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Origin of Current High Inflation in the Czech Economy (2022)

Bachelor's Thesis

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Declaration of Authorship

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Prague, May 2, 2023

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Abstract

The thesis presents new evidence on the relative importance of seven domestic and foreign inflation drivers in the Czech Republic over the past two decades. A structural vector autoregressive (VAR) model with short-run zero and sign restrictions is estimated within a Bayesian framework, enabling the decomposition of the sources of inflation. A comparative forecast error variance decomposition (FEVD) analysis is performed among three baseline models to investigate the underlying causes of the recent surge in inflation in the Czech economy. The results show a growing prominence of both domestic and foreign supply factors. Furthermore, over the entire period of 2000Q3-2022Q3, demand shocks contribute more than supply shocks to the changes in the price level. This paper also highlights the remarkable role of fiscal policy shocks, while monetary conditions have a minor impact. Additionally, the effectiveness of monetary policy tools is evaluated.

JEL Classification	F12, F21, F23, H25, H71, H87
Keywords	inflation, SVAR model, monetary policy, supply and demand shocks
Title	Origin of Current High Inflation in the Czech Economy (2022)

Abstrakt

Tato práce přináší nové poznatky ohledně relativní důležitosti domácích a zahraničních faktorů ovlivňujících inflaci v České republice v posledních dvou desetiletích. Pro odhad strukturálního vektorového autoregresního (VAR) modelu jsou využity nulové a znaménkové restrikce v bayesovském rámci, což umožňuje efektivní rozklad původu inflace. Prozkoumání příčin nedávného vzestupu inflace v české ekonomice je provedeno pomocí komparativní analýzy rozkladu rozptylu chyb předpovědi mezi třemi základními modely. Výsledky naznačují, že nabídkové faktory, jak domácí, tak zahraniční, hrály významnou roli. Navíc je zjištěno, že během celého období (2000-2022) přispívají poptávkové šoky více než nabídkové šoky ke změnám v cenové hladině. Práce rovněž zdůrazňuje význam šoků fiskální politiky, kdežto měnové podmínky hrají menší roli. Dále je zkoumána účinnost nástrojů měnové politiky.

Klasifikace JEL	F12, F21, F23, H25, H71, H87
Klíčová slova	inflace, SVAR model, monetární politika, nabídkové a poptávkové šoky
Název práce	Původ současné vysoké inflace v české ekonomice (2022)

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Acronyms

BVAR Bayesian vector autoregressive

CNB Czech National Bank

CZSO Czech Statistical Office

DSGE dynamic stochastic general equilibrium

FEVD forecast error variance decomposition

FRED Federal Reserve Economic Data

IRFs impulsive response functions

OECD Organisation for Economic Co-operation and Development

RGDP real gross domestic product

SVAR structural vector autoregressive

VAR vector autoregressive

Chapter 1

Introduction

Advanced economies have encountered the issue of high inflation after a relatively prolonged period, as in recent years, the threat was instead centred around low inflation and the risk of deflation[1]. Regarding the Czech Republic, it has experienced a noticeable increase in its annual inflation rate, as measured by the consumer price index (CPI), attaining 3.8% in 2021 (World Bank). This rate has continued to rise in 2022, reaching double figures (Keseliová *et al.* 2023) and resulting in the highest inflation rate since December 1993 (World Bank). This trend is noteworthy since the inflation rate in the Czech Republic is higher than in other countries, even though the Czech National Bank (CNB) responded early and swiftly to the situation by increasing interest rates (Matějková *et al.* 2021).

To examine the determinants of inflation in the Czech economy, a structural VAR model is estimated using both short-run zero and sign restrictions within the Bayesian framework. The structural analysis decomposes the sources of inflation into seven distinct factors: domestic demand, domestic supply, monetary policy, exchange rate, fiscal policy, foreign demand, and foreign supply. In order to assess the sources of the current high inflation in the Czech Republic, three baseline models spanning different periods are compared using forecast error variance decomposition. It is noteworthy that no recent study in the Czech literature has conducted such a comprehensive analysis. In addition, this study investigates the impact of CNB tools, such as interest rate and exchange rate interventions, on the inflation situation in the Czech economy. Overall, this research presents a sophisticated approach to analysing the sources of inflation and provides valuable insights into the effectiveness of monetary policy tools

[1] `https://www.ecb.europa.eu/home/search/review/pdf/ecb.strategyreview_mon/pol_strategy_overview.en.pdf`

in reducing inflation, thereby contributing to the existing literature in several ways.

Notably, the results suggest an increasing prominence of domestic and foreign supply factors in explaining the recent price upsurge. Furthermore, the exchange rate shock is likewise noted to play a significant role. Upon examining the FEVD throughout the entire period spanning 2000Q3-2022Q3, it is observed that demand shocks make a greater contribution than supply shocks in explaining the fluctuations in the price level. The paper likewise highlights the significant role of fiscal policy shocks in explaining the variations in the price level, while monetary conditions have a relatively minor impact overall. Additionally, the efficacy of monetary policy is investigated, and the findings demonstrate that the primary effect of both instruments occurs during the first ten quarters. It is found that a relatively modest initial interest rate shock is sufficient to decrease inflation by one percentage point. Consequently, it can be inferred that tightening the interest rate would be a more effective strategy for regulating inflation at the monetary policy horizon. Nevertheless, intervening to support the koruna also has long-term effects on reducing inflation and represents an effective supplementary instrument.

The thesis is structured as follows: In Chapter 2, an overview of previous research on the determinants of inflation in the Czech economy and other countries is presented, along with various approaches for identifying the sources of inflation. The effectiveness of monetary policy tools is likewise discussed. Chapter 3 introduces a structural VAR model and Bayesian inference. Chapter 4 provides a detailed description of data from the CNB, Czech Statistical Office (CZSO) and Federal Reserve Economic Data (FRED) database. Chapter 5 presents the estimation results and discusses the origins of inflation in the Czech Republic, along with implications for practical use, such as the efficiency of CNB's monetary policy. Finally, the Chapter 6 summarizes the findings of the paper.

Under the guidelines set forth by the university, tools such as Grammarly, QuillBot and ChatGPT (versions 3.5 and 4) were employed to enhance vocabulary, grammatical precision and writing proficiency.

Chapter 2

Literature Review

The chapter is structured into two distinct sections. The first section focuses on the theoretic perspective regarding supply and demand shocks. It likewise provides a comprehensive overview of the existing empirical literature concerning the source of inflation across various countries and time periods. Subsequently, the second section encompasses investigations into the efficacy of diverse monetary policy instruments.

2.1 Inflation Determinants

2.1.1 Supply and Demand as Inflation Pressures

According to Mankiw (2003), a supply shock is an event that affects the production capacity and can be caused by various factors such as changes in technology, natural disasters, or government policies. When a negative supply shock occurs, the cost of production increases, leading to an upward shift in the supply curve. On the other hand, a positive demand shock is an event that stimulates the demand for goods and services, shifting the demand curve to the right. Although negative supply and positive demand shocks affect the output differently, both shocks lead to higher prices. Therefore, the author describes two main types of inflation: cost-push inflation and demand-pull inflation.

Prior studies have utilised dynamic stochastic general equilibrium (DSGE) and structural vector autoregressive (SVAR) models providing evidence that supports the causality relationship mentioned earlier. In the context of a DSGE framework, Millard (2011) emphasizes that a positive demand shock increases inflation. Uhlig (2017) conducts an additional investigation into the identification of demand and supply shocks using sign restrictions within a standard demand and supply model. Fry & Pagan (2011) likewise report a positive association between a positive demand shock and increased prices and output. Conversely, a negative supply shock leads to increased prices and decreased output. These sign restrictions are evident in various research papers, including Baumeister & Hamilton (2015), Comunale & Kunovac (2017), Forbes *et al.* (2018), Kronborg (2021), Časta (2022).

2.1.2 Empirical Research

This section intends to present a comprehensive review of empirical studies investigating the factors determining inflation in various countries, including the Czech economy, through out different time periods.

It is noteworthy to indicate that advanced economies have been confronted with the issue of high inflation after a relatively long period, given that the menace of deflation has been prevalent in recent years. Therefore, it is essential to emphasize the significance of foreign literature that examines the period known as the "Great Inflation" characterised by annual inflation rates surpassing 10% across the Organisation for Economic Co-operation and Development (OECD) countries in the 1970s[1].

Blanchard & Gali (2007) investigated the impact of exogenous oil shocks on the US economy during two episodes - 1973-1974 and 1979-1981 - using a VAR model. The study reveals that exogenous oil shocks played a substantial role in both episodes. Specifically, the analysis shows that oil price shocks accounted for a significant portion (between 67-86%) of the overall increases in inflation (measured by CPI, GDP and wage inflation variables) during the two episodes. Drawing on evidence from a DSGE model, Smets & Wouters (2007) offer a historical analysis of the contribution of various types of shocks to inflation in the US during the Great Inflation period spanning from 1966 to 1979. They find that the primary source of long-term changes in inflation was driven by supply shocks, specifically those related to price and wage markups. The authors also note that while monetary policy played a role in the rise of inflation during the 1970s, it was also instrumental in the subsequent disinflation during the Volcker period (1979-1987).

Afterwards, Mumtaz *et al.* (2011) investigate the transmission of monetary

[1] https://www.ecb.europa.eu/pub/pdf/other/mopo_strat_art1.pdf

policy and demand shocks in the UK. The authors observe that, in the pre-inflation targeting era, particularly in the 1980s, demand shocks accounted for the majority of the variance in forecast errors of inflation indicators, contributing around 30% to 40%. However, in the post-1992 inflation targeting period, the impact of monetary policy shocks on prices increased significantly.

Canova & De Nicolò (2003) examine the determinants of inflation in the G7 countries, namely the United States, Canada, Japan, the United Kingdom, Germany, Italy, and France, during the period from 1973 to 1998. The FEVD indicate that demand shocks were the most significant source of inflation fluctuations in five of the seven countries, except for Japan and Italy[2]. Nominal disturbances played a critical role in all countries. Additionally, supply shocks were a significant contributor to inflation fluctuations in all countries, except for Japan.

In the context of the global financial crisis, Millard (2011) suggest that in the UK, the price mark-up shock exerted a substantial downward pressure on inflation in 2009. The financial shock and energy prices also contributed to this trend. Nevertheless, the negative productivity shock had an opposing effect, leading to an upward push on inflation. Therefore, high oil and gas prices in 2008 contributed to an increase in inflation during that year, while their subsequent decline in 2009 had a converse effect, leading to a reduction in inflation.

Jovičić & Kunovac (2015) present empirical evidence on the relative significance of domestic and foreign drivers of inflation in Croatia, a small open economy. Their analysis using FEVD reveals that a substantial proportion of the variation in domestic prices can be attributed to foreign shocks. Specifically, foreign shocks account for 50% of the variation in the import deflator and 68% of the variation in consumer inflation.

More recently, O'Brien *et al.* (2021) investigate the primary determinants of the decline in inflation in the eurozone during 2020. The five main drivers are analysed, including global demand, domestic demand, domestic supply, oil supply, and monetary policy. The study underlines the critical role of the downward domestic and global demand shocks in contributing to the decline in inflation.

Additionally, Eickmeier & Hofmann (2022) explain the recent upsurge in

[2] In the context of Japan, inflation variations are predominantly accounted for by nominal shocks. On the other hand, in Italy, supply shocks appear to be the primary explanatory factor.

inflation observed in the US and the euro area since mid-2021. According to their analysis, inflationary pressures in the US economy resulted from the combination of highly expansionary demand and constrained supply conditions. In the case of the euro area, their investigation also revealed a similar pattern. However, tight supply conditions have been more substantial compared to the US, particularly during the first two quarters of 2022. This observation aligns with the severe energy supply constraints faced by the eurozone due to the Russia-Ukraine war. These findings are consistent with those reported by Gonçalves *et al.* (2022).

Regarding the Czech Republic and current context, Keseliová *et al.* (2023) provide an explanation for the deviation from the CNB's 2% inflation target that began in 2021. They begin by examining economic trends abroad and note a gradual increase in inflationary pressures in foreign markets during the spring of 2022, attributed to disrupted global value chains and an increase in energy commodity prices. The outbreak of war in Ukraine further exacerbated the increase in prices, resulting in an energy crisis. This aligns with Eickmeier & Hofmann (2022) and Gonçalves *et al.* (2022). Subsequently, they contextualise the domestic economy environment and note that the rapid recovery of domestic demand following the relaxation of most anti-pandemic restrictions led to an inflationary environment by mid-2021. The elimination of the super-gross wage and other fiscal measures combined with an overheated labour market with low unemployment rates, led to the stimulation of demand, as households were willing to accept rising prices. This enabled firms to increase their prices further and compensate for their pandemic-related losses by rising their profit margins. Additionally, the authors evaluate the Czech monetary policy and argue that the CNB should have implemented less accommodative monetary policy in the past. They note that the CNB kept interest rates close to zero in early 2021 due to uncertainty about the duration of disruptions to global value chains and their impact on prices. However, contrary to expectations, demand-pull inflationary pressures did not ease as anticipated, partly due to the implementation of fiscal measures. The effect of monetary policy was combined with an overheated domestic economy and labour market, as well as high growth in energy prices that gradually affected all price categories.

Furthermore, Brůha *et al.* (2022) conducted an analysis of the contributing factors to domestic consumer price inflation. The findings indicate that demand factors have substantially impacted core inflation more than supply factors since late 2021. However, the effect of demand pressures has gradually diminished since the third quarter of 2022. Nonetheless, from a long-term perspective, the influence of demand factors on core inflation remains significant.

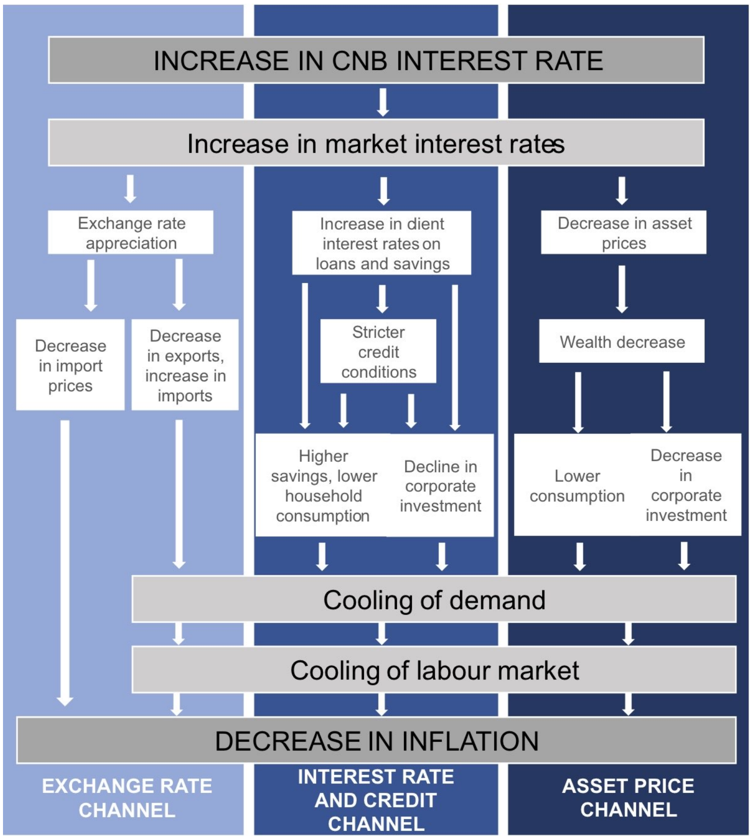
2.2 Effectiveness of Monetary Policy Instruments

The primary aim of the CNB is to ensure price stability in the economy, which has been pursued by implementing an inflation-targeting regime since 1998. The inflation target of 2%, measured by the CPI, has been publicly announced since 2010. The CNB adjusts the 2W repo rate to steer inflation toward the desired target. Additionally, the exchange rate serves as a complementary instrument for monetary policy (Kukal *et al.* 2014). Given the fact that Czech Republic is characterised as a small open economy with a managed floating exchange rate (Geršl & Holub 2006), it is worthwhile to investigate the degree to which contractionary monetary policy instruments, such as increasing the interest rate or selling foreign exchange reserves, are efficacious in promoting inflation stabilization. In addition, it would be interesting to examine the extent to which the effectiveness of these tools in mitigating inflationary pressures is influenced by the nature of the underlying economic shock, as also stated by Ha *et al.* (2020).

Brázdik *et al.* (2021) provide an explanation of the pass-through mechanism of the CNB interest rate to prices in the Czech economy. The authors note that three transmission channels, namely the exchange rate channel, the interest rate and credit channel, and the asset price channel, have a significant impact on the overall effect of interest rate changes on the economy, as illustrated in Figure 2.1. The exchange rate channel is the most rapid transmission channel. This is attributed to the instantaneous expansion of the interest rate differential in relation to the rest of the world. On the other hand, the transmission of a monetary policy shock through the interest rate and credit channel is characterised by a delay that arises from the inertia in households' consumption patterns and firms' demand for labour and capital. The empirical model indicates that a rise in interest rates by 1 percentage point results in a reduction in inflation by approximately 0.4 percentage points. The peak of the impact is observed after a time frame of 20 to 24 months.

It is generally believed that monetary policy transmission to the economy has extensive and variable lags. In order to look into the causes of diversity

Figure 2.1: Interest Rate Transmission Channel



in reported transmission lags, Havránek & Rusnák (2012) undertake a meta-analysis of 67 prior empirical studies on the transmission of monetary policy. The maximum price decline is 0.9 percent on average following a policy rate increase of 1 percentage point, and the average transmission lag is 29 months. The study identifies financial development as the primary factor underlying this variability. Specifically, transmission lags are found to be larger in developed countries (25 to 50 months) than in emerging economies (10 to 20 months). This can be explained by the fact that countries with more developed financial systems offer financial institutions more options to hedge against unforeseen changes in monetary policy, causing monetary policy shocks to be transmitted with a longer lag period.

Using a VAR model analysis, Arnoštová & Hurník (2005) conduct a study to investigate the impact of a monetary policy shock in the Czech economy. The findings suggest that an unanticipated contractionary monetary policy results in a decrease in output, while prices display persistence for a certain duration. The paper tackles the exchange rate puzzle; when the policy regime change is removed from the data sample, the exchange rate response becomes intuitive, i.e., an appreciation immediately follows the tightening of monetary policy. As a result, a notable decrease in prices occurs after approximately two quarters, reaching its maximum drop after one and a half years.

Additionally, Kim & Roubini (2000) tackle liquidity, price, exchange rate and forward discount bias puzzles with a structural VAR model and suggest that monetary authorities in small open economies should be permitted to respond contemporaneously to exchange rate shocks.

Performing a meta-analysis to further address the price puzzle problem, Rusnák *et al.* (2013) conclude that the issue is brought on by model misspecifications, such as the exclusion of commodity prices, disregard for output gap, or use of recursive identification. Furthermore, according to the findings, the degree of central bank independence, economic cycle stage, and openness of the nation all affect how effective monetary policy is.

Franta *et al.* (2014) study the evolution of the monetary policy transmission mechanism in the Czech Republic between 1996 and 2010. The objective is to determine whether GDP and price levels responded differently to exchange rate or interest rate shocks. The findings indicate that prices have become more sensitive to the initial impact of a monetary policy shock. Nonetheless, it should be noted that the 68% credible intervals indicate considerable uncertainty concerning these results. Additionally, the authors demonstrate that the exchange rate pass-through has remained relatively stable throughout the period under investigation.

In addition, Havránek *et al.* (2016) focus on the interest rate pass-through in the Czech Republic before and after the fall of Lehman Brothers. The authors present a comprehensive analysis of the pass-through of financial market interest rates to client rates for various loan and deposit products offered by commercial banks in the Czech Republic. Their study highlights the Czech Republic as an interesting case study, since its banking sector remained stable during the financial crisis and did not experience the same level of disruption as many other European countries. It is hence argued that any observed change in the interest rate pass-through can be attributed to modifications in the banks' pricing policies rather than changes stemming from banks' liquidity issues. The authors further contend that the financial crisis caused a significant shift in the interest rate pass-through mechanism, with a substantial weakening of the pass-through for all product categories except mortgages. Prior to the crisis, the long-term pass-through was almost complete for most products.

Similar findings are made by Babecká-Kucharčuková *et al.* (2013), who suggest that the global financial and economic crisis may have hindered and impaired the transmission of monetary impulses in the Czech economy. According to the authors, changes in how the interest rate channel operates are primarily due to rising risk premiums.

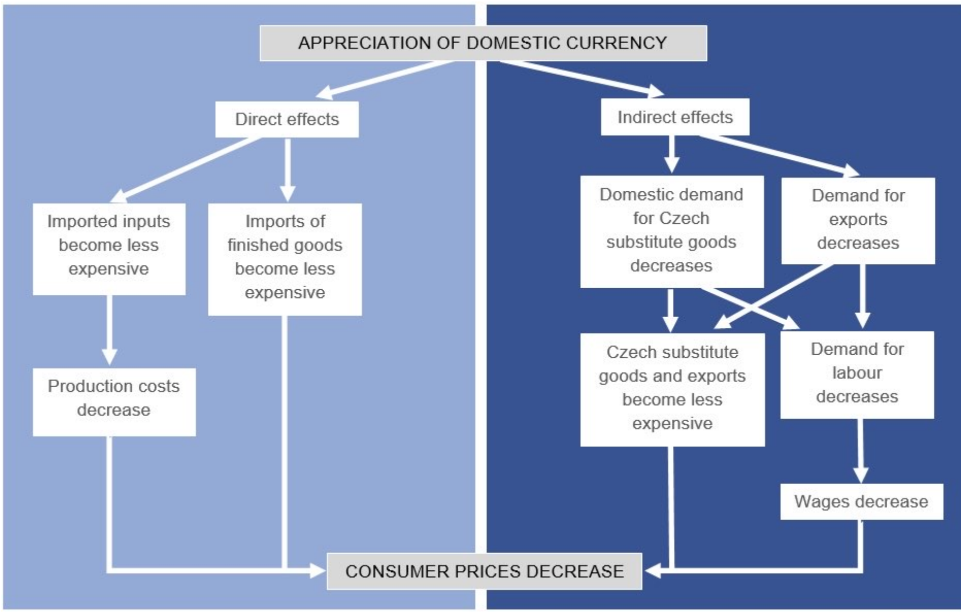
Ha *et al.* (2020) investigate the extent of exchange rate pass-through (ERPT) into consumer prices and identifies the crucial role played by the nature of the shock that induces currency movements. The research paper reveals that monetary policy shocks lead to higher exchange rate pass-through measures than other domestic shocks, whereas global shocks exert different impacts across countries. In particular, countries that adopt flexible exchange rate regimes and credible inflation targets tend to exhibit lower pass-through measures, owing to the central bank's independence, which facilitates the stabilization of inflation by utilising the exchange rate as a buffer against external shocks. Consequently, the findings suggest that the examination of ERPT necessitates the consideration of the shock causing currency movements and the country-specific characteristics that affect price responses.

Using a Bayesian VAR model with zero and sign restrictions, Comunale & Kunovac (2017) examine the ERPT in the euro area and for four specific countries - Germany, France, Italy, and Spain. The findings indicate that the pass-through in the euro area is not constant over time, and it may depend on the mix of economic shocks that influence the exchange rate. In terms of the relative importance of individual shocks, the pass-through is strongest when the exchange rate movement is caused by monetary policy and exchange rate shocks. Nonetheless, overall, the analysis notes a minimal ERPT to consumer inflation in the euro area.

Forbes *et al.* (2018) demonstrate that prices respond differently to exchange rate movements based on the underlying causes of such movements. Specifically, the study reveals that the pass-through of exchange rates is modest when triggered by domestic demand shocks, while it is more pronounced when associated with domestic monetary policy shocks.

Baxa *et al.* (2019) investigate the ERPT in the Czech Republic during a period when the CNB intervened in the foreign exchange market in response to deflationary pressures. Notably, the robustness of the results remains intact even after the exclusion of the period during which the exchange rate floor and the zero lower bound were implemented. The authors find that a 7% depreciation of the Czech koruna against the euro in November 2013 led to a price level increase of 0.13%-0.33%. Based on this finding, they conclude that the impact of the exchange rate commitment on inflation is rather limited. Figure 2.2, adapted from Baxa *et al.* (2019) to depict the case of currency appreciation, illustrates the mechanism by which exchange rate shocks are transmitted. The pass-through of such shocks to consumer prices takes place through several channels, including direct effects on imported inputs and goods prices, as well as indirect effects on export prices and wage formation.

Figure 2.2: Exchange Rate Shock Transmission Mechanism (Based on Baxa *et al.* (2019))



While effecting this transformation to the case of appreciation, it is important to consider the findings of Delatte & López-Villavicencio (2012), who provide evidence that price adjustments are more pronounced in response to currency depreciations compared to appreciations. Put differently, domestic prices tend to rise more significantly in response to a domestic currency depreciation, than they decline on account of a domestic currency appreciation. In the case of appreciation, the authors suggest that domestic importers lack a strong incentive to lower their prices due to the resulting increase in profits caused by the exchange rate shift, indicating weak market competition and downward price rigidities.

Chapter 3

Methodology

3.1 Reduced Form VAR Model

In accordance with Dieppe *et al.* (2016), the following reduced form VAR model with n variables and p lags is constructed:

$$y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + \varepsilon_t, \tag{3.1}$$

where $y_t = (y_{1,t}, y_{2,t}, \ldots, y_{n,t})$ for $t = 1, \ldots, T$ is an $n \times 1$ vector of endogenous variables, $A_1, A_2, \ldots, A_p$ are $n \times n$ matrices of coefficients (autoregressive parameters), c is an $n \times 1$ vector of intercepts, $\varepsilon_t = (\varepsilon_{1,t}\varepsilon_{2,t} \ldots \varepsilon_{n,t})$ is an $n \times 1$ vector of residuals following a multivariate normal distribution: $\varepsilon_t \sim N(0, \Sigma)$. The residual (variance-)covariance matrix is defined as:

$$E(\varepsilon_t \varepsilon_t') = \Sigma, \tag{3.2}$$

or

$$E \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \vdots \\ \varepsilon_{n,t} \end{pmatrix} \begin{pmatrix} \varepsilon_{1,t} & \varepsilon_{2,t} & \cdots & \varepsilon_{n,t} \end{pmatrix} = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1n} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{n1} & \sigma_{n2} & \cdots & \sigma_{nn} \end{pmatrix} \tag{3.3}$$

This matrix Σ is typically not diagonal, indicating that the reduced-form shocks in ε_t are correlated. To address this issue, a set of structural uncorrelated shocks needs to be extracted. This can be done using the SVAR approach, which allows for obtaining responses of variables to orthogonal shocks.

3.2 SVAR Model

3.2.1 Model

The SVAR model represents an alternative specification of the model described by Equation 3.1:

$$D_0 y_t = c + D_1 y_{t-1} + D_2 y_{t-2} + \cdots + D_p y_{t-p} + \eta_t, \tag{3.4}$$

with $\eta_t \sim N(0, \Gamma)$ a vector of structural innovations with variance-covariance matrix Γ. Typically, it is desirable for Γ to be diagonal, as this leads to the shocks in η_t being mutually orthogonal. This condition is necessary to obtain accurate impulse response functions that are not impacted by the issue of shock correlation. To simplify the notation, $D = D_0^{-1}$ is defined. Afterwards, by pre-multiplying both sides of Equation 3.4 by D, the relationship between Equations 3.1 and 3.4 can be established readily:

$$\varepsilon_t = D\eta_t, \tag{3.5}$$

which indicates that D can be considered as a structural matrix as it enables the identification of structural innovations from the reduced-form VAR residuals. Additionally, it is worth noting that Equation 3.5 further implies:

$$\Sigma = E(\varepsilon_t \varepsilon_t') = E(D\eta_t \eta_t' D') = DE(\eta_t \eta_t')D' = D\Gamma D' \tag{3.6}$$

The matrix D equired to identify structural shocks is obtained from the covariance matrix Σ. Nevertheless, Equation 3.1 does not provide any information regarding D. Equation 3.6 implies that in a VAR model with n variables, D comprises n^2 elements to be identified, while Γ contains $\frac{n\times(n+1)}{2}$ distinct elements. The identification problem arises because there are fewer parameters estimated in the reduced-form VAR compared to the structural form. Thus, $n^2 - \frac{n\times(n+1)}{2} = \frac{n\times(n-1)}{2}$ restrictions need to be imposed to achieve a just identified system (Dieppe *et al.* 2016).

3.2.2 Choleski Decomposition

The Choleski decomposition represents the most straightforward identification scheme, although its implementation may result in various challenges or puzzles.

First, as suggested by Dieppe *et al.* (2016), within the framework of Choleski decomposition, it is assumed that Γ is diagonal and further simplifies by assuming unit variance for all shocks. This results in $\Gamma = I$, which implies that $\Sigma = D\Gamma D' = DD'$. The identification scheme involves finding a lower triangular matrix D such that $DD' = \Sigma$, where Σ is a symmetric matrix. Practically, this implies that certain variables are assumed not to respond contemporaneously to certain structural shocks.

Nevertheless, as observed in previous studies such as Estrella (2015) and Krusec (2010), the application of this identification scheme in the present analysis results in a price puzzle. Dieppe *et al.* (2016) suggest that assuming $\Gamma = I$ may be overly restrictive, as it assumes that all structural shocks have a similar unit variance, even though the variance may vary from unity and different shocks may have different sizes. The orthogonalization of the shocks can be obtained via more sophisticated methods which ensure larger flexibility and address the price puzzle more effectively.

3.2.3 Zero-Sign Identification Pattern

As seen in previous works by Forbes *et al.* (2018) or Kronborg (2021), a combination of zero short-run and sign restrictions is utilised to accommodate the small open economy assumption. The latter allows for relatively loose assumptions about the responses, such as certain shocks causing an increase or decrease in one or more endogenous variables, as discussed by Uhlig (2017). Arias *et al.* (2018) describe the orthogonalization with the aid of zero and sign restrictions implemented in this work. As noted by Dieppe *et al.* (2016), the objective is to identify a structural matrix D that ensures the structural impulsive response functions (IRFs) generated from model 3.4 conform to the zero and sign restrictions. For further details, see Arias *et al.* (2014) or Arias *et al.* (2018).

This study examines the effect of seven types of shocks, including domestic demand, domestic supply, domestic monetary policy, exchange rate, domestic fiscal policy, foreign demand and supply shocks. Kilian & Lütkepohl (2017) and Kuschnig & Vashold (2021) highlight the importance of ensuring that the shocks are uniquely identifiable. Additionally, Arias *et al.* (2018) further emphasize that a maximum of $n - j$ zero restrictions can be applied to the jth column. The restrictions are presented concisely in Table 3.1.

Similarly to Kronborg (2021), given that the Czech Republic is characterised as a small open economy, it can be hypothesised that domestic shocks

Table 3.1: Identification Matrix

Variable\Shock	Domestic D	Domestic S	Monetary Policy	Exchange Rate	Fiscal Policy	Foreign D	Foreign S
Real Output	+	−			+	+	−
Inflation	+	+	−	−		+	+
Interest Rate	+		+				
Exchante rate	−		−	−			
Gvt Expenditure					+		
Import Prices				−			+
Real Exports	0	0				+	

Note: A "0" ensures that this variable cannot move contemporaneously in response to the particular shock. A " + "(" − ") indicates that this variable must respond positively (negatively) to the particular shock. No sign () implies that the variable is not expected to respond to the specific shock in any particular direction.

do not immediately affect real exports in the Czech Republic. Appropriate zero restrictions are imposed on the exports responses to ensure this. Nevertheless, despite this assumption, both import prices and real exports are endogenously incorporated into the model, as it is possible that imposing a block exogeneity of these variables could be overly restrictive. As a result, the zero restrictions are only applicable in period $t = 0$, and then, the impact is allowed to propagate through subsequent lags.

Afterwards, as stated by Forbes *et al.* (2018), the application of multiple short-term sign restrictions in economic models is justified by open-economy DSGE models. The application of these sign restrictions has been extensively utilised in previous research and demonstrated to conform to theoretical models, as illustrated by Fry & Pagan (2011). To be more precise, domestic demand shocks affect real output and prices positively, and cause a contractionary monetary policy response as well as an exchange rate appreciation (noted with a negative sign due to the use of CZK/EUR), as argued by Ellis *et al.* (2014). Despite the exchange rate appreciation that follows a domestic demand shock, inflation still rises. This is attributed to the assumption that the increase in prices resulting from stronger demand is more significant than the decrease in prices due to the appreciation and cheaper imports (Forbes *et al.* 2018; Comunale & Kunovac 2017). Afterwards, domestic supply shocks affect real output positively but prices negatively (Hjortsoe *et al.* 2016; Mountford 2005). In terms of monetary policy shocks, a rise in the interest rate corresponds to a decline in inflation, as well as an appreciation of the exchange rate. These assumptions are supported by the research of Forbes *et al.* (2018) and Comunale & Kunovac (2017). The exchange rate appreciation is associated with a decrease in both domestic import and consumer inflation (Audzei & Brázdik 2018). Based on the findings of Mountford & Uhlig (2009) and Giordano *et al.*

(2007), an increase in government spending is assumed to affect real output positively. Regarding the foreign shocks, these demand and supply shocks (identified via an increase in Czech real exports and Czech import prices, respectively) are assumed to influence domestic real output and inflation. On the basis of Kronborg (2021), including exports in the analysis provides a more accurate estimate of the impact of foreign shocks on the Czech economy. For instance, if only real output is considered, it becomes difficult to differentiate between the direct impact of exports and the effects caused by the resulting increase in domestic demand due to changes in the business cycle. Additionally, the import price index is a significant measure of the interface between domestic and foreign economies since it is influenced by foreign prices and fluctuations in the exchange rate. The changes in import prices reflect both the direct effects of foreign shocks on foreign export prices and their pass-through to import prices, as well as the pass-through effects from the exchange rate (Forbes *et al.* 2018).

3.3 Bayesian Framework for SVAR Model

The fundamental principle of Bayesian econometrics is to conceptualize model coefficients as conditional probabilities, rather than as fixed parameters with a "true" value. This approach involves treating each parameter of interest as a random variable with an underlying probability distribution. Bayesian analysis combines any prior knowledge the econometrician may have about the distribution of parameters (the prior distribution) with the information empirically derived from the data (the likelihood function) to produce an updated distribution (the posterior distribution) (Dieppe *et al.* 2016).

Kuschnig & Vashold (2021) note that the number of coefficients to be estimated in VAR models, $T + T^2p$, increases quadratically with the number of included variables and linearly with the lag order, which can lead to errors in structural inference known as the "curse of dimensionality". Bayesian methods can impose supplementary structure on the model to reduce the number of coefficients and errors. More specifically, using prior information can result in the desired shrinkage.

3.3.1 Priors for VAR Model

Giannone *et al.* (2015) suggest that, from a Bayesian viewpoint, the decision of how informative a prior distribution should be is equivalent to the inference of any other unknown parameter in the model. The authors illustrate this by considering a model consisting of a likelihood function $\pi(y|\theta)$ and a prior distribution $\pi_\gamma(\theta)$, where θ is a vector of parameters, and γ is a set of hyperparameters that parameterize the prior distribution but do not impact the likelihood directly. Selecting the hyperparameters for a model can be achieved by adopting a hierarchical approach. This involves substituting $\pi_\gamma(\theta)$ with $\pi(\theta|\gamma)$, followed by assessing the posterior distribution of the hyperparameters using Bayes' law (Equation 3.7). Indeed, prior hyperparameters are set based on data and are considered as additional parameters to be estimated. These hyperparameters are assigned their own hyperpriors in the hierarchical approach (Kuschnig & Vashold 2021).

$$\pi(\gamma|y) \propto \pi(y|\gamma)\pi(\gamma), \tag{3.7}$$

where $\pi(\gamma)$ refers to the prior density on the hyperparameters (the hyperprior) and $\pi(y|\gamma)$ denotes the marginal likelihood (ML). The hyperprior is hence a "second-order" prior assigned to a hyperparameter, which transforms the hyperparameter into a random variable under a hierarchical model. This approach offers the advantage of freeing the researcher from the challenge of explicitly specifying the hyperparameter value. Additionally, it also accounts for and quantifies the uncertainty associated with the hyperparameter. On the other hand, the ML is a measure of the extent to which a model fits the observed data when provided with a specific set of hyperparameters. It can be determined by integrating out the model's parameters θ (Equation 3.8) and, therefore, the uncertainty surrounding them.

$$\pi(y|\gamma) = \int \pi(y|\theta, \gamma)\pi(\theta|\gamma)d\theta \tag{3.8}$$

Prior beliefs regarding parameters can be specified in numerous ways, as discussed by Koop *et al.* (2010), among others. In this work, according to Giannone *et al.* (2015), natural conjugate priors are utilised. These prior distributions are classified under the Normal-Inverse-Wishart family:

$$\Sigma \sim IW(\Psi; d), \tag{3.9}$$

$$\beta|\Sigma \sim N(b, \Sigma \otimes \Omega), \tag{3.10}$$

where Ψ, d, b and Ω are functions of a vector of hyperparameters γ. The vector b and the matrix Ω are known. Hence, it is necessary to specify a prior for the covariance matrix Σ and also, a prior for the vector of regression parameters $\beta = vec(A)$ (with $A = [c, A_1, \ldots, A_p]^T$) that conforms to the Kronecker structure $\otimes$ of the likelihood function. In fact, the term "natural" indicates that priors are from the same family of distributions as the likelihood and posterior, while conjugacy implies that the ML is available in closed form, thereby facilitating efficient computation. As such, the analytical posterior can be obtained from the natural conjugate prior without assuming that Σ is known (Kuschnig & Vashold 2021).

To be more precise, the following three prior densities are combined.

The baseline prior is a variant of the Minnesota prior originally proposed by Litterman (1980). It is based on the assumption that each variable follows a random walk process and is characterised by hyperparameters λ, α and ψ. The crucial hyperparameter λ regulates the tightness of the prior, determining the relative importance of prior and data. The key observation is that this hyperparameter is convergent: as $\lambda \to 0$, the prior becomes more influential than the observed data, and the posterior distribution approaches the prior. Hyperparameter α governs the degree of shrinkage applied to remote observations. Additionally, ψ_j, the jth variable of Ψ, shrinks lags of variables other than the dependent.

The Minnesota prior is frequently enhanced with supplementary priors in order to alleviate the influence of the deterministic component, which is deduced from VAR models estimated by conditioning on initial observations. As such, two pre-defined dummy-observation priors, namely the sum-of-coefficients (SOC) and single-unit-root (SUR) priors, are incorporated into the model. The SOC prior is designed such that it centres the prior beliefs at 1 for the sum of coefficients on own lags for each variable and at 0 for the sum of coefficients on other variables' lags. The SOC prior hence implements a correlation among the coefficients on each variable in each equation, which assists in regularising the estimates and enhancing their precision. The hyperparameter μ regulates the variance of the prior beliefs. The prior beliefs become uninformative when $\mu \to \infty$. On the other hand, when $\mu \to 0$, the presence of a unit root in each equation is indicated, thereby excluding cointegration (correlation among multiple time series over a prolonged period). The discrepancy between the SOC prior and the concept of cointegration leads to using SUR prior, which permits the cointegration among the data. The tightness of this prior is determined by the hyperparameter δ. Similar to the previous cases, when $\delta \to 0$, all the variables of the VAR are constrained to their unconditional mean or the system is characterised by an unspecified number of unit roots without less accuracy (Kuschnig & Vashold 2021; Giannone *et al.* 2015).

Hyperparameters λ, α, ψ, μ, and δ are therefore treated as additional parameters. The selection of specific values for the hyperparameters is based on the works of Sims & Zha (1998), Giannone *et al.* (2015) and Kuschnig & Vashold (2021). Specifically, Gamma densities with modes set to 0.2, 1, and 1, respectively are chosen as hyperpriors for λ, μ, and δ. The standard deviations for the hyperpriors equal 0.4, 1, and 1, respectively. Afterwards, the hyperparameter α is not treated hierarchically, and instead is specified through a fixed value determined by the mode argument equal to 2. ψ is set automatically, such that it equals the square root of the innovations variance. As suggested by Giannone *et al.* (2015), including proper hyperpriors ensures the properness of the posterior distribution. This is particularly relevant when the curvature of the ML is low, indicating weak evidence about the parameters from the available data. Under such circumstances, the choice of hyperparameters can considerably impact the posterior distribution. Indeed, non-flat hyperpriors can stabilise inference, improving accuracy of the estimation. In conclusion, the success of this hierarchical approach is attributed to its ability to determine the appropriate degree of shrinkage automatically. Specifically, the method implements tighter priors when the model includes numerous unknown coefficients compared to the available data, whereas looser priors are utilised in the opposite scenario.

3.3.2 Metropolis-Hastings Algorithm

According to Kuschnig & Vashold (2021), the final step before estimation involves adjusting the Metropolis-Hastings (MH) algorithm. This algorithm is a widely used Markov chain Monte Carlo (MCMC) method for Bayesian inference. Roberts & Smith (1994) highlight that MCMC simulation methods are used to explore and estimate features of likelihood surfaces and Bayesian posterior distributions. The primary advantage of MCMC simulation is the convergence of draws towards the true values of parameters as the number of iterations increases. The MH algorithm hence ensures that the initial draws or serial correlations do not impact the estimation of the mean of the parameter θ_i (Kuschnig & Vashold 2021).

3.3.3 Model Specification and Estimation

Upon configuring the model's priors and the MH step, it is possible to specify further and estimate the model. The arguments include likewise a specified lag order denoted as p (Kuschnig & Vashold 2021). The model is estimated using two lags of the endogenous variables, which is further discussed in Chapter 5. The algorithm undergoes 50,000 iterations; however, the initial 45,000 draws are excluded. Moreover, a denominator is established to determine the proportion of draws to retain (known as "thinning") in order to prevent undue autocorrelation, so that every 5th draw is retained. In estimating this model, the final 1,000 draws are considered accepted for further analysis.

In order to carry out additional analysis, as presented in Chapter 5, such as FEVD, the median of the 1,000 saved models (draws) is employed, using the median target method as suggested by Fry & Pagan (2011).

Chapter 4

Data

4.1 Dataset

The dataset is composed of seven macroeconomic variables: real gross domestic product (RGDP), consumer price index (CPI), three months Prague InterBank Offered Rate (3M PRIBOR), bilateral exchange rate CZK/EUR, government expenditure (GVTEXP), import prices (MPRICES), and Czech real exports (XCZREAL).

The primary data source is the FRED database, with utilised data initially sourced from the OECD or Eurostat. CNB ARAD database contains the bilateral exchange rate. Import prices are collected from the CZSO.

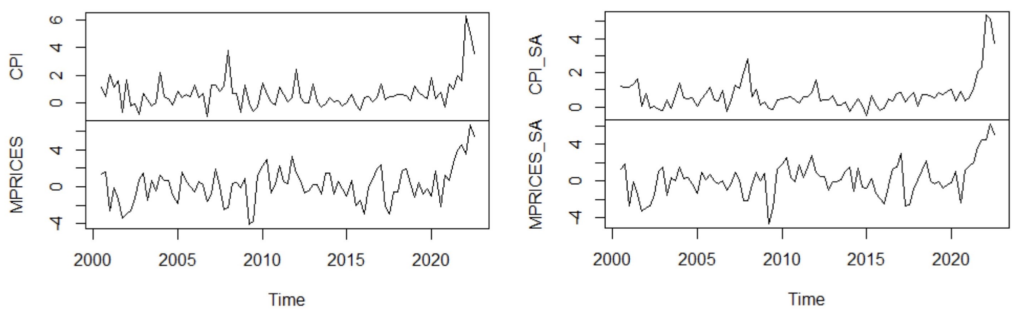
RGDP reflects the real economic activity of the economy and serves as a proxy for a shock to domestic demand. Afterwards, CPI depicts the modifications in prices of consumer goods over time. The interest rate 3M PRIBOR represents the primary tool employed to tackle inflation. Since the eurozone constitutes the primary destination for Czech exports (Mejstřík 2016), the CZK/EUR exchange rate has been selected. A decline in the bilateral exchange rate indicates appreciation. Government spending is the primary measurement used to account for fiscal policy. The import price index is a significant measure of the interface between domestic and foreign economies since it is influenced by international prices and fluctuations in the exchange rate. Shifts in import prices might thus be considered as foreign supply shocks, whereas shifts in real exports as foreign demand shocks.

The data utilised in this study comprises quarterly series depicting the condition of the Czech economy from 2000Q3 to 2022Q3, resulting in a total of 89 observations.

Due to the volatility of the data, all variables except the interest rate are transformed to the quarter-on-quarter growth rate. This approach is preferred to utilising log differentials, which tend to provide a reliable approximation only during normal times, i.e., in times of relative stability, where there are no significant disruptions or crises affecting economic activity. The 3M PRIBOR variable therefore remains in levels.

In order to seasonally adjust the time series CPI and import prices, the X-12-ARIMA procedure was utilised. Figure 4.1 provides a visual representation of this adjustment. It should be noted that 3M PRIBOR and the CZK/EUR exchange rate remain seasonally non-adjusted. Remaining variables were directly obtained seasonally adjusted from the source. The time series used in the primary analysis are presented in Figure 4.2.

Figure 4.1: Time Series Comparison (Non Adjusted vs Adjusted)

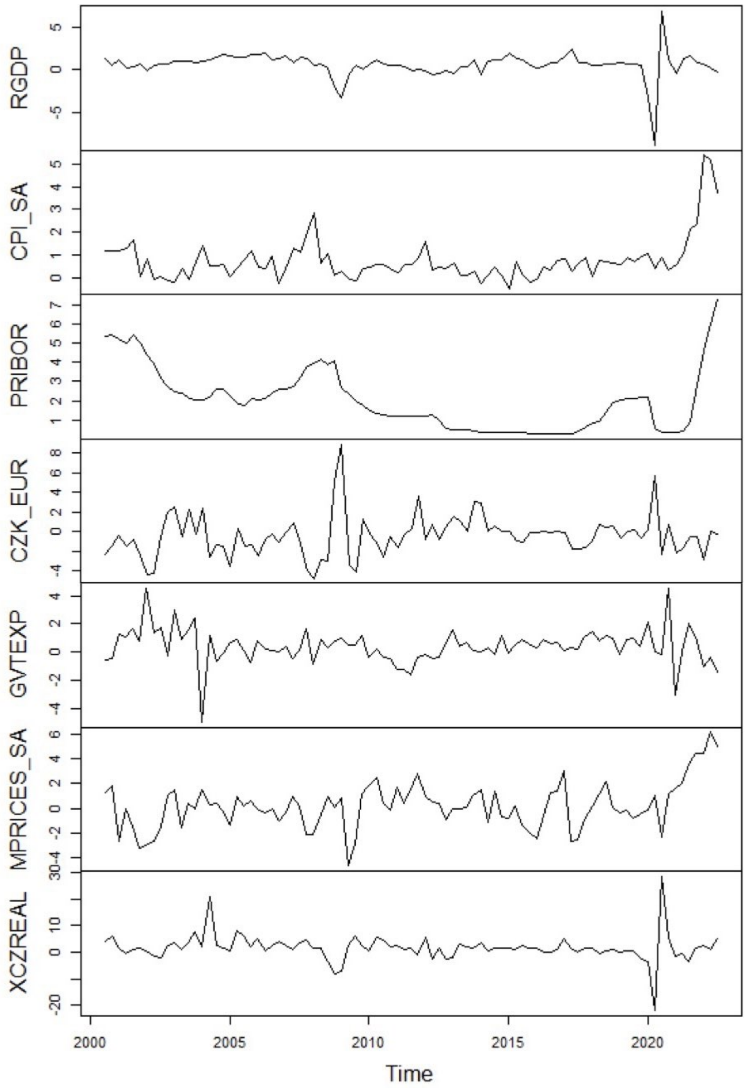


4.2 Data Stationarity

First and foremost, it is crucial to highlight that the entire model's stationary nature matters most in a VAR (Enders 2004). In order to ensure this stability, all variables, except for the 3M PRIBOR, are transformed to quarter-on-quarter growth rates. A more detailed analysis of the reduced form model stability is presented in the following chapter 5. Furthermore, the stability of Bayesian VAR models is ensured through the imposition of conditions on the prior distributions.

Therefore, the fact that some variables are nonstationary does not present an issue. However, it might be of interest to consider whether the variables under study are stationary or to explore how the occurrence of the COVID-19 has impacted their stationarity. The subsequent analysis will employ Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS)

Figure 4.2: Time Series (full sample)



tests to examine the stationarity of utilised time series. The null of the ADF test indicates that the variable has a unit root. Therefore, a p-value smaller than 5% suggests that the variable is stationary. However, according to Korkos (2020), the conventional ADF test may yield spurious results indicating stationary behaviour even when the data is non-stationary, a phenomenon known as “pseudo stationarity”. This implies that the alternative hypothesis fails to exclude the possibility of explosive behaviour in time series. As a result, it is recommended that the KPSS test should be employed in such cases in order to confirm stationarity (Šestořád 2017). The null hypothesis of the KPSS test indicates that the variable is level or trend stationary. Since the data has been quarter-on-quarter transformed, it can be assumed that the percentage changes remain consistent throughout time. Therefore, the null hypothesis test for level stationarity has been chosen rather than testing for trend.

Table 4.1: ADF and KPSS Unit Root Tests Results (full sample)

Variable	ADF test p-value	KPSS test p-value	Result
RGDP	0.02	0.10	I(0)
CPI	0.32	0.10	I(0)
3M PRIBOR	0.78	0.01	I(1)
CZK/EUR	0.01	0.10	I(0)
Gvt Expenditure	0.19	0.10	I(0)
Import Prices	0.63	0.05	I(1)
Real Exports	0.01	0.10	I(0)

Based on the p-values reported in Table 4.1, it is evident that the ADF test fails to reject the presence of a unit root in the CPI, interest rate, government spending and import prices time series. Nevertheless, upon conducting the KPSS test, it is found that only the interest rate and import prices time series exhibits non-stationarity. Thus, it can be inferred that every time series, except for those two, is stationary at 5% significance level.

A pre-COVID-19 sample is likewise evaluated as Figure 4.2 implies that time series behave abnormally due to the COVID-19 pandemic. If the abnormal COVID-19 period is removed from the sample, the p-value in the KPSS test for import prices increases. Thus, the null hypothesis that indicates stationarity can no longer be rejected at 5% significance level (Table 4.2).

Table 4.2: ADF and KPSS Unit Root Tests Results (pre-COVID-19 period)

Variable	ADF test p-value	KPSS test p-value	Result
RGDP	0.15	0.10	I(0)
CPI	0.01	0.10	I(0)
3M PRIBOR	0.08	0.01	I(1)
CZK/EUR	0.01	0.10	I(0)
Gvt Expenditure	0.24	0.10	I(0)
Import Prices	0.07	0.10	I(0)
Real Exports	0.07	0.10	I(0)

Chapter 5

Results and Discussion

5.1 Reduced Form VAR Model Analysis

5.1.1 Model Selection

When selecting the desired lag order p model, the decision is based on various information criteria, including the Akaike Information Criterion (AIC), Schwarz Criterion (SC), Hannan Quinn (HQ) Criterion and Akaike's Final Prediction Error (FPE) criterion.

Table 5.1: Lag Selection Criteria

	AIC	HQ	SC	FPE
2000Q3-2022Q3	6	1	1	2
2000Q3-2019Q4	6	1	1	2

The estimated model has incorporated two lags, as evidenced by the Final prediction error criterion. This is close to the minimum number of lags suggested by other information criteria. Specifically, the HQ and Schwarz information criteria propose only one lag as the optimal choice. However, it should be noted that the Schwarz information criterion penalizes larger models significantly, which may have resulted in an underestimation of the optimal lag number (Šestořád 2017). In contrast, the AIC information criterion suggests a model with more lags than the one employed. In order to see how the results are sensitive to the lag length, a model with more lags is also examined and discussed in the robustness analysis.

The VAR model demonstrates covariance-stationarity (stability) when the impacts of the shocks dissipate over time, which occurs when the eigenvalues of the companion-form matrix are all less than one in absolute value. Some scholars assess model stability by utilising the definition of characteristic roots instead of eigenvalues. Tsay (2005) proposes that for an autoregressive (AR) series to be stationary, all its characteristic roots must have an absolute value less than one. The model summary reveals that it is stable for up to six lags.

5.1.2 Residual Diagnostics

The following four diagnostic tests were conducted on the residuals of the model:

A Portmanteau test can be utilised to test for serial correlation. For multivariate series, the null hypothesis of the test statistic is that all autocorrelations and cross-correlations in the vector series are equal to zero (i.e., H_0: $\rho_1 = \cdots = \rho_m = 0$), while the alternative hypothesis states that at least one correlation coefficient is not equal to zero (i.e., H_a: $\rho_i \neq 0$ for some $i \in 1, \ldots, m$). Thus, this statistic is employed to test the presence of auto- and cross-correlations (Tsay 2005). To interpret these statistics, a p-value greater than 5% typically suggests the absence of serial correlation. In Table 5.2, the p-value of the Portmanteau test at a lag length of 20 is 0.99 for VAR(2), indicating that the assumption of no serial correlation cannot be rejected at the 5% significance level.

To diagnose the presence of heteroscedasticity in the residuals of a VAR model, a multivariate ARCH Lagrange-Multiplier test is commonly employed. This test is used to determine whether the variance of the residuals is constant or not across time. If the p-value resulting from the test is greater than 5%, then it can be concluded that there is no significant heteroscedasticity present in the residuals. The results presented in Table 5.2 suggest that there is no evidence of heteroscedasticity in the residuals.

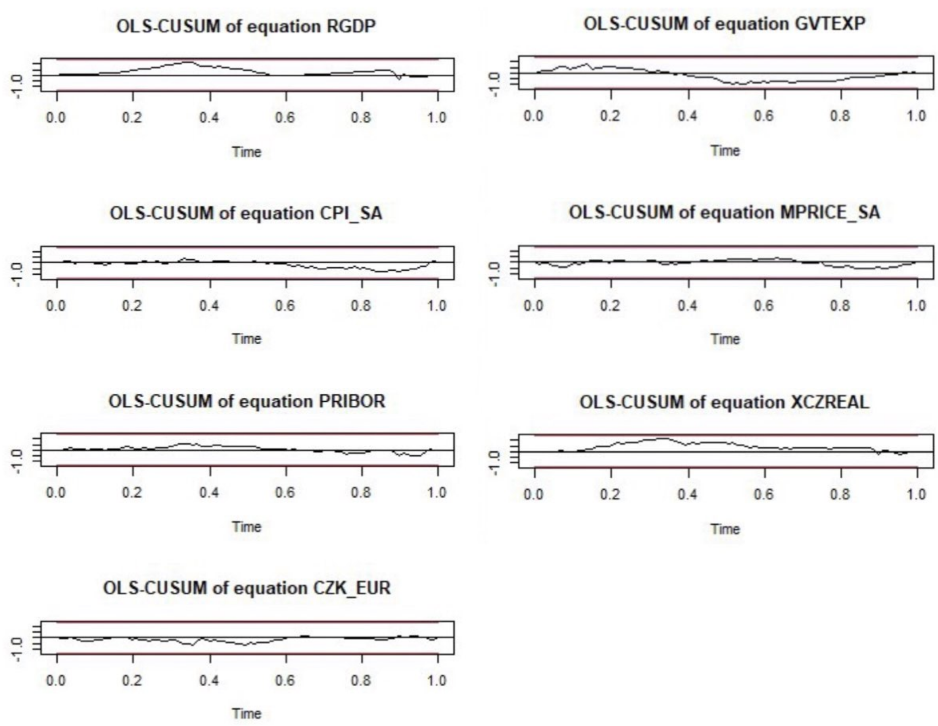
Afterwards, in a frequentist approach, it is typically essential to assess the distributional properties of residuals in a VAR model, as deviation from the assumption of normality can lead to inappropriate confidence intervals. One way to assess normality is by conducting a Jarque-Bera test on the residuals (Lütkepohl 2006). The results presented in Table 5.2 indicate that the p-value obtained from the Jarque-Bera test is less than 5%, which suggests that the residuals do not conform to a normal distribution. Nevertheless, in this thesis, the structural model is then estimated within a Bayesian framework, whereby the posterior distribution is derived through MCMC sampling (Chapter 3). Consequently, violating the normality assumption does not present a severe issue.

Table 5.2: Residual Diagnostic Tests (full sample)

Model\p-values	Portmanteau	Lagrange-Multiplier	Jarque–Bera
VAR(1)	0.99	1.00	0.00
VAR(2)	0.99	1.00	0.00
VAR(3)	0.99	1.00	0.00
VAR(4)	0.88	1.00	0.00
VAR(5)	0.42	1.00	0.00
VAR(6)	0.01	1.00	0.00

Additionally, in order to investigate the possibility of a structural break in the residuals, a CUSUM test is employed. In this case, the CUSUM test (Figure 5.1) does not indicate the presence of a structural break, as none of the time series fall outside the critical values represented by the red lines.

Figure 5.1: CUSUM test

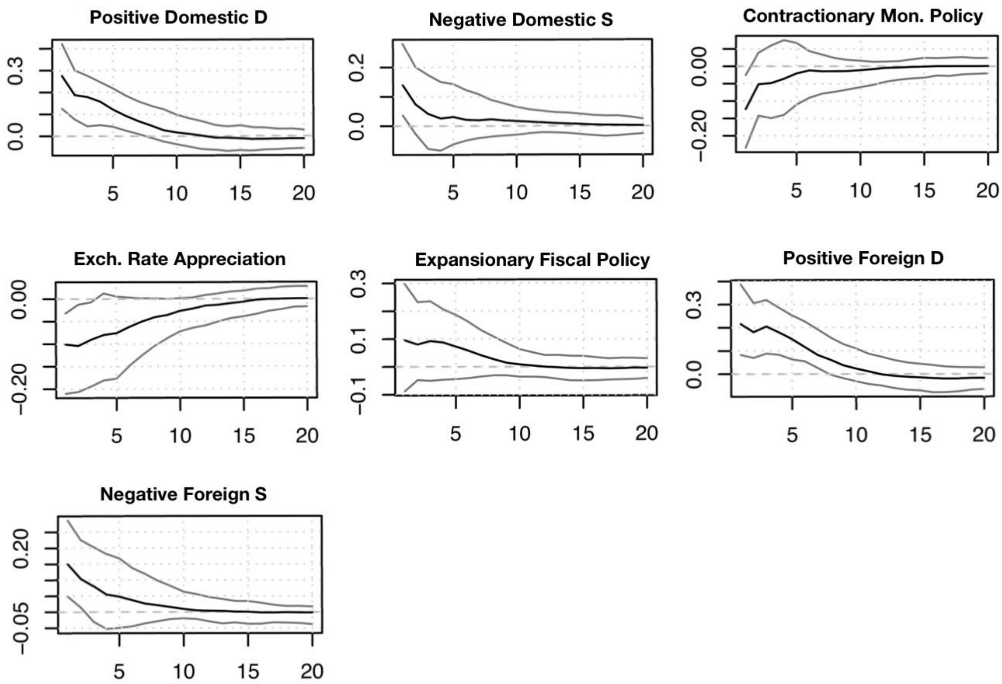


5.2 Structural Analysis

5.2.1 Impulse Response Functions

Figure 5.2 displays the impulse responses of CPI to various shocks, where the solid black line represents the median impulse response, accompanied by a 95% credible interval derived from 1,000 draws. The impulse responses are to one-standard-deviation shocks.

Figure 5.2: Responses of CPI to Different Shocks



The applied identification technique effectively yields well-behaved responses of CPI (Figure 5.2). In response to a positive domestic demand shock, prices increase and eventually return to their steady state after ten quarters. In the case of a negative domestic supply shock, inflation returns to its steady state value after approximately four quarters. Consequently, it may be deduced that domestic demand shocks have a more enduring impact than domestic supply shocks. Furthermore, positive foreign demand and adverse foreign supply shocks temporarily increase domestic prices for approximately ten quarters. Therefore, the findings imply that domestic and foreign demand shocks remain similarly persistent for about ten quarters. However, interestingly, foreign supply shocks demonstrate a greater degree of persistence than domestic supply shocks. As demonstrated by (Dees *et al.* 2010), the persistence of inflation responses to foreign demand and supply shocks varies significantly among countries, and therefore, there is no consistent pattern in these dynamics.

Afterwards, the tightening of interest rates results in a decrease in prices, which gradually subsides after a period of five quarters. This is consistent with existing literature (Borys *et al.* 2009). An appreciation of the exchange rate brings about a decline in prices, which eventually return to their steady-state level after slightly more than ten quarters. This empirical observation is atypical since it is commonly expected that the transmission of an exchange rate shock is shorter than that of a monetary policy shock. However, the persistence of a exchange rate shock is likewise noted by Audzei & Brázdik (2018) for Poland. According to the analysis, an increase in government spending leads to a rise in inflation, implying a nonconflicting economic theory (Migliardo *et al.* 2010).

All estimated responses are presented in the appendix A.1, A.2. It is worth noting that the response of real output to the appreciation shock is somewhat puzzling. The typical assumption is that the appreciation of the koruna would impose a penalty on Czech exporters, which would typically result in a contraction in economic growth in an export-oriented economy such as the Czech Republic. However, the estimated impulse response of real gross domestic product (RGDP) to the appreciation shock (Figure A.1) suggests the opposite, as RGDP exhibits an increase instead. The findings presented do not hence align with prior research, as evidenced by Audzei & Brázdik (2018). To address this inconsistency, additional estimations are conducted and thoroughly discussed in the robustness analysis.

5.2.2 Monetary Policy Implications

To avoid ambiguity, it is essential to clarify that throughout this section, the term "interest rate (IR) shock" denotes an increase in 3M PRIBOR, representing the monetary policy shock throughout this thesis.

This section aims to investigate the impact of IR and ER on inflation and, consequently, to evaluate the effectiveness of monetary policy tools. In order to achieve this aim, normalised CPI responses to IR and ER shocks are calculated at a six-quarters monetary policy horizon[1]. The initial step is to compute the

[1] This term denotes the timeframe within which the central bank is expected to restore inflation to its target level in case of any deviation. Immediate efforts to return inflation to the target may have considerable implications for the stability of the real econ-

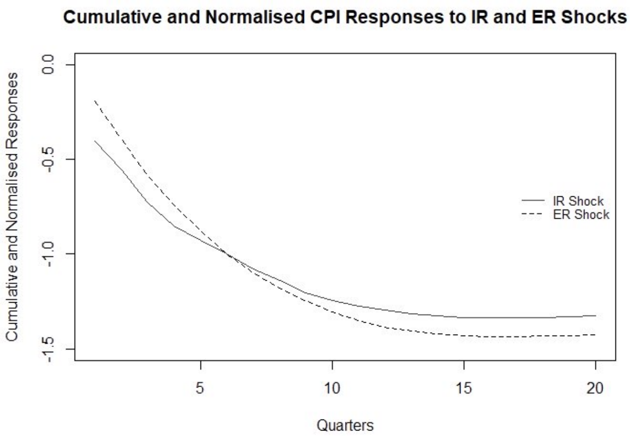
cumulative responses of inflation to the IR shock. To ensure the comparability of results, the median impulse responses are normalised at the monetary policy horizon. This normalisation involves rescaling the responses so that the average impact on the price level after six quarters equals minus one per cent. The scaling constant is then employed to recalculate the magnitude of the original shock. A similar procedure is applied to the ER shock.

Figure 5.3 displays the cumulative responses of prices to both shocks, revealing that the principal effect of both instruments occurs during the initial ten quarters. The impact of the IR channel on reducing the price level is more effective than that of the ER channel at a six-quarters horizon. Conversely, the ER shock becomes more pronounced after this initial period, exhibiting slightly more remarkable persistence. The persistent impact of monetary policy is consistent with previous research. First, Kronborg (2021) observe that the effects of monetary policy shocks on real economic variables are relatively persistent, despite the transitory nature of the shock itself. Furthermore, Jarociński (2010) find that an increase in interest rates can lead to a potentially permanent decline in the price level. These findings align with the results of Franta *et al.* (2014), who conclude that exchange rate shocks have long-lasting effects on prices. Afterwards, a meta-analysis by Havránek & Rusnák (2012) on the transmission of monetary policy suggests that transmission lags are found to be more prominent in developed countries (25 to 50 months) than in emerging economies (10 to 20 months). This can be attributed to the fact that economies with more advanced financial systems provide financial institutions with a broader range of hedging instruments to mitigate unexpected fluctuations in monetary policy, leading to a more prolonged transmission of monetary policy shocks. From the persistence of the shocks displayed in Figure 5.3, one can infer that the Czech economy should be classified as developed. Additionally, several studies conclude that the transmission of monetary policy shock should peak at the monetary policy horizon. Brázdik *et al.* (2021) suggest that the peak of the impact on prices is observed after 20 to 24 months. Arnoštová & Hurník (2005) investigate the impact of a contractionary monetary policy shock in the Czech economy and find that a maximum price decrease occurs after one and a half years. These findings are consistent with the results obtained, as the most significant change in the CPI response to IR shock is observed at a

omy or the financial sector. Thus, central banks usually aim to achieve the inflation target over a more distant horizon of 6 to 8 quarters: `https://www.cnb.cz/cs/o_cnb/cnblog/Jak-dlouhy-je-spravny-horizont-menove-politiky/`

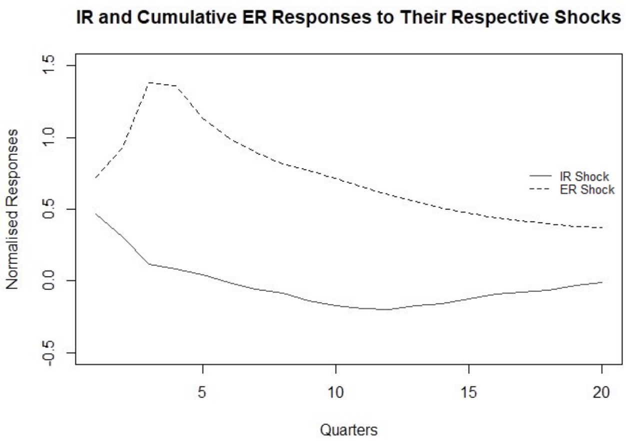
horizon of seven quarters.

Figure 5.3: Cumulative CPI Responses: IR and ER Shocks Comparison



Furthermore, Figure 5.4 illustrates the evolution in IR and cumulative ER responses to their respective shocks. This provides insight into the magnitude of shocks required to achieve changes in the price level over time. The results suggest that a greater appreciation shock (0.72 p.p.) is required to decrease inflation by one p.p. than a tightening IR shock (0.47 p.p.).

Figure 5.4: IR and Cumulative ER Responses to Their Respective Shocks



Note: To facilitate comparison, the cumulative ER response was multiplied by -1. Thus, in this particular instance, a positive value associated with an ER shock indicates currency appreciation.

Upon comparison of the results obtained from this analysis, it appears that a relatively less remarkable initial IR shock is required to reduce inflation by one p.p. Therefore, it can be inferred that tightening the interest rate would be a more effective strategy for curbing inflation at the monetary policy horizon. However, intervening to support the koruna also has long-lasting effects on reducing inflation and, therefore, serves as an effective complementary tool.

5.2.3 Forecast Error Variance Decomposition

FEVD represents an additional tool that is commonly utilised for conducting structural analysis. Its primary purpose is to examine the variables that determine the trajectories of other variables following a specific shock. FEVD can be readily computed in Bayesian vector autoregressive (BVAR) and enables a more comprehensive structural analysis (Kuschnig & Vashold 2021).

Table 5.3 reports the share of the variance for the Czech consumer prices explained by domestic demand, supply, monetary policy, the exchange rate, fiscal policy and two foreign shocks. Overall, it can be noted that demand shocks outweigh supply shocks. The government also plays a substantial role, but monetary conditions have quite minor impact.

Table 5.3: FEVD of CPI (QoQ, in %)

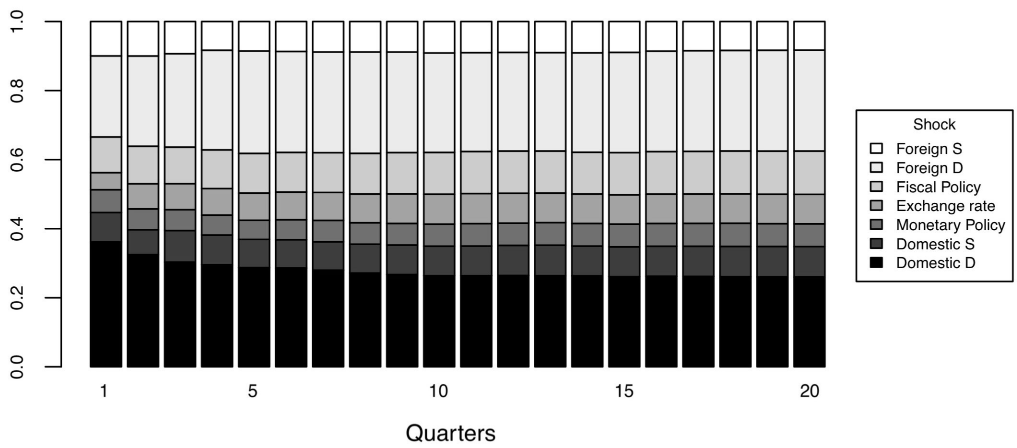
Period\Shock	Domestic D	Domestic S	Monetary Policy	Exchange Rate	Fiscal Policy	Foreign D	Foreign S
1	0.36	0.09	0.07	0.05	0.10	0.23	0.10
2	0.33	0.07	0.06	0.07	0.11	0.26	0.10
3	0.30	0.09	0.06	0.08	0.11	0.27	0.09
4	0.30	0.09	0.06	0.08	0.11	0.29	0.08
5	0.29	0.08	0.06	0.08	0.12	0.30	0.09
6	0.29	0.08	0.06	0.08	0.11	0.29	0.09
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
16	0.26	0.09	0.07	0.08	0.12	0.29	0.09
17	0.26	0.09	0.07	0.09	0.12	0.29	0.08
18	0.26	0.09	0.07	0.09	0.12	0.29	0.08
19	0.26	0.09	0.07	0.09	0.13	0.29	0.08
20	0.26	0.09	0.07	0.09	0.13	0.29	0.08

The analysis results indicate that domestic demand shocks have contributed to approximately 36% of the variation in the price level at a one-quarter horizon. In comparison, foreign demand shocks have accounted for 23%. Over the long term, however, this relationship has been reversed, resulting in domestic demand shocks explaining 26% of the variations in CPI, while foreign demand shocks account for 29%. This significant role of demand factors is in line with recent literature in the Czech Republic (Brůha *et al.* 2022). In contrast, domestic supply shocks exhibit stability, explaining 9% of the variations. Likewise, foreign supply shocks account for 10% after one quarter and 8% in the long run. Additionally, it is noteworthy that over the long term, the role of domestic demand and supply shocks is equivalent to that of foreign ones.

Afterwards, it is found that the contribution of monetary policy and exchange rate shocks is relatively minor in the short term, with each factor explaining only about 7% and 5% of the variance after one quarter, respectively. Over the long term, the impact of monetary policy shocks remains unchanged, accounting for 7% of the variance. A similar observation regarding the modest role of symmetric monetary policy is made by Audzei & Brázdik (2018) for the period between 1998Q1 and 2013Q4 in the Czech Republic. However, in the long term, there is an amplified impact of the exchange rate, contributing to approximately 9% of the variance. The overall limited influence of the exchange rate is also affirmed by Forbes *et al.* (2018) for the period from 1993Q1 to 2015Q1 in the UK.

In contrast, greater importance is attributed to fiscal policy shocks, which account for 13% of the variance in the long run. It is noteworthy that the literature on the inflation determinants, as exemplified by Jovičić & Kunovac (2015) and Eickmeier & Hofmann (2022), generally does not incorporate fiscal policy shocks, so this finding cannot be contextualised. The outcomes are illustrated graphically in Figure 5.5.

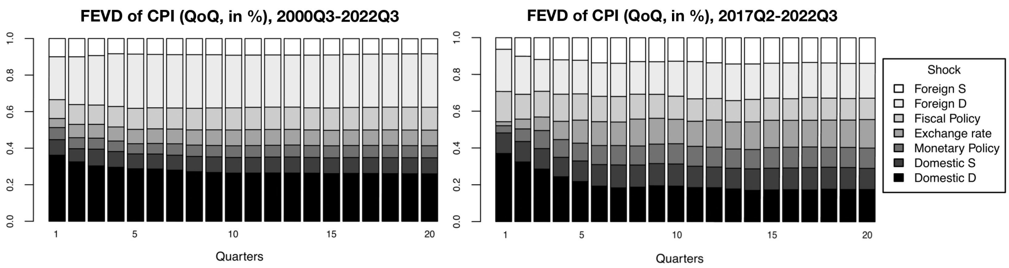
Figure 5.5: FEVD of CPI (QoQ, in %)



5.2.4 Origin of Current Inflation

In order to investigate the underlying causes of the recent increase in inflation in the Czech economy, a comparative analysis is conducted among three baseline models that correspond to distinct time periods. The first model covers the entire period from 2000Q3 to 2022Q3, while the second model spans from 2000Q3 to 2019Q4, before the COVID-19 pandemic. The third model covers the period from 2017Q2 to 2022Q3[2]. This allows for examining the evolution of structural shocks' contribution to inflation and explaining the current inflation in the Czech economy.

Figure 5.6: FEVD of CPI: 2000Q3-2022Q3 vs. 2017Q2-2022Q3 Models Comparison



To begin with, it is worth noting that the FEVD of the CPI for the pre-COVID-19 period model resembles the baseline model, which is discussed in greater detail in the robustness analysis. When examining the variation in the contributions of different factors across the models, as illustrated in Figure 5.6, it is pertinent to highlight that supply factors assume an increasingly prominent role. Specifically, domestic and foreign supply factors have become more important in the model corresponding to the most recent years. This trend aligns closely with the findings of recent studies in the Czech and eurozone contexts (Brůha *et al.* 2022; Eickmeier & Hofmann 2022; Gonçalves *et al.* 2022). According to Keseliová *et al.* (2023), inflationary pressures in foreign markets gradually escalated in the spring of 2022 due to disruptions in global value chains and a surge in energy commodity prices. Despite the recent amplified role of the supply factors, a long-term perspective reveals that demand shocks (37%) continue to play a more prominent role than supply shocks (25%) in explaining the CPI variations, as also stated by Brůha *et al.* (2022).

Furthermore, the exchange rate shock is found to be a significant contributing factor. Cohn-Bech *et al.* (2023) likewise emphasise the notable role of the exchange rate in explaining Hungarian inflation. In the context of eurozone,

[2] The reason for selecting this particular period is due to the decision of the CNB Bank Board in April 2017 to terminate the exchange rate commitment. The Board decided after determining that the future price development aligned with achieving the 2% inflation target sustainably: `https://commission.europa.eu/system/files/2017-04/2017-european-semest/er-convergence-czech-republic-programme-en.pdf`

Leiva-Leon *et al.* (2022) highlight that headline inflation, particularly its energy component, has become considerably more susceptible to exogenous exchange rate shocks since the beginning of the 2010s.

Additionally, the role of fiscal and monetary policy shocks remains mainly unchanged across the models. Consequently, it can be inferred that these shocks do not account for the substantial surge in inflation that has occurred recently within the Czech economy. However, the impact of fiscal policy shocks on the price level remains notable, explaining around 12% of the variations in CPI over the long run.

5.3 Robustness Analysis

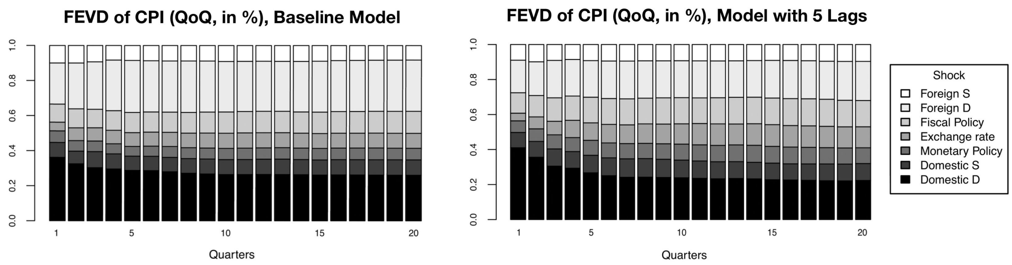
This section offers insights into the degree of sensitivity of the results to different model alterations.

5.3.1 Model (5 lags)

In the principal analysis, the findings indicate that the AIC criterion recommends the utilisation of six lags. Based on the characteristic roots, the model exhibits stability up to six lags. However, upon conducting the Portmanteau test to evaluate residual autocorrelation, a model comprising six lags does not reject autocorrelation. As a result, an alternative model utilising five lags is estimated to assess the model's sensitivity to the lag length.

As depicted in Figure A.7, the credible intervals overlap with those of the baseline model, indicating that the impulse responses obtained in this analysis are nearly indistinguishable from those in the baseline model. However, the findings of the FEVD analysis reveal minor alterations in the respective roles of domestic and foreign demand factors. Specifically, as shown in Figure 5.7, in the short term, domestic demand shocks exert a more substantial influence compared to the baseline model, while both demand factors demonstrate a reduced role over the long run. Notably, in the long term, domestic and foreign demand shocks explain only about 23% of the variability in CPI, respectively, as opposed to their original contributions of 26% and 29%. In addition, there appears to be a slightly more significant impact of monetary and fiscal conditions. Based on these results, it can be concluded that the use of two lags is adequate for capturing the transmission within the economy, as changes in the model with five lags are quite minor.

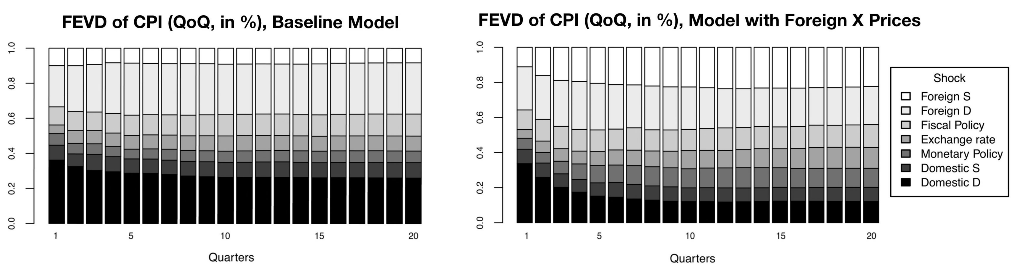
Figure 5.7: FEVD of CPI: Baseline vs. 5-Lags Models Comparison



5.3.2 Model with Foreign Export Prices (2 lags)

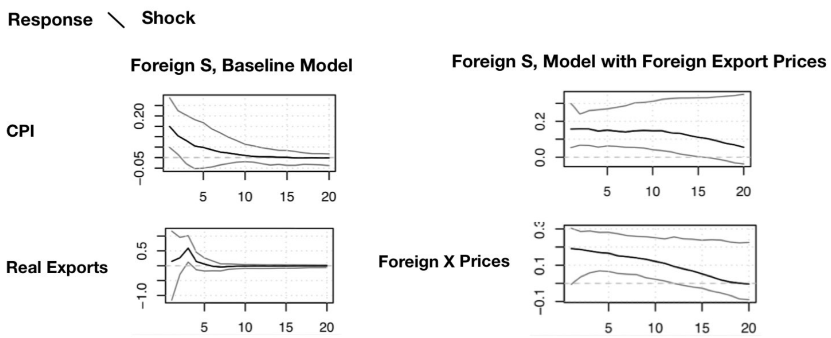
Afterwards, a substitution of real exports with export prices is effectuated. To remind, as Kronborg (2021) argues, the inclusion of real exports in the model facilitates the disentanglement of the effects of foreign shocks on the domestic economy through the trade channel. This is crucial because the exclusion of real exports from the model would result in an inaccurate interpretation of the effects of foreign shocks as a shock to domestic output, which does not reflect reality. On the other hand, Comunale & Kunovac (2017) use foreign export prices, which can also approximate a positive foreign demand shock. If foreign export prices increase, it may lead to higher demand for Czech exports which might be cheaper. This increased demand could boost the Czech economy. Since Germany is the Czech Republic's largest trading partner (World Bank), this analysis includes German export prices sourced from the DESTATIS and converted to the quarter-on-quarter growth.

Figure 5.8: FEVD of CPI: Baseline vs. Foreign Export Prices Models Comparison



Regarding the FEVD of CPI (Figure 5.8), there is a noticeable change over the long term. It can be highlighted that the role of foreign shocks is more substantial, along with a minor role of domestic demand. Foreign supply shocks account for around 24% of the variation in the long run. In contrast, the baseline model shows that foreign supply shocks explain approximately 8% of the variation. It can be hypothesised that foreign export prices can affect domestic inflation through two channels: trade and supply channels. The trade channel functions similarly to when real exports are incorporated into the model. An increase in foreign export prices results in an augmented demand for domestic exports, leading to increased production and income in the domestic economy and, hence, higher inflation. Nevertheless, the supply channel operates distinctively from the trade channel. An increase in foreign export prices may also result in high costs of imported inputs for domestic producers, which can raise production costs and lead to higher prices. This effect could be more pronounced since the Czech Republic relies on imported inputs from Germany. The contrast is also evident in Figure 5.9, which reveals significant variations when examining the impulse responses of CPI to foreign supply shocks. Notably, the model incorporating foreign export prices indicates a persistent price response over the twenty quarters, with much wider credible intervals.

Figure 5.9: IRFs to Foreign Supply Shock: Baseline vs. Foreign Export Prices Models Comparison

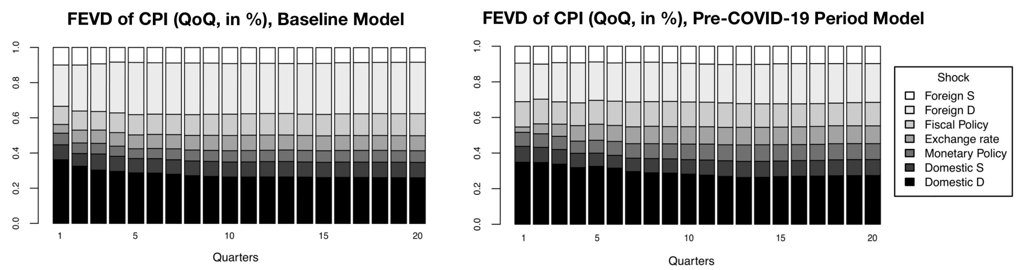


In conclusion, there are visible differences between the two models. Although Germany is the Czech Republic's leading trading partner, it should be noted that in 2020, according to the World Bank, the Czech Republic exported largely also to other countries such as the Slovak Republic, Poland, France, and Austria, and imported goods from countries such as China, Poland, Slovak Republic, and Italy. This suggests that German export prices may not capture the entire spectrum of the Czech economy's dynamics. As a result, it can be hypothesised that the baseline model with real exports provides a more accurate representation of the effects of foreign shocks. The precision of the results is further confirmed by the narrower credible intervals observed in the baseline analysis of the impulse responses.

5.3.3 Pre-COVID-19 Period Model (2 lags)

This estimation aims to analyse the effects of the COVID-19 pandemic and the Ukraine-Russia War. The findings from the impulse responses (Figure A.13) remain remarkably similar to those of the baseline model. Given that the constraints of the model remain unchanged and there is no evidence of a structural break in the time series as indicated by the CUSUM test, the outcomes were predictable. Figure 5.10 suggests that over the long term, the contribution of foreign demand shocks is slightly less remarkable, accounting for approximately 22% of its variability, compared to 29% in the baseline model. The changes, therefore, remain negligible.

Figure 5.10: FEVD of CPI: Baseline vs. Pre-COVID-19 Models Comparison



Overall, the impulse responses exhibit no significant changes. Therefore, as previously mentioned in the main analysis, the problem of the unexpected response of RGDP to an appreciation shock is not resolved by the adjustments made to the model. Nonetheless, remaining responses are widely align with economic theory.

Chapter 6

Conclusion

This paper provides an insightful analysis of the inflation determinants in the Czech Republic over the last two decades. The study employs a structural VAR model incorporating short-run zero and sign restrictions within a Bayesian framework. This structural approach enables the disentanglement of the sources of inflation into seven distinct factors: domestic demand, domestic supply, monetary policy, exchange rate, fiscal policy, foreign demand, and foreign supply.

First, the utilised identification technique has produced impulse response functions of the CPI to various shocks that behave well, indicating the effectiveness of the chosen approach. The results suggest domestic demand shocks have a more persistent impact than domestic supply shocks. Subsequently, the findings indicate that domestic and foreign demand shocks exhibit similar degrees of persistence over roughly ten quarters. Notably, foreign supply shocks display more remarkable persistence than domestic supply shocks. The direction of the impulse responses obtained is consistent with both theoretical and empirical literature. Furthermore, the paper has demonstrated the robustness of the results to various model specifications.

Afterwards, a comparative analysis is carried out among three baseline models, each representing distinct time periods, to investigate the causes of the recent surge in inflation in the Czech Republic. Notably, the model corresponding to the most recent years reveals an increasing prominence of domestic and foreign supply factors. This trend is consistent with recent studies conducted in the Czech Republic and the eurozone (Brůha *et al.* 2022; Eickmeier & Hofmann 2022; Gonçalves *et al.* 2022). Specifically, Keseliová *et al.* (2023)

report a gradual rise in inflationary pressures in foreign markets during the spring of 2022, attributed to disruptions in global value chains and a surge in energy commodity prices. Furthermore, the exchange rate is noted to play a remarkable role.

When analysing the FEVD over the entire period of 2000Q3-2022Q3, it is observed that demand shocks contribute more than supply shocks in explaining the variations in the price level. This is consistent with the findings of Brůha *et al.* (2022). Moreover, the paper highlights the significant role of fiscal policy shocks in accounting for price variations, while monetary conditions have a relatively minor impact overall.

Furthermore, the effectiveness of monetary policy is examined. To do so, cumulative and normalised responses of CPI to both monetary policy and exchange rate shocks are calculated. The results reveal that the primary effect of both instruments occurs during the first ten quarters. It is found that a relatively modest initial interest rate shock is sufficient to decrease inflation by one percentage point. Thus, it can be inferred that tightening the interest rate would be a more effective strategy for controlling inflation at the monetary policy horizon. However, intervening to support the koruna also has long-term effects on reducing inflation and constitutes an effective complementary tool.

In addition, it is possible to conduct further structural analysis by visualising the historical decomposition of error variance to assess the factors contributing to inflation for each year of the sample.

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Appendix A

Supplement Figures

A.1 Principal Analysis

A.1.1 Baseline Model: 2000Q3-2022Q3

Figure A.1: IRFs for Different Variables (1)

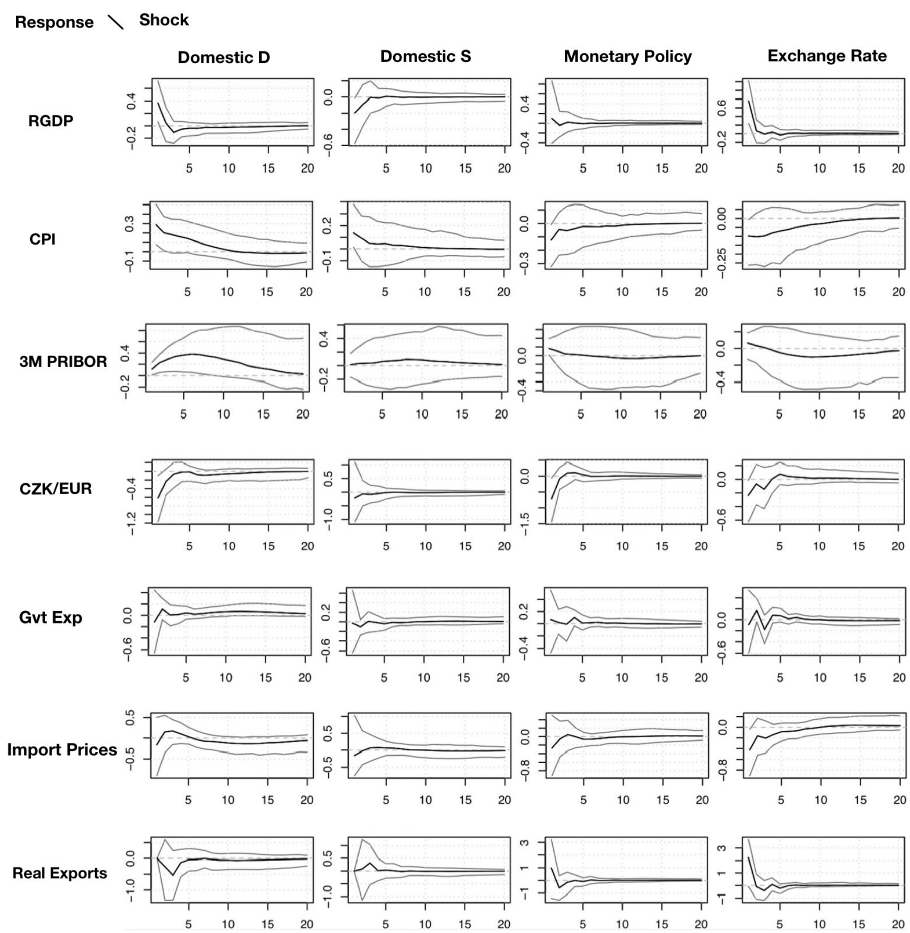


Figure A.2: IRFs for Different Variables (2)

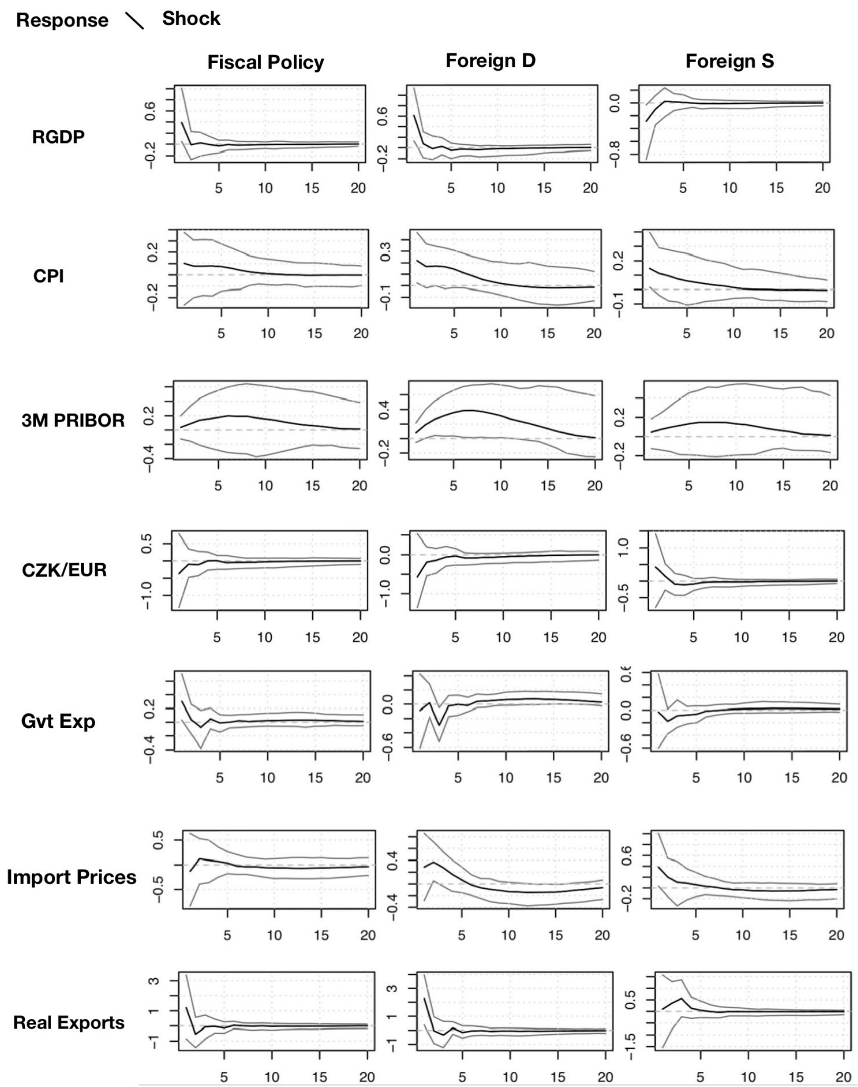
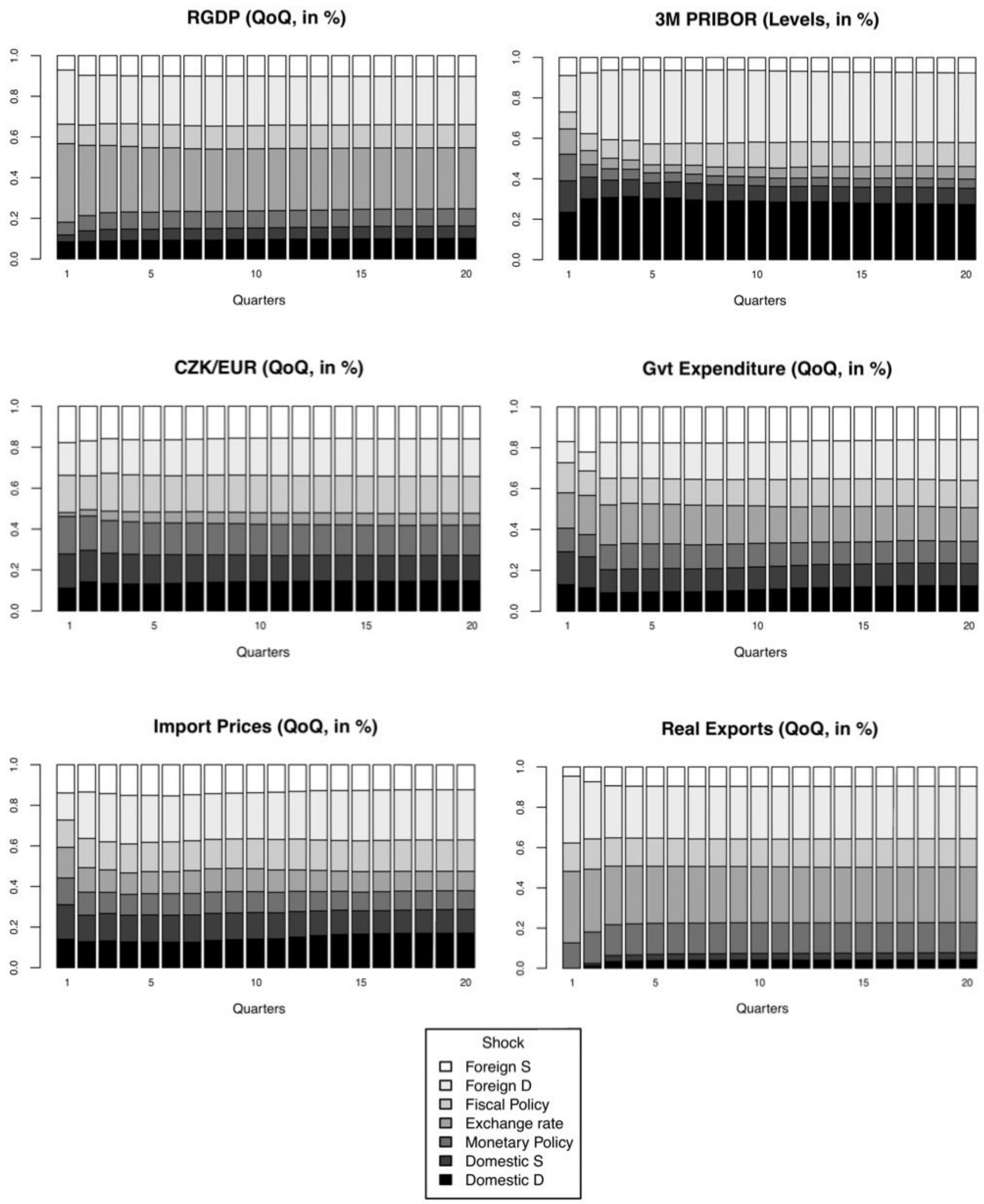


Figure A.3: FEVD for Different Variables



A.1.2 Baseline Model: 2017Q2-2022Q3

Figure A.4: IRFs for Different Variables (1)

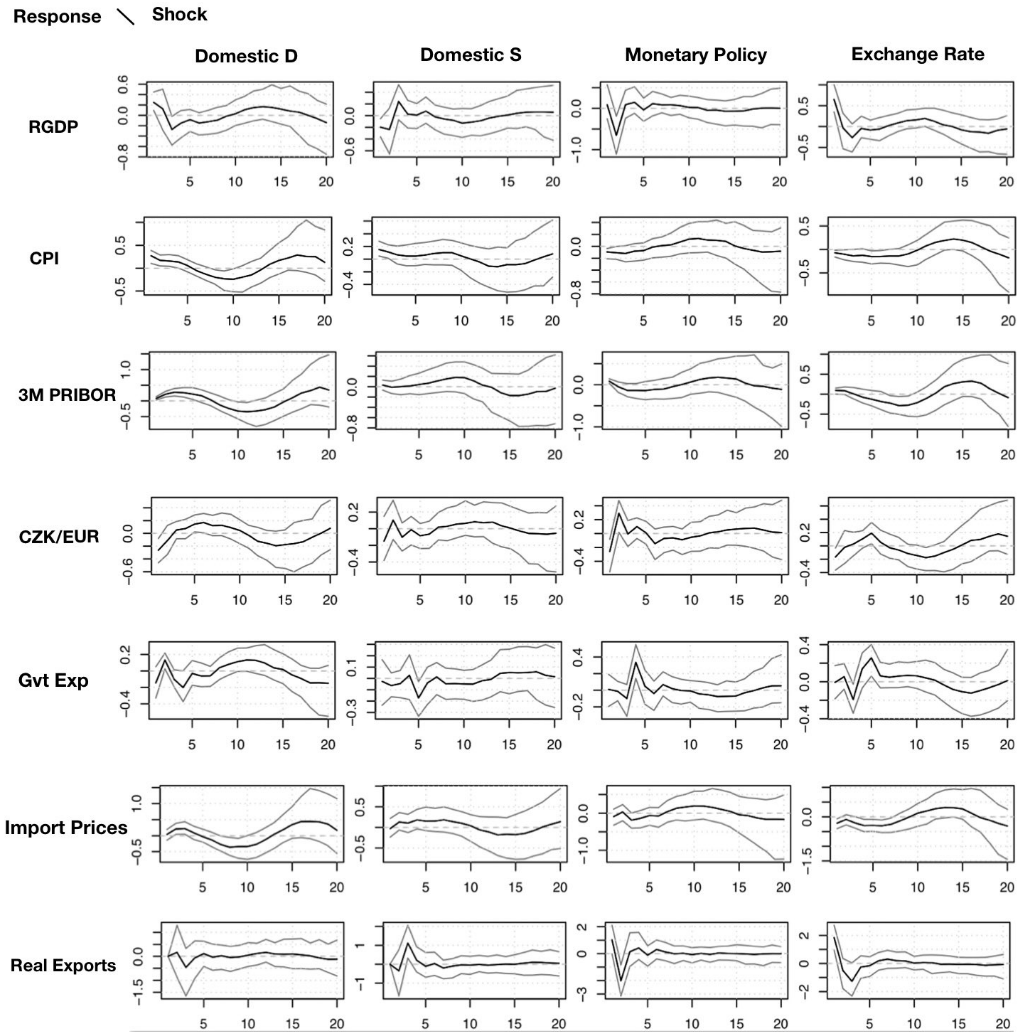


Figure A.5: IRFs for Different Variables (2)

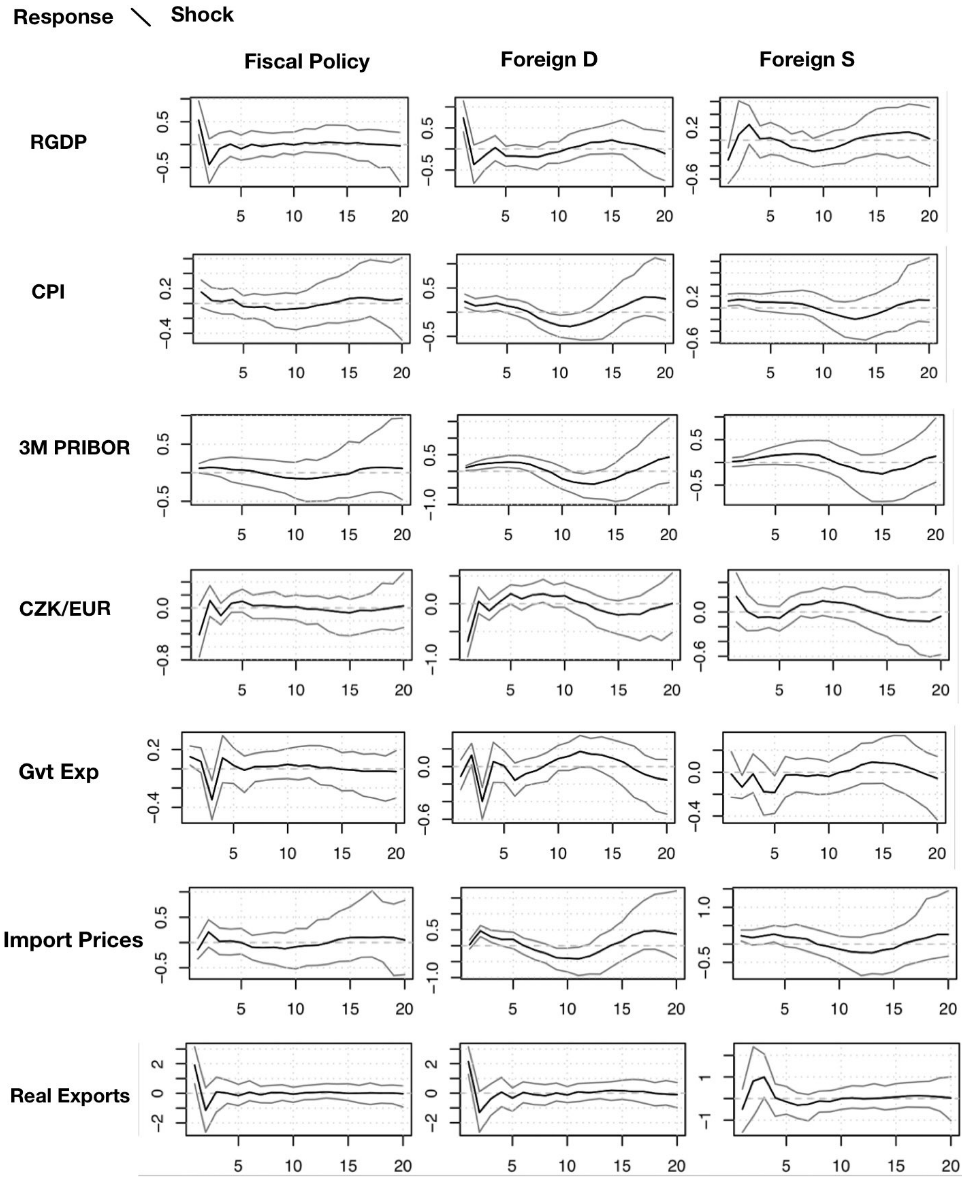
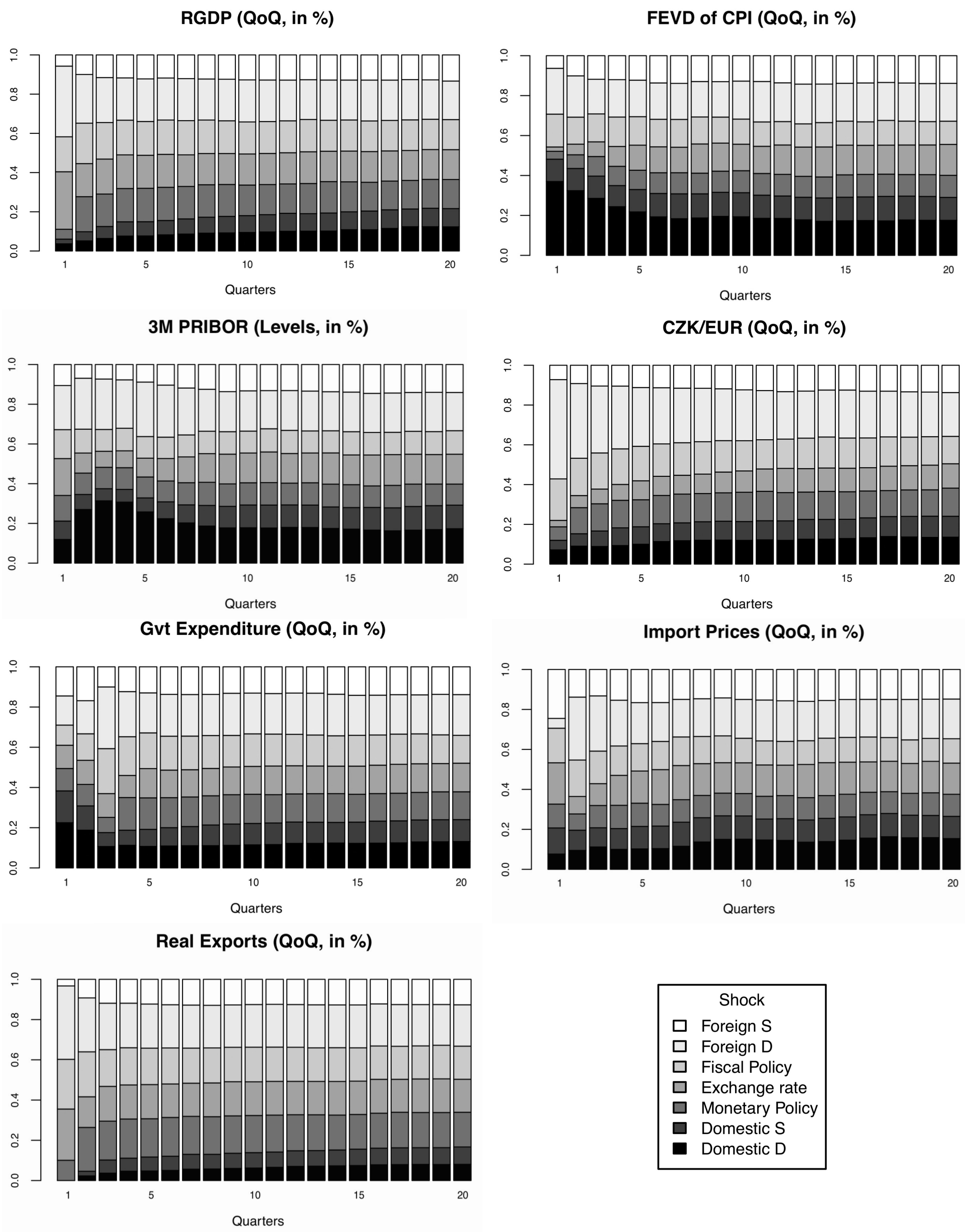


Figure A.6: FEVD for Different Variables



A.2 Robustness Analysis

A.2.1 Model (5 lags)

Figure A.7: IRFs for Different Variables (1) - Model with 5 Lags

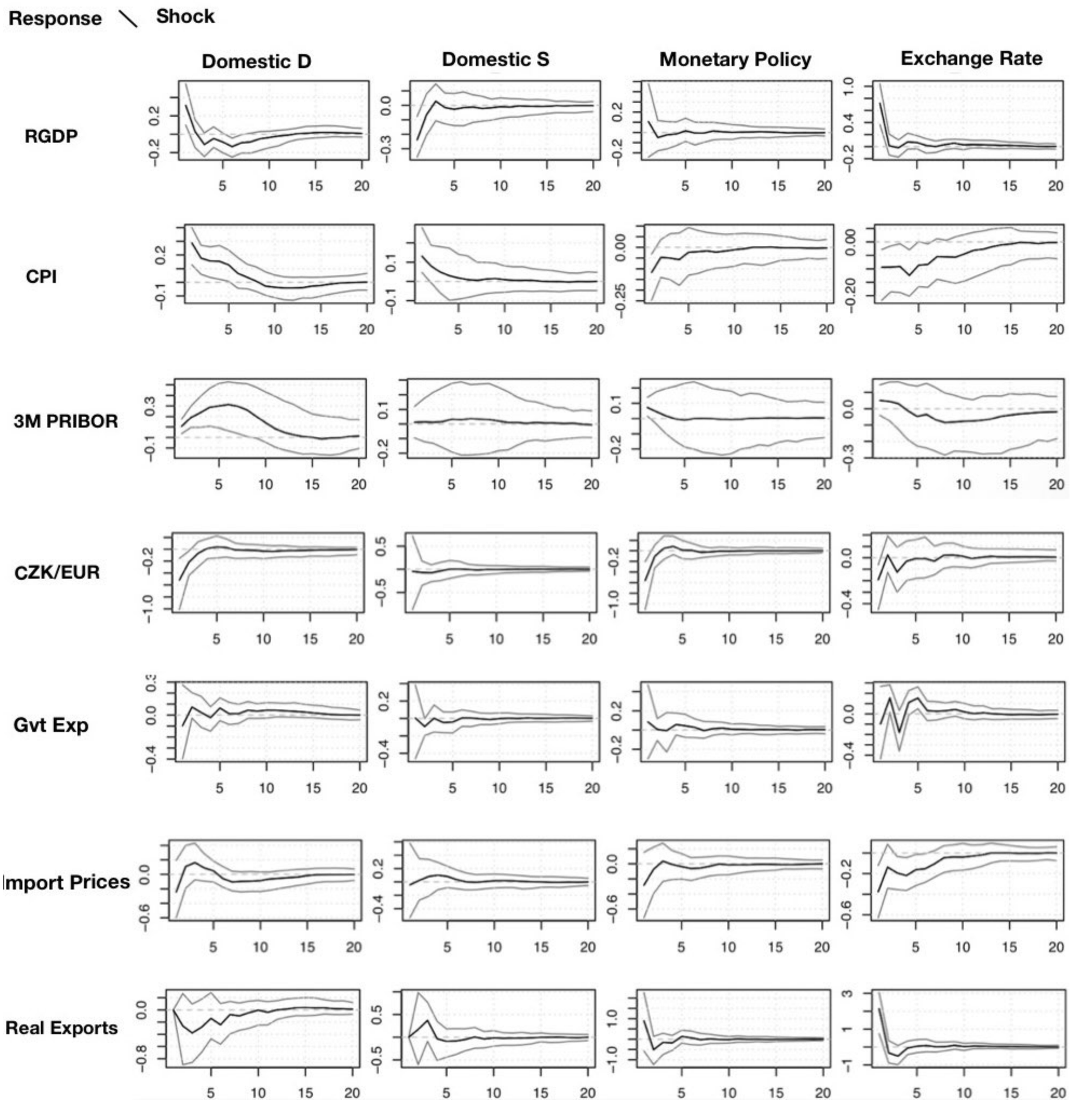


Figure A.8: IRFs for Different Variables (2) - Model with 5 Lags

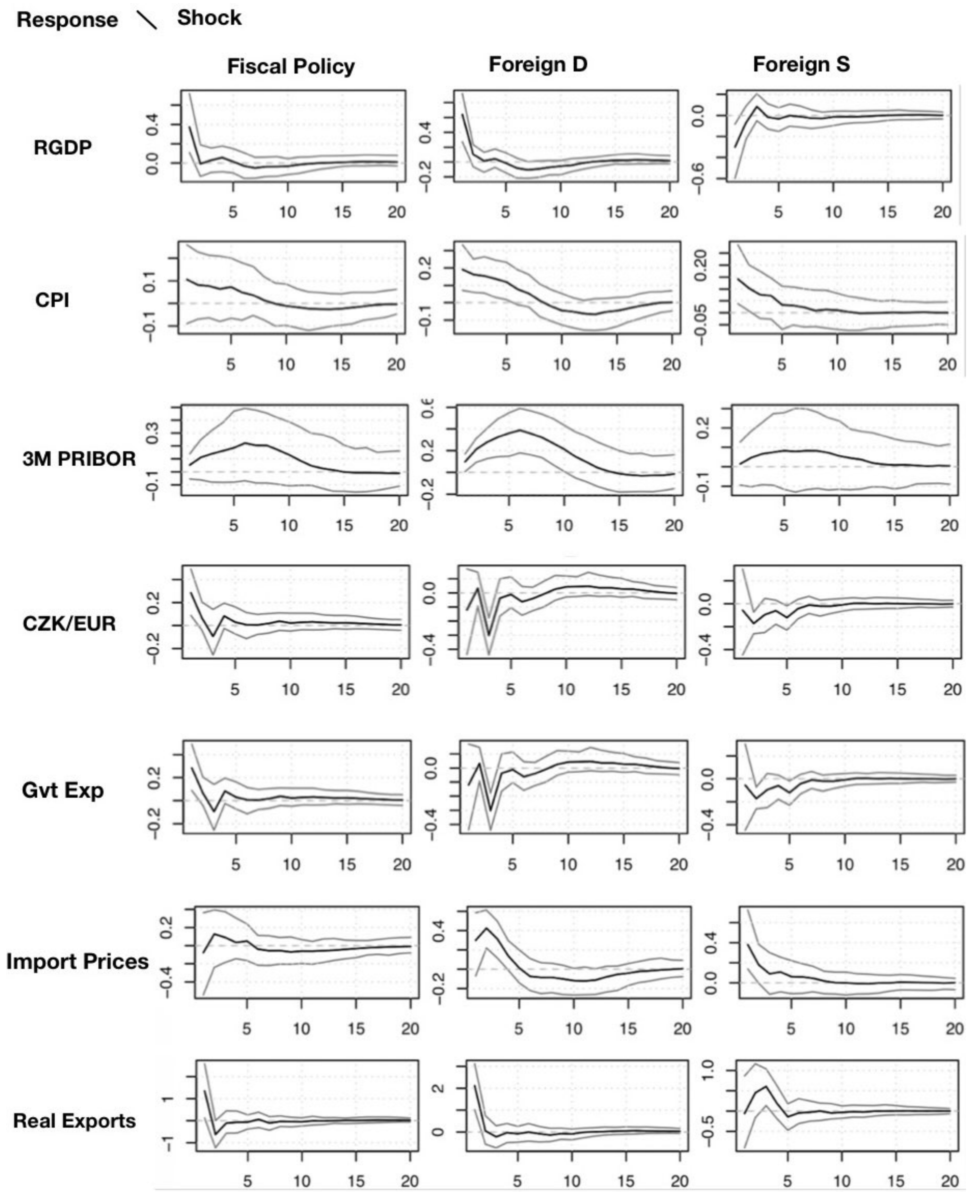
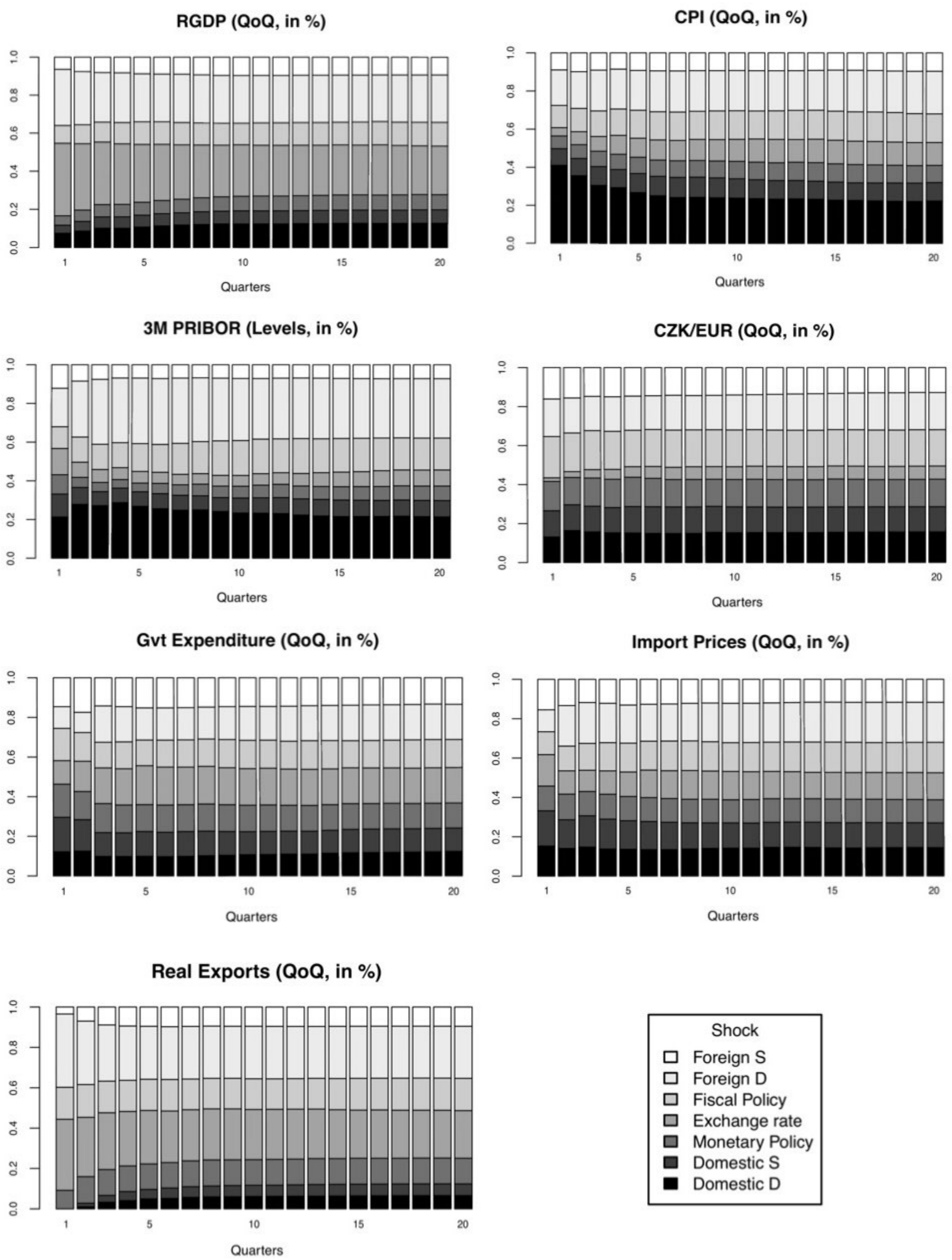


Figure A.9: FEVD for Different Variables - Model with 5 Lags



A.2.2 Model with Foreign Export Prices (2 lags)

Figure A.10: IRFs for Different Variables (1) - Model with Foreign X Prices

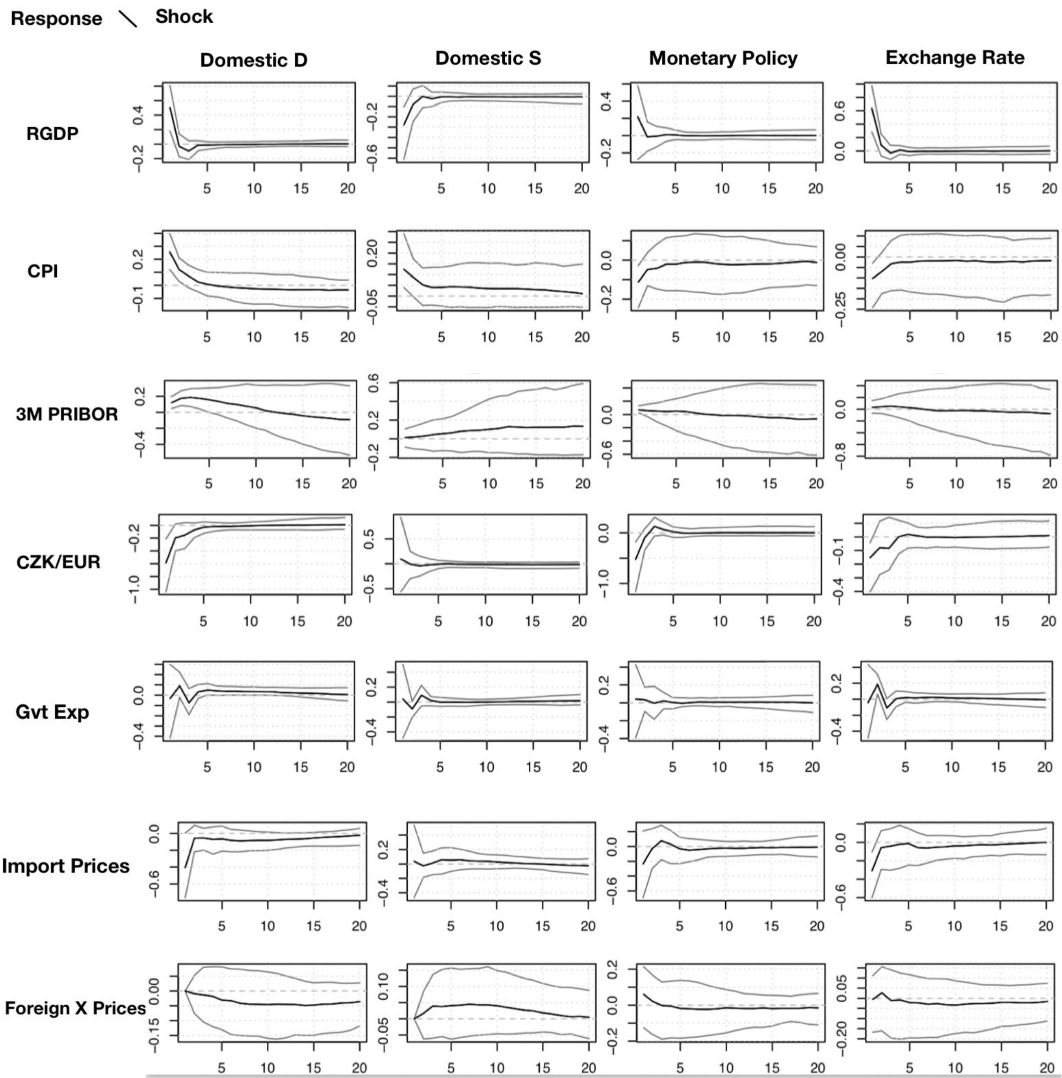


Figure A.11: IRFs for Different Variables (2) - Model with Foreign X Prices

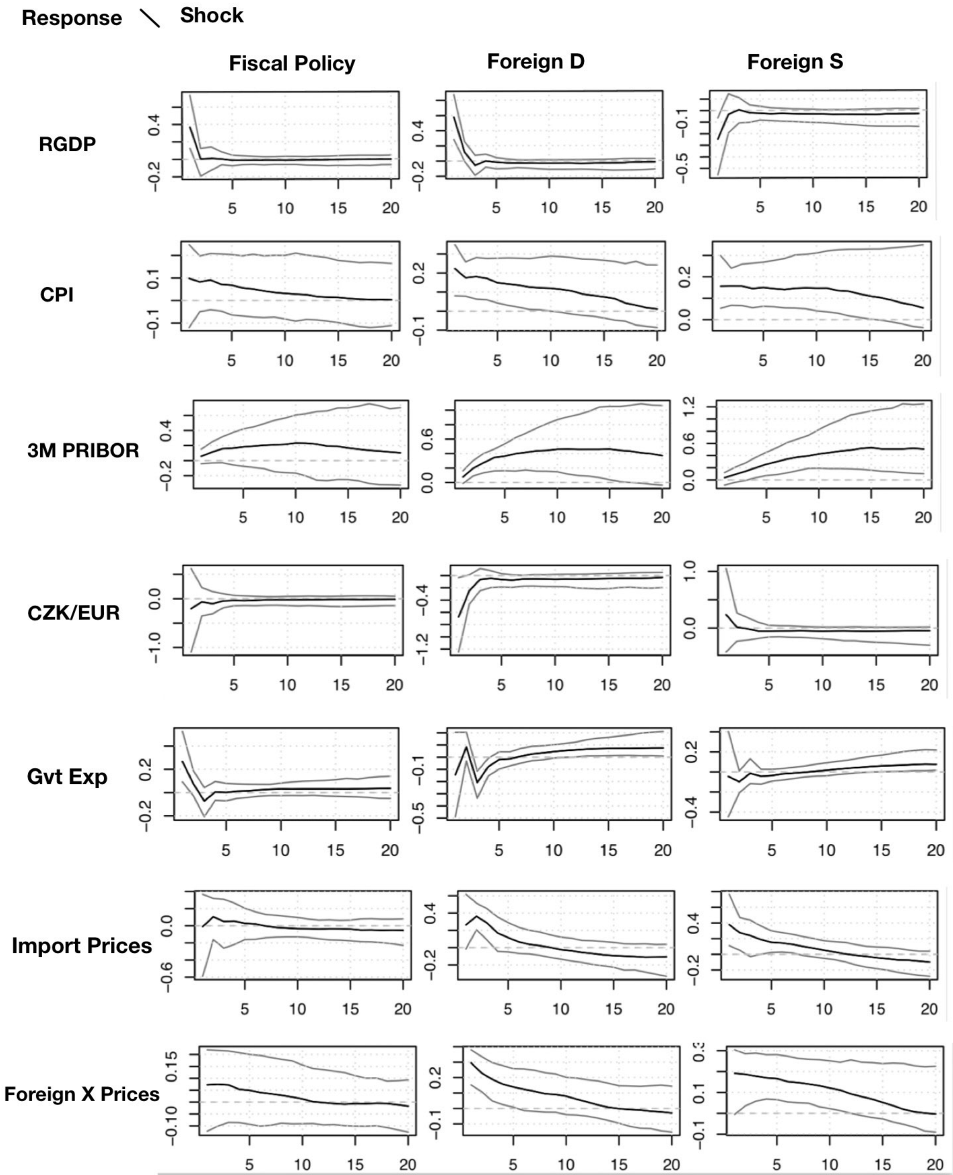
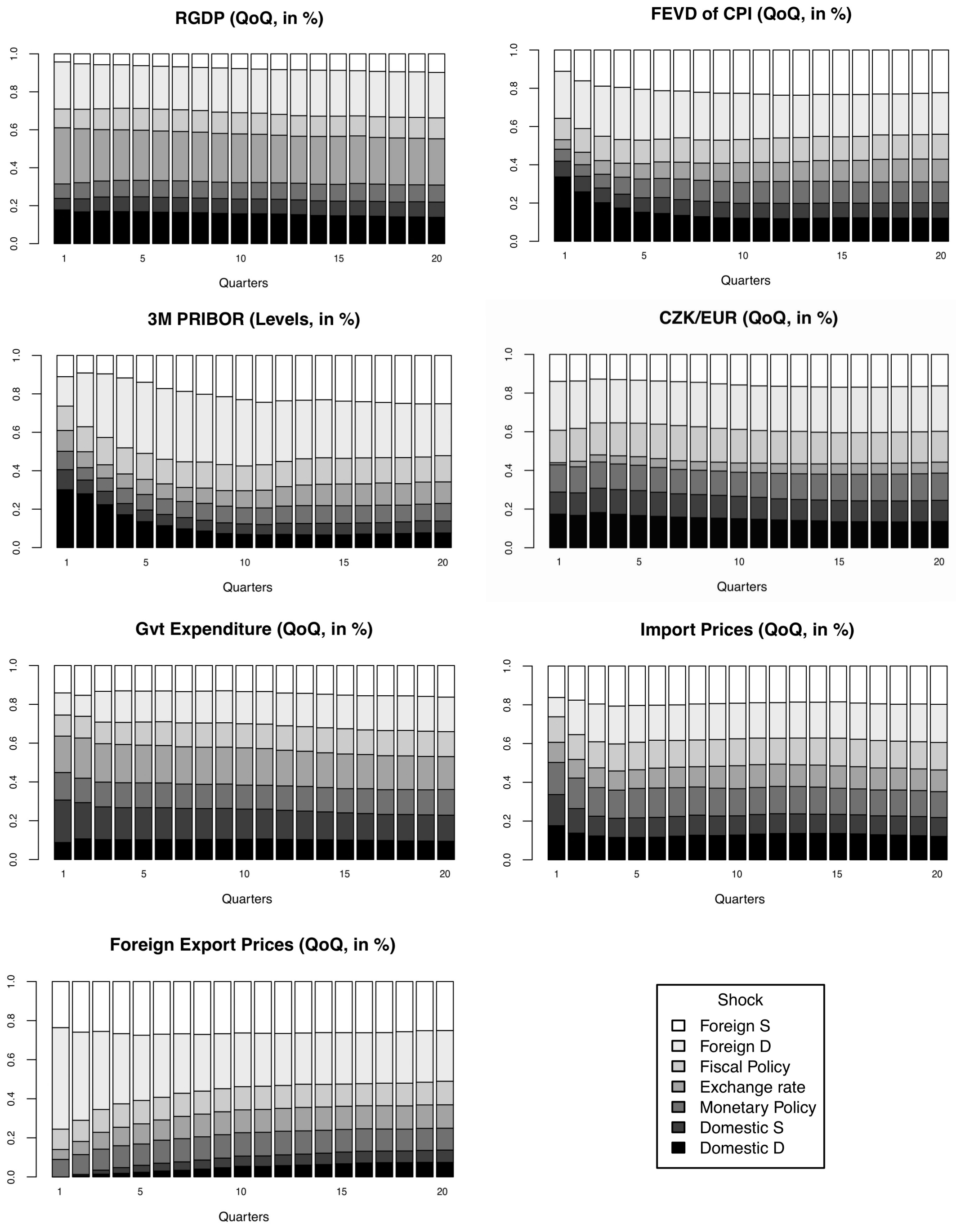


Figure A.12: FEVD for Different Variables - Model with Foreign X Prices



A.2.3 Pre-COVID-19 Period Model (2 lags)

Figure A.13: IRFs for Different Variables (1) - Pre-COVID-19 Period Model

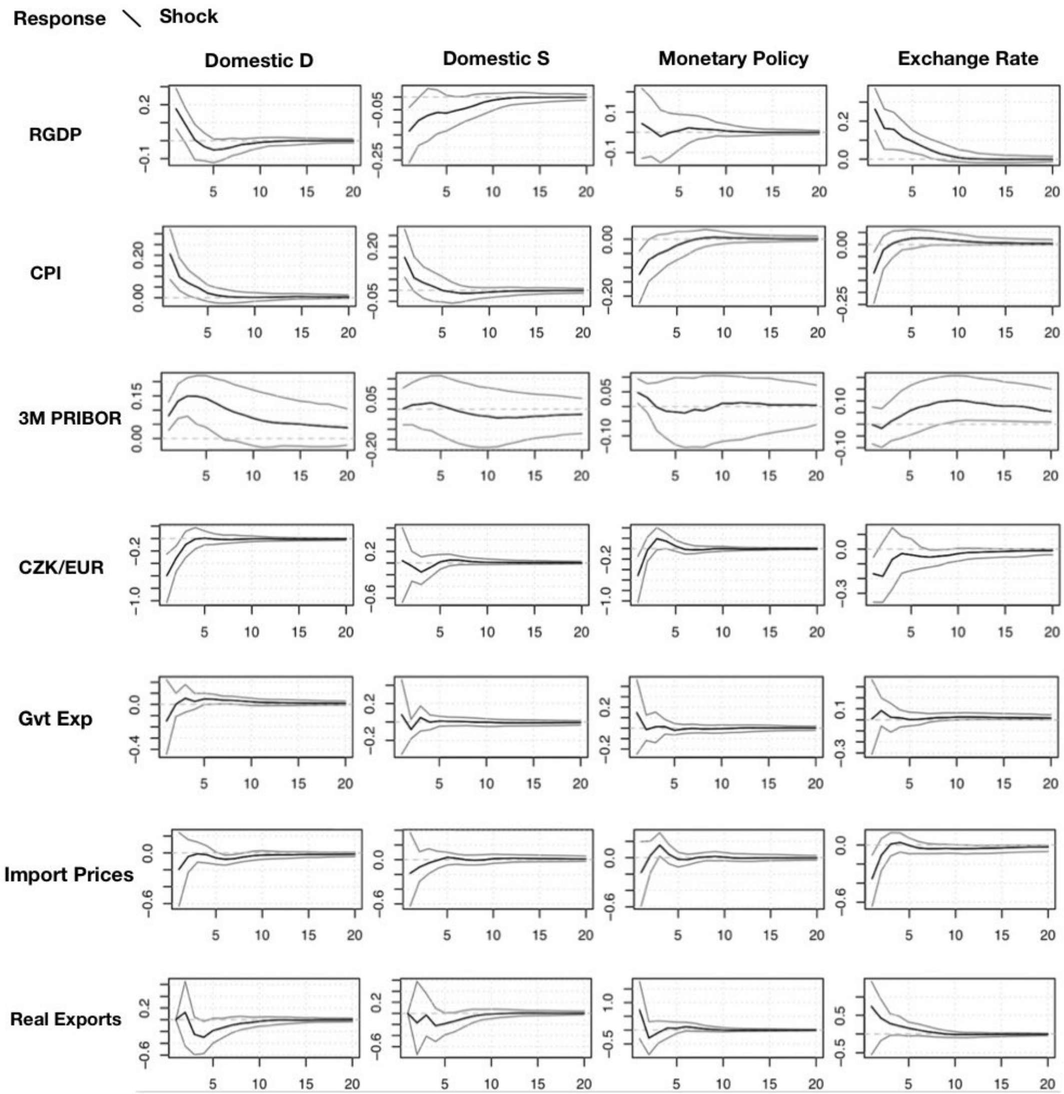


Figure A.14: IRFs for Different Variables (2) - Pre-COVID-19 Period Model

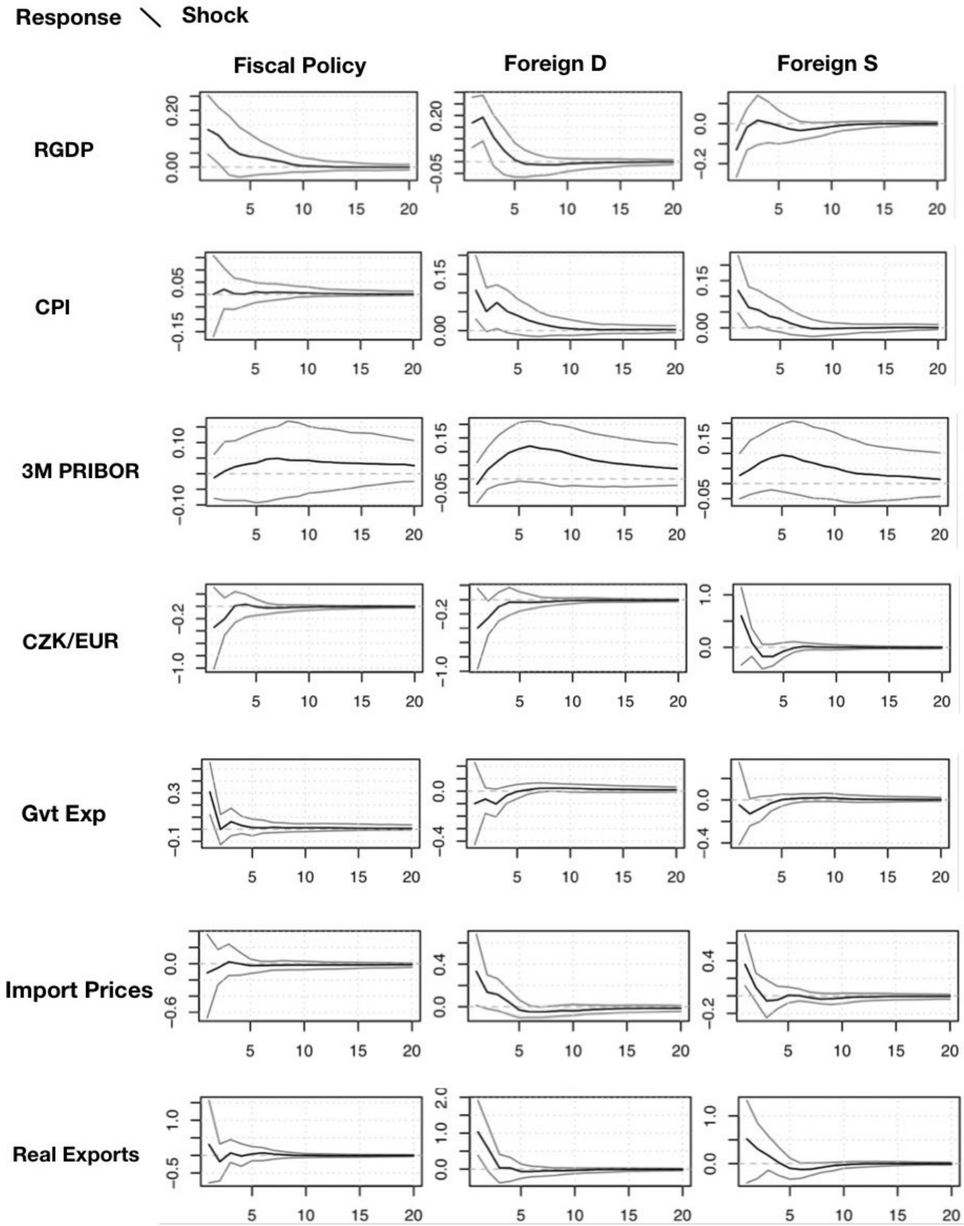


Figure A.15: FEVD for Different Variables - Pre-COVID-19 Period Model