. Karadi (2014): "Monetary policy surprises, credit costs and economic activity." *Working Paper 20224*, National Bureau of Economic Research.

Hermannová, L. (2012): *Forecasting Ability of Confidence Indicators: Evidence for the Czech Republic*. Master's thesis, Charles University in Prague.

Horváth, R. & J. Hájek (2017): "International spillovers of (un)conventional monetary policy: The effect of the ecb and us fed on non-euro eu countries." *CNB Working Paper Series* pp. 1–32.

Huber, F. & M. T. Punzi (2016): "International housing markets, unconventional monetary policy and the zero lower bound." *FinMaP-Working Papers 58*, Collaborative EU Project FinMaP - Financial Distortions and Macroeconomic Performance: Expectations, Constraints and Interaction of Agents.

INV (2017): "Investing.com uk." https://uk.investing.com/.

Ivanov, V. & L. Kilian (2005): "A practitioner's guide to lag order selection for var impulse response analysis." *Studies in Nonlinear Dynamics & Econometrics* **9(1)**: pp. 1–36.

Krippner, L. (2012): "Modifying Gaussian term structure models when interest rates are near the zero lower bound." *Discussion Paper Series* pp. 1–49.

Krippner, L. (2013): "A tractable framework for zero lower bound Gaussian term structure models." *Reserve Bank of New Zealand Discussion Paper Series* pp. 1–65.

Kuusela, A. & J. Hännikäinen (2017): "What do the shadow rates tell us about future inflation?" *Mpra paper*, University Library of Munich, Germany.

Lawrence, C., C. L. Ilut, R. Motto, & M. Rostagno (2010): "Monetary policy and Stock Market Booms." *National Bureau of Economic Research* **16402**: pp. 1–38.

Liew, V. K.-S. (2004): "Which lag length selection criteria should we employ?" *Economics Bulletin* **3(33)**: pp. 1–9.

Lombardi, M. J. & F. Zhu (2014): "A shadow policy rate to calibrate US monetary policy at the zero lower bound." *BIS Working Papers 452*, Bank for International Settlements.

Lütkepohl, H. (2005): *New introduction to multiple time series analysis.* Berlin [u.a.]: Springer.

Mishkin, F. S. (2008): "How should we respond to asset-price bubbles?" *National Bureau of Economic Research* pp. 1–20.

Mishkin, F. S. (2011): "Monetary policy strategy: Lessons from the crisis." *Working Paper 16755*, National Bureau of Economic Research.

Morgese Borys, M., R. Horvath, & M. Franta (2009): "The effects of monetary policy in the czech republic: an empirical study." *Empirica* **36(4)**: pp. 419–443.

Musso, A., S. Neri, & L. Stracca (2010): "Housing, consumption and monetary policy: how different are the us and the euro area?" *Working Paper Series 1161*, European Central Bank.

NAR (2016): "National association of realtors." https://www.nar.realtor/.

OECD (2016): "The organisation of economic co-operation and development." https://www.oecd.org/.

Paul, P. (2017): "The Time-Varying Effect of Monetary Policy on Asset Prices." *Working Paper Series 2017-9*, Federal Reserve Bank of San Francisco.

Pfaff, B. (2008): *Analysis of Integrated and Cointegrated Time Series with R.* Springer.

Posen, A. S. (2006): "Why central banks should not burst bubblesand may be highly dangerous.and may be highly dangerous." *International Finance* **9(1)**: pp. 109–124.

Posen, A. S. (2010): "Do we know what we need to know in order to lean against the wind?" *Cato Institute 28th Annual Monetary Conference, Washington* pp. 1–10.

Primiceri, G. (2005): "Time varying structural vector autoregressions and monetary policy." *Review of Economic Studies* **72(3)**: pp. 821–852.

Rahal, C. (2016): "Housing markets and unconventional monetary policy." *Journal of Housing Economics* **32(C)**: pp. 67–80.

RBNZ (2016): "Reserve bank of new zealand." https://www.rbnz.govt.nz/.

Reinhart, C. M. & K. S. Rogoff (2009): "The aftermath of financial crises." *Working Paper 14656*, National Bureau of Economic Research.

Rigobon, R. & B. Sack (2002): "The Impact of Monetary Policy on Asset Prices." *National Bureau of Economic Research* **2002(8794)**: pp. 1–36.

Roubini, N. (2006): "Why central banks should burst bubbles." *International Finance* **9(1)**: pp. 87–107.

Shiller, R. J. (2007): "Low Interest Rates and High Asset Prices: An Interpretation in Terms of Changing PopularEconomic Models." *Brookings Papers on Economic Activity* **2007(2)**: pp. 111–132.

Sims, C. A. (1980): "Macroeconomics and reality." *Econometrica* **48(1)**: pp. 1–48.

Sims, C. A. (1992): "Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy." *Cowles Foundation Discussion Papers 1011*, Cowles Foundation for Research in Economics, Yale University.

Svensson, L. E. (1995): "Optimal inflation targets, 'conservative' central banks, and linear inflation contracts." *Working Paper 5251*, National Bureau of Economic Research.

Taylor, J. (1993): "Discretion versus policy rules in practise." *Carnegie-Rochester Conference Series on Public Policy* **39**: pp. 195–214.

Wesselbaum, D. & M.-A. Luik (2016): "Did the FED React to Asset Price Bubbles?" *Working Papers 1602*, University of Otago, Department of Economics.

Wright, J. H. (2011): "What does monetary policy do to long-term interest rates at the zero lower bound?" *Working Paper 17154*, National Bureau of Economic Research.

Wu, J. C. (2017): "Jing cynthia wu." https://sites.google.com/site/jingcynthiawu/.

Wu, J. C. & F. D. Xia (2016): "Measuring Macroeconomic Impact of Monetary Policy at the Zero Lower Bound." *Journal of Money, Credit and Banking* **48(2-3)**: pp. 254–291.

Wu, J. C. & F. D. Xia (2017): "Time-Varying Lower Bound of Interest Rates in Europe." *Chicago Booth Research Paper* **(17-06)**: pp. 1–41.

Appendix A

Title of Appendix

Table A.1: Stability of Baseline VARX model for EA - Eigenvalues of the companion form

SP model	0.976	0.924	0.924	0.871	0.871	0.835	0.835	0.659
	0.659	0.653	0.628	0.628	0.536	0.536	0.391	0.391
HP model	0.983	0.933	0.933	0.876	0.876	0.861	0.861	0.826
	0.826	0.622	0.548	0.548	0.493	0.475	0.475	0.235

Table A.2: Stability of Baseline VARX model for UK - Eigenvalues of the companion form

SP model	0.969	0.969	0.938	0.867	0.867	0.848	0.848	0.618
	0.618	0.509	0.509	0.497	0.497	0.398	0.398	0.268
HP model	0.980	0.980	0.979	0.979	0.868	0.868	0.811	0.811
	0.626	0.626	0.563	0.563	0.447	0.447	0.407	0.293

Table A.3: Stability of Baseline VARX model for US - Eigenvalues of the companion form

SP model	0.959	0.865	0.865	0.841	0.775	0.775
	0.742	0.535	0.535	0.191	0.191	0.097
HP model	0.964	0.964	0.921	0.921	0.764	0.764
	0.721	0.721	0.647	0.647	0.228	0.228

Figure A.1: Parameter Stability of Baseline VARX for EA - SP model

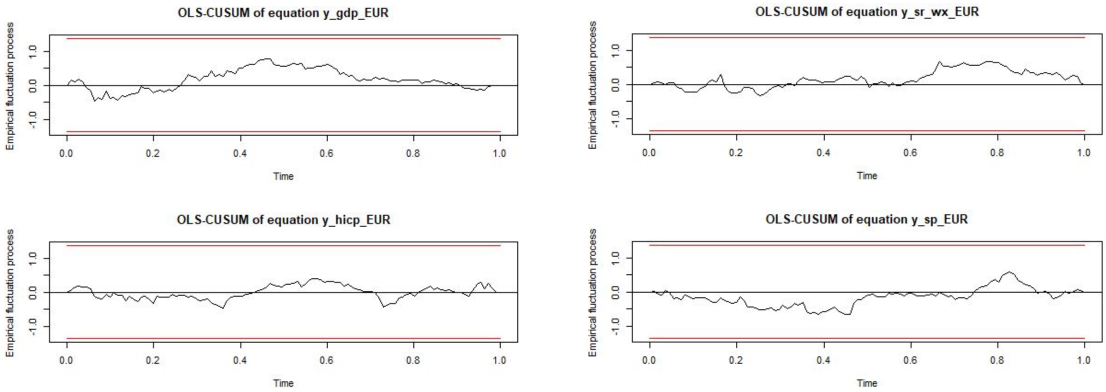


Figure A.2: Parameter Stability of Baseline VARX for EA - HP model

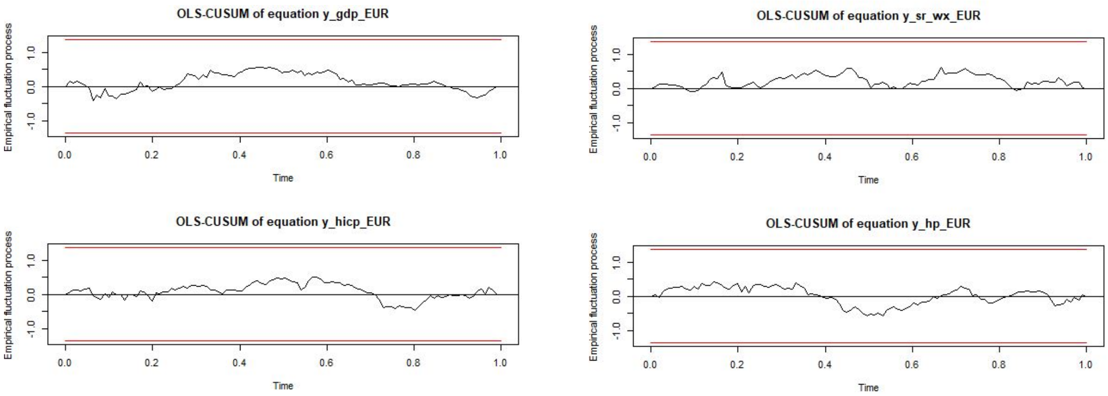


Figure A.3: Parameter Stability of Baseline VARX for UK - SP model

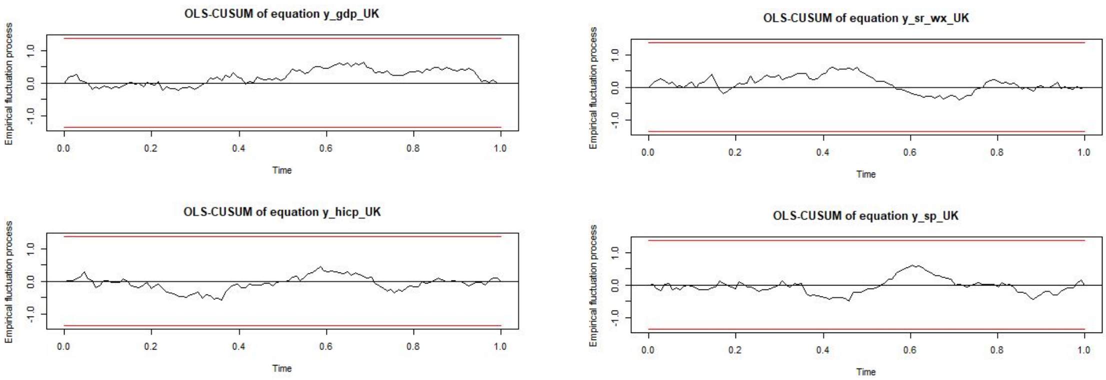


Figure A.4: Parameter Stability of Baseline VARX for UK - HP model

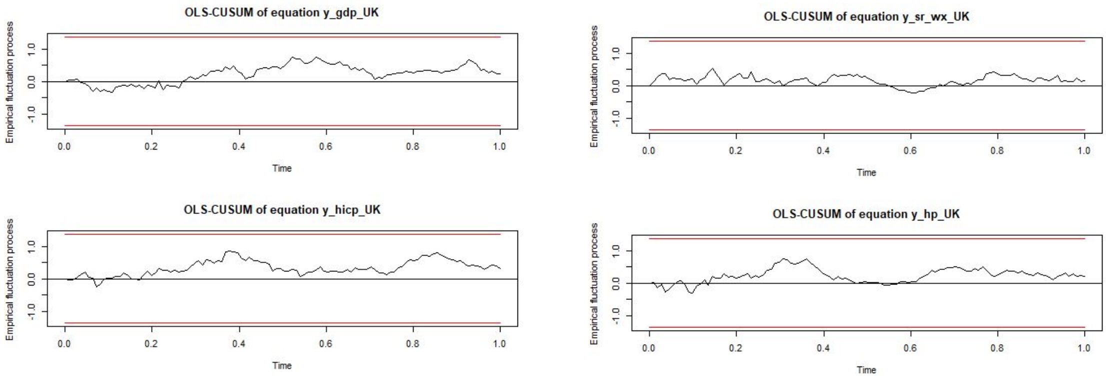


Figure A.5: Parameter Stability of Baseline VARX for US - SP model

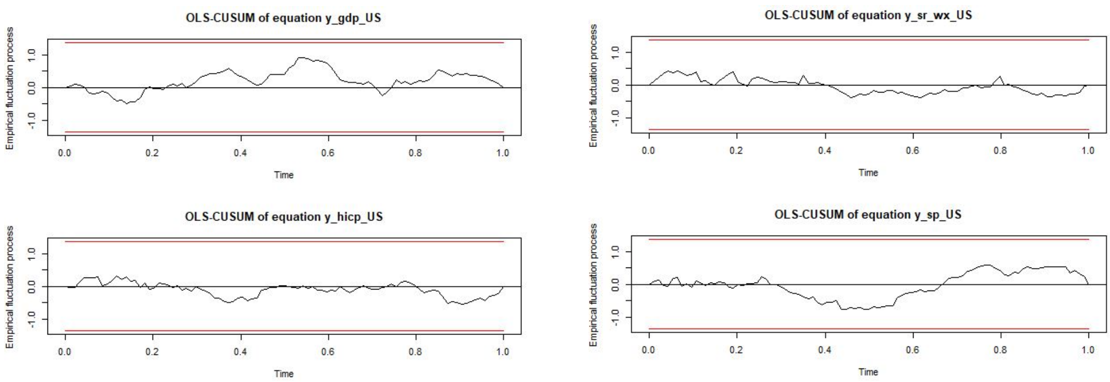


Figure A.6: Parameter Stability of Baseline VARX for US - HP model

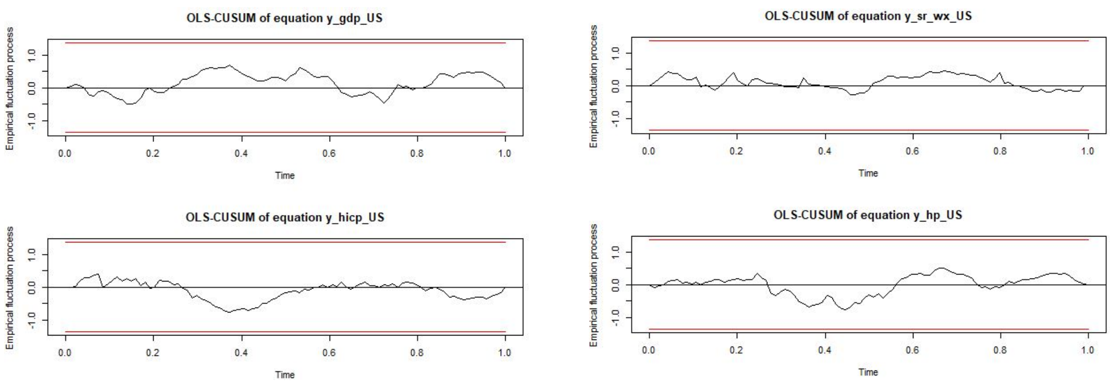


Figure A.7: Diagnostics - Fit and Residuals of Baseline VARX model for EA

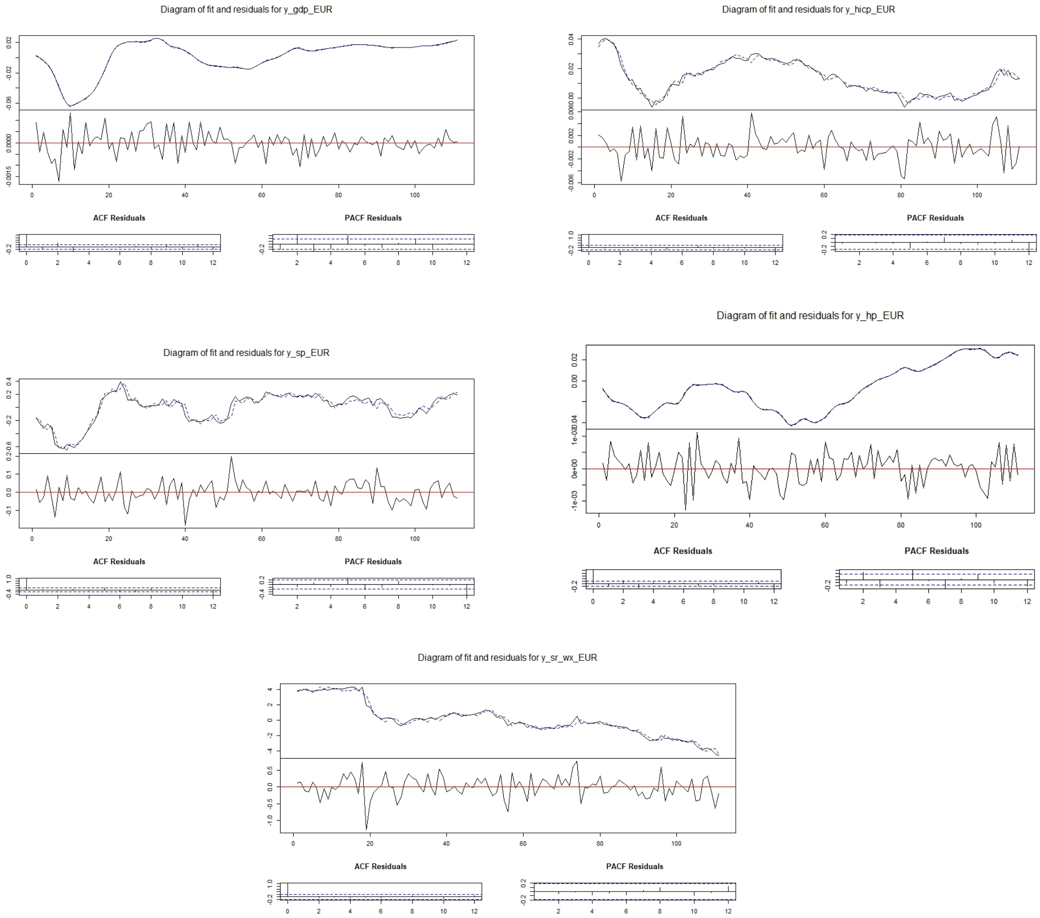


Figure A.8: Diagnostics - Fit and Residuals of Baseline VARX model for UK

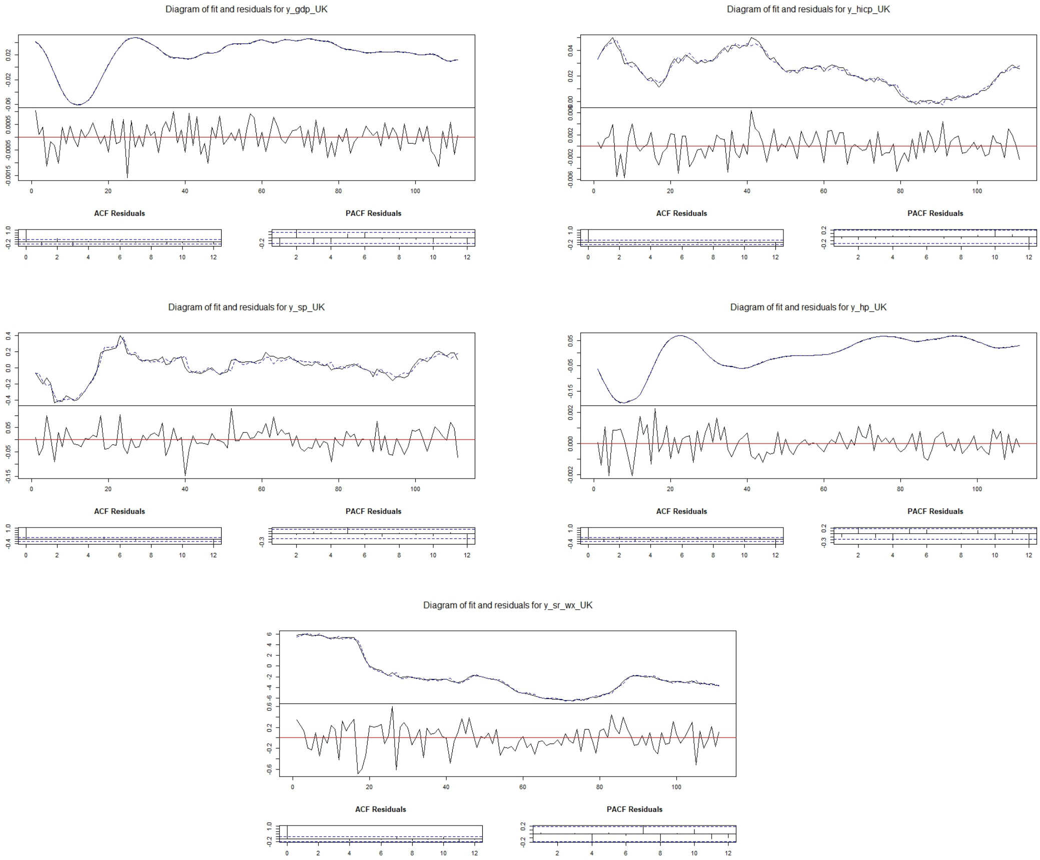


Figure A.9: Diagnostics - Fit and Residuals of Baseline VARX model for US

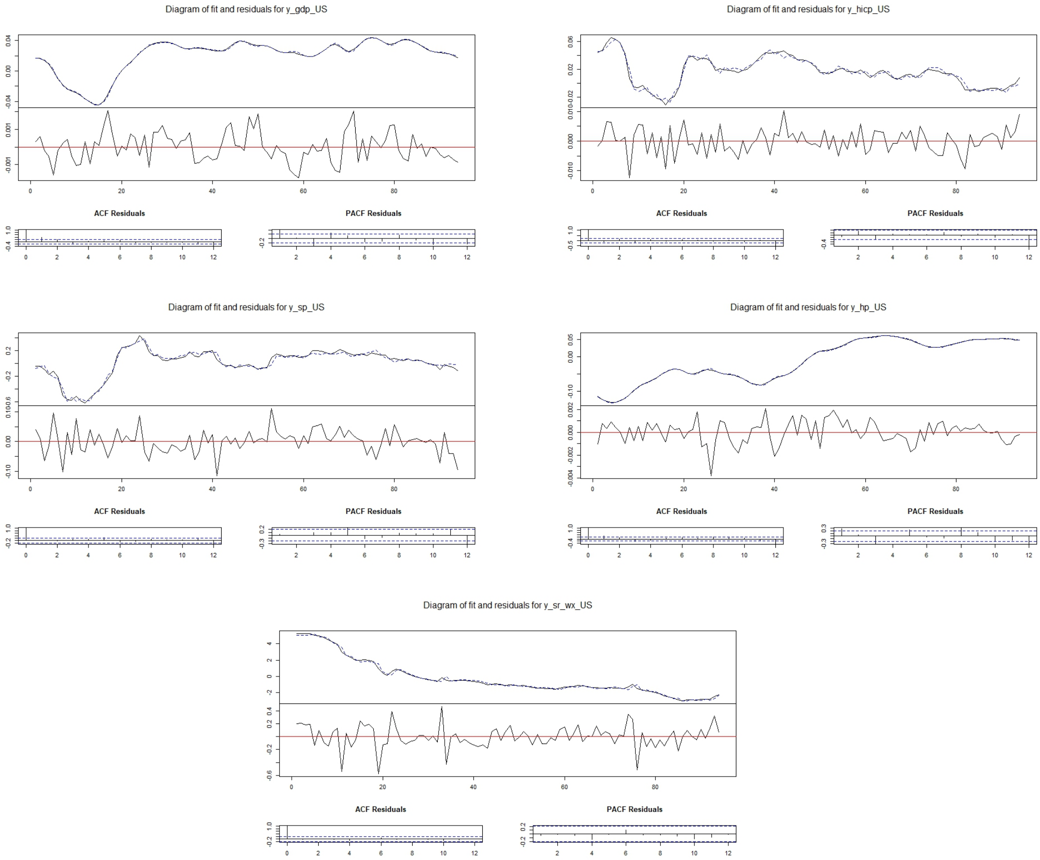


Figure A.10: Impulse response functions - Baseline SVARX SP model-EA

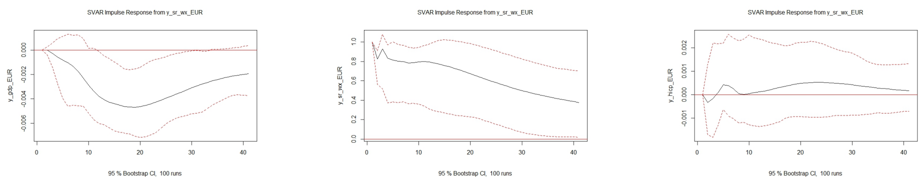


Figure A.11: Impulse response functions - Baseline SVARX HP model-EA

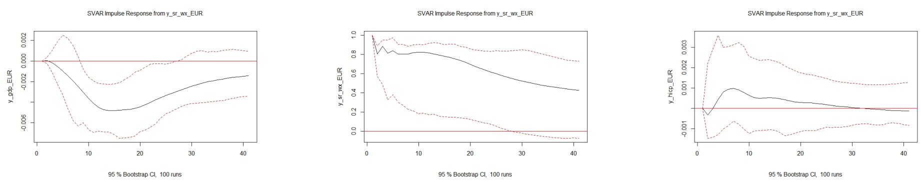


Figure A.12: Impulse response functions - Baseline SVARX SP model-UK

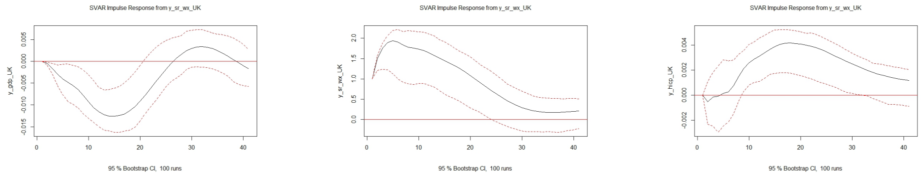


Figure A.13: Impulse response functions - Baseline SVARX HP model-UK

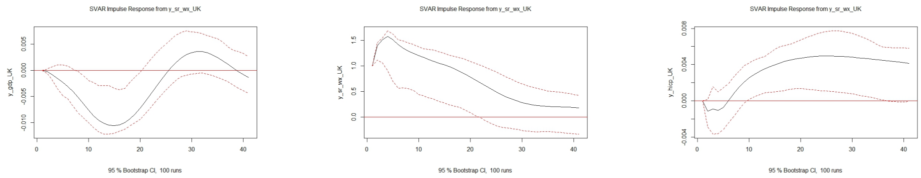


Figure A.14: Impulse response functions - Baseline SVARX SP model-US

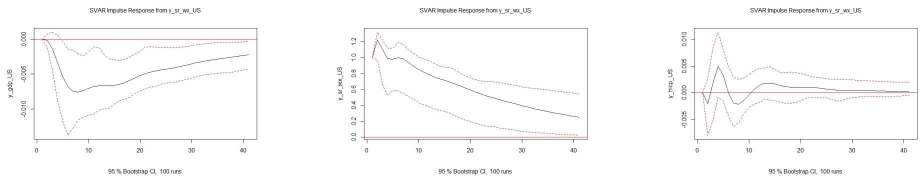


Figure A.15: Impulse response functions - Baseline SVARX HP model-US

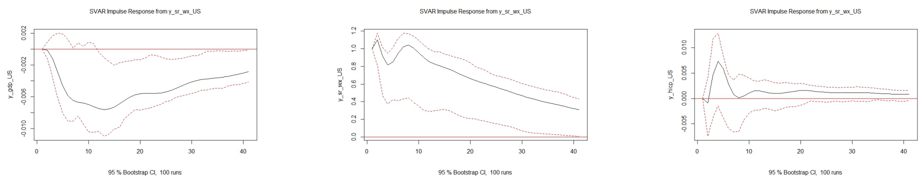


Figure A.16: Impulse response functions - SVARX-U SP model - EA

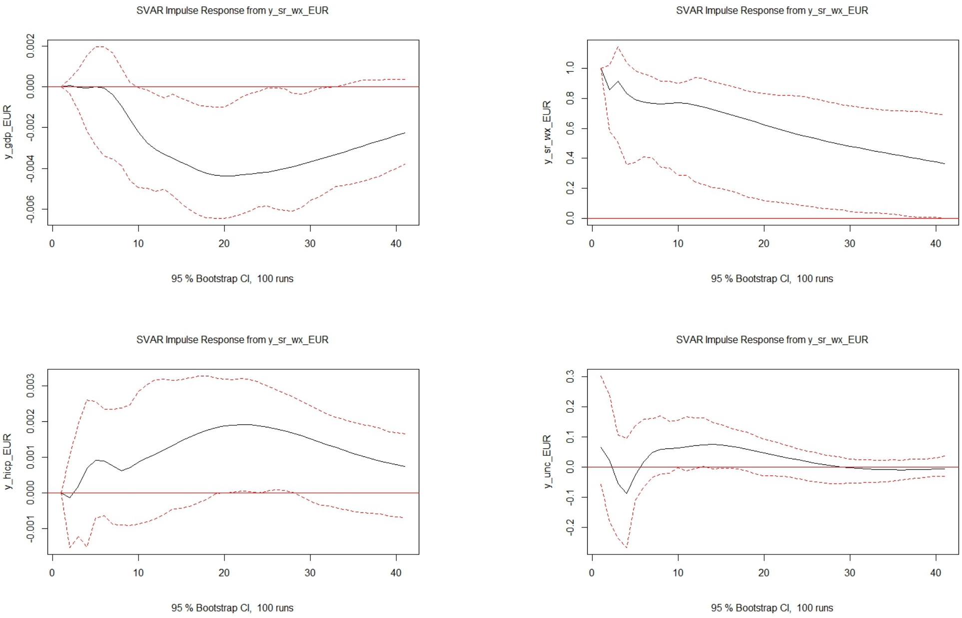


Figure A.17: Impulse response functions - SVARX-U HP model - EA

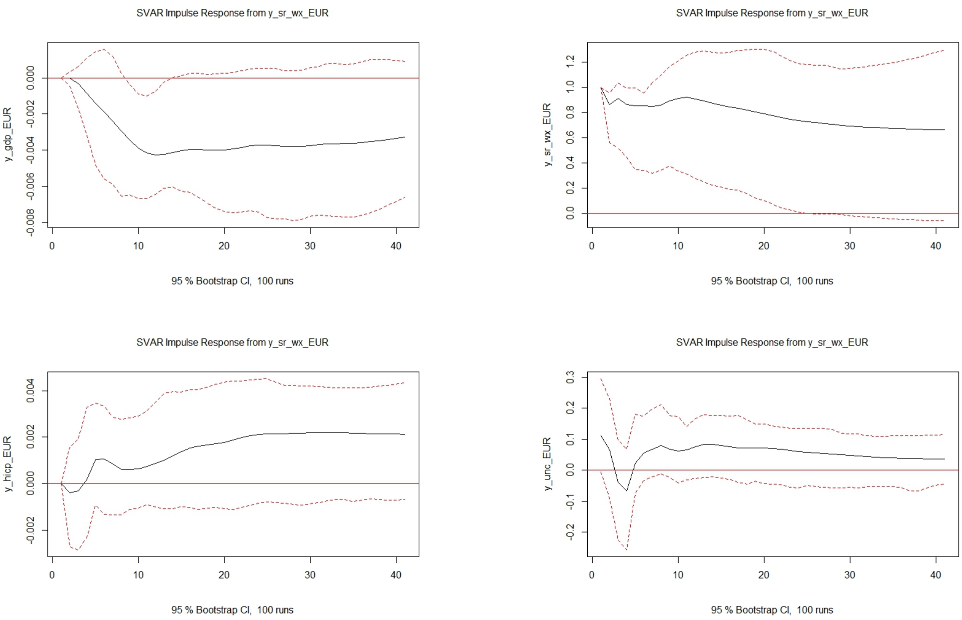


Figure A.18: Impulse response functions - SVARX-U SP model - UK

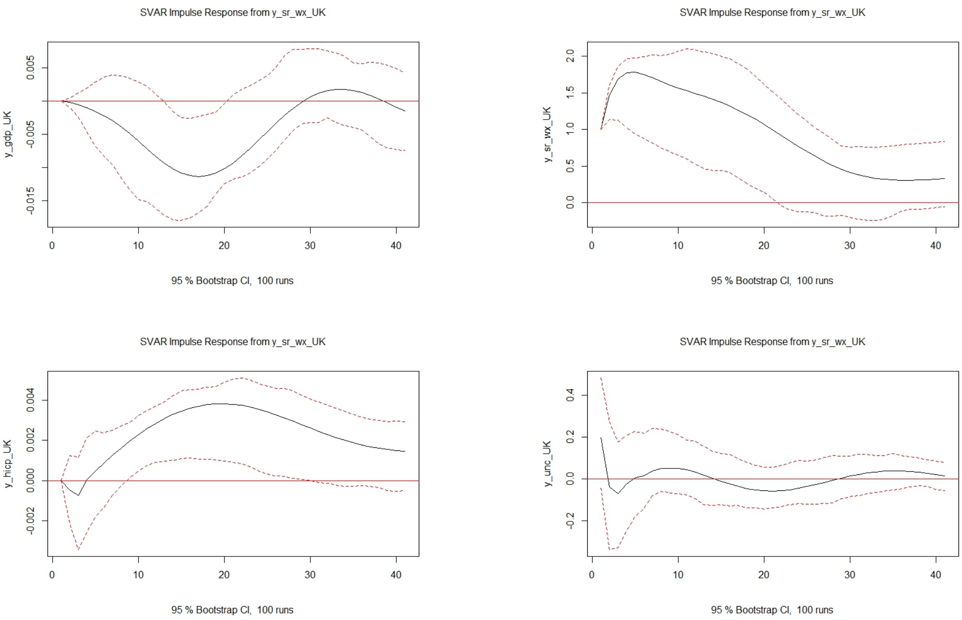


Figure A.19: Impulse response functions - SVARX-U HP model - UK

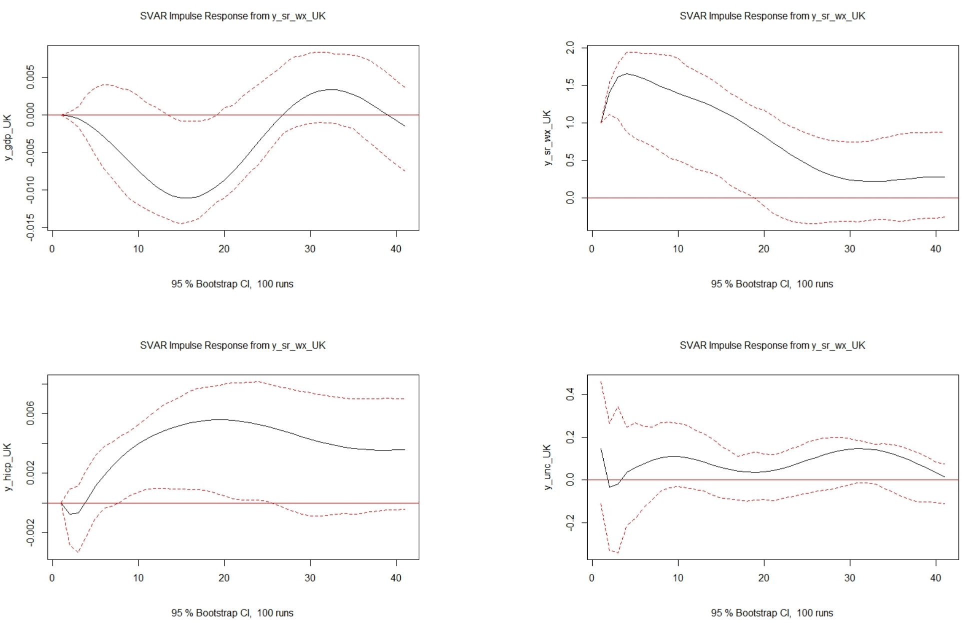


Figure A.20: Impulse response functions - SVARX-U SP model - US

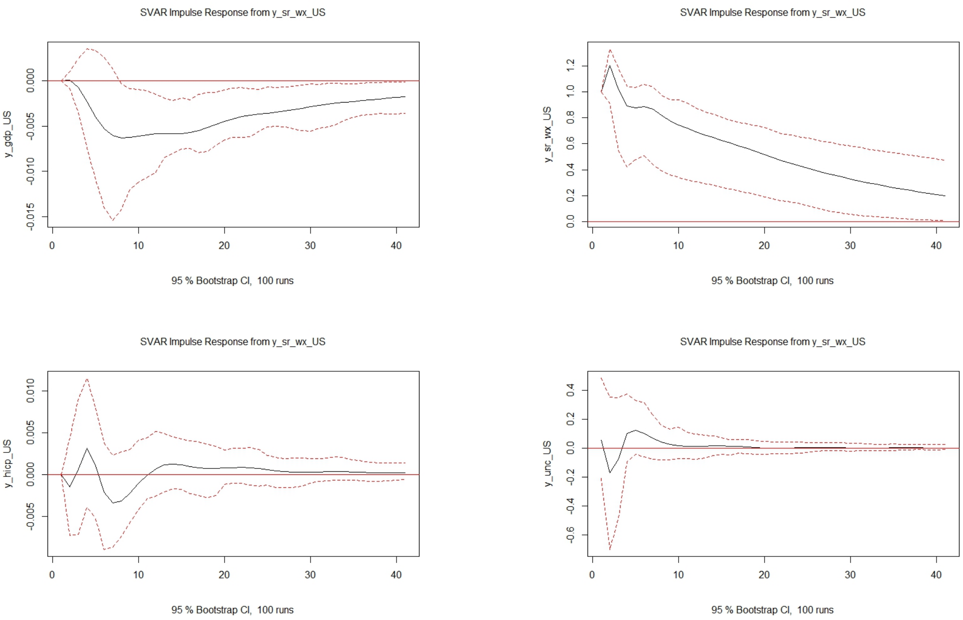


Figure A.21: Impulse response functions - SVARX-U HP model - US

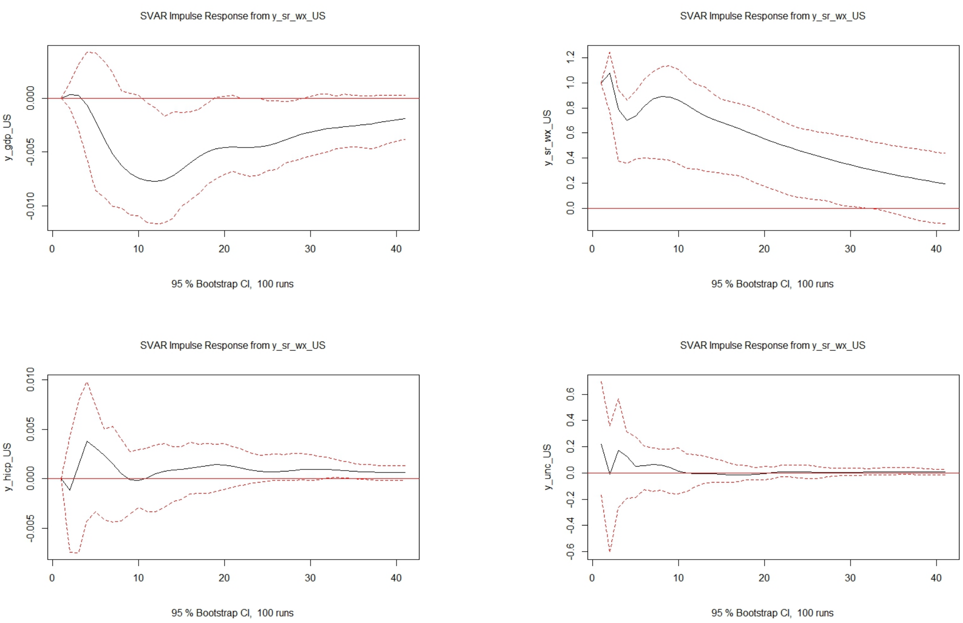


Figure A.22: Impulse response functions - SVARX-M SP model - EA

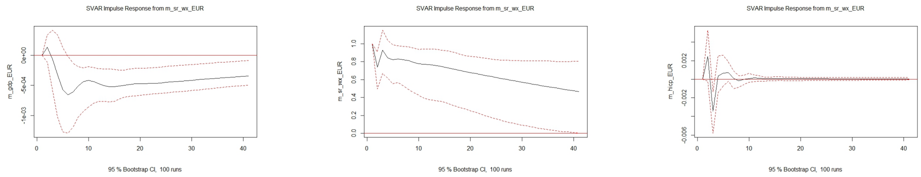


Figure A.23: Impulse response functions - SVARX-M HP model - EA

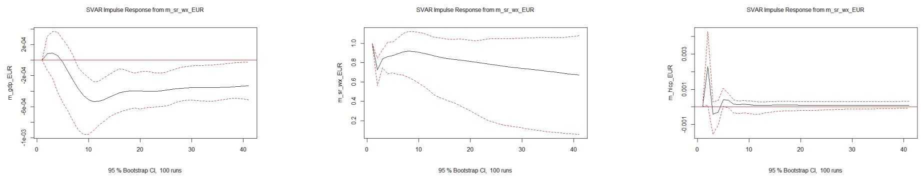


Figure A.24: Impulse response functions - SVARX-M SP model - UK

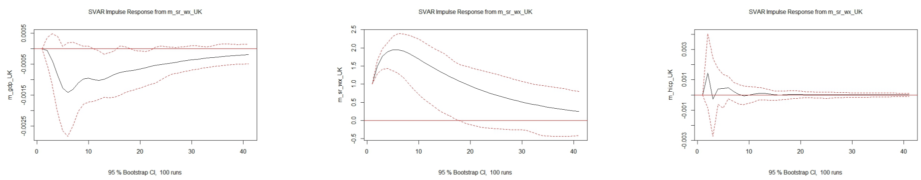


Figure A.25: Impulse response functions - SVARX-M HP model - UK

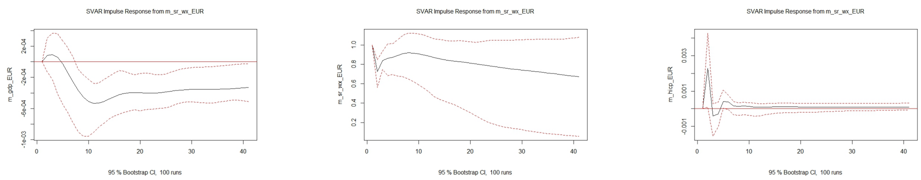


Figure A.26: Impulse response functions - SVARX-M SP model - US

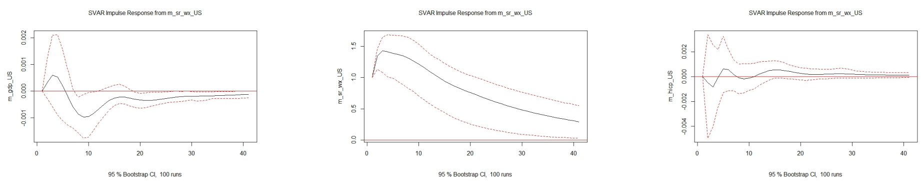


Figure A.27: Impulse response functions - SVARX-M HP model - US

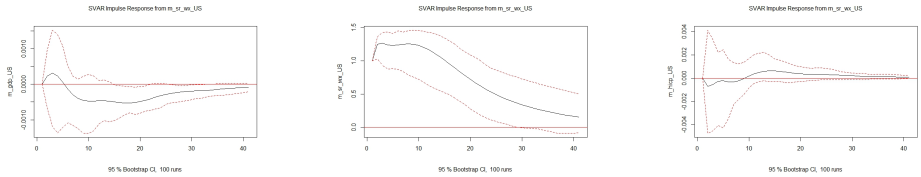


Figure A.28: Impulse response functions - SVARX-K SP model - EA

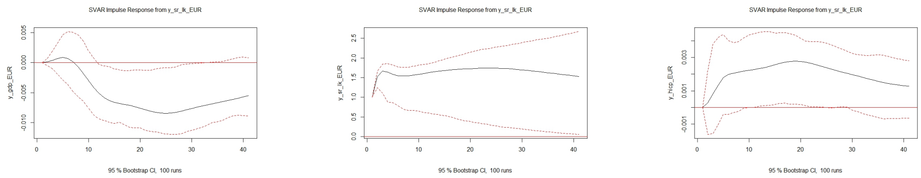


Figure A.29: Impulse response functions - SVARX-K HP model - EA

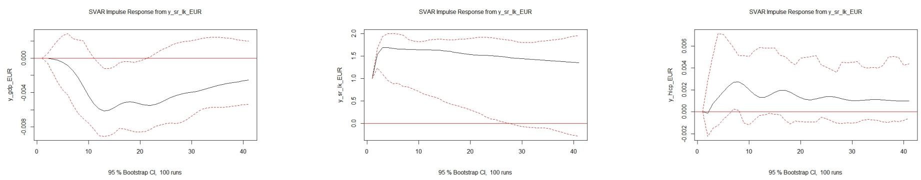


Figure A.30: Impulse response functions - SVARX-K SP model - UK

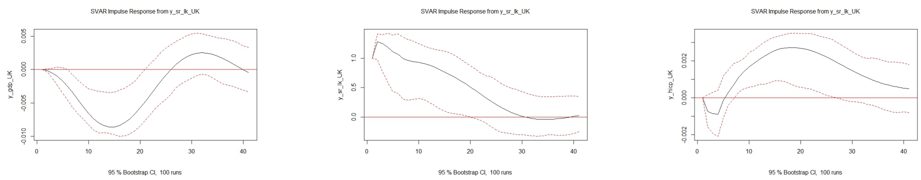


Figure A.31: Impulse response functions - SVARX-K HP model - UK

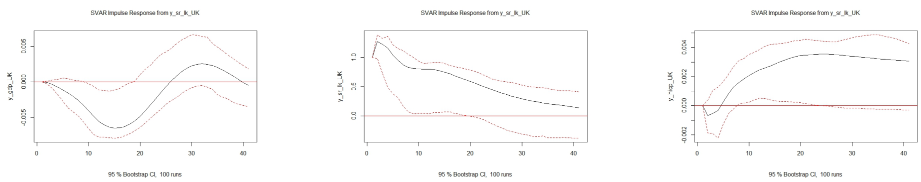


Figure A.32: Impulse response functions - SVARX-K SP model - US

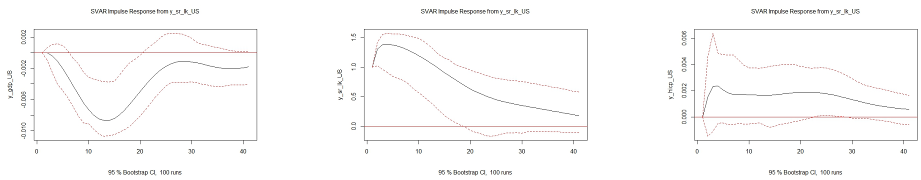


Figure A.33: Impulse response functions - SVARX-K HP model - US