

Explaining the Strength and the Efficiency of Monetary Policy Transmission: A Panel of Impulse Responses from a Time-Varying Parameter Model*

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Abstract

This paper analyzes both the cross-sectional and time variation in aggregate monetary policy transmission from nominal short term interest rates to price level. Using Bayesian TVP-VARs where the structural interest rate shocks are identified by sign restrictions, we show that monetary policy transmission became stronger over the last decades. This applies both to developed and emerging economies. Monetary policy sacrifice ratios (the output costs of disinflation induced by monetary policy tightening) gradually decreased from their peak in the 1980's. Exploring the cross-country and time variation in panel regressions, we show that when a country adopted inflation targeting regime, monetary transmission became stronger (by about 0.8% of price level response to 1% shock to the policy rate) and sacrifice ratios decreased. In periods of banking crises, the transmission from monetary policy interest rate shocks to prices is weaker (by about 1% of price level response to a 1% shock to the policy rate) and the related costs in output are higher. Further, countries with higher domestic credit to GDP have stronger transmission while countries with higher foreign debt seem to be less influenced by domestic monetary policy. The results also indicate that eurozone members feature stronger response to monetary policy shock as opposed to other monetary policy arrangements.

Keywords: monetary policy transmission, TVP-VAR, sign-restrictions

JEL Codes: E52, C54

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1 Introduction

The knowledge of the functioning of transmission mechanism from the short-term policy interest rate to price level and output is crucial for the conduct of monetary policy. Central bankers need to know how do their decisions about policy interest rates affect the economy. How large is the expected impact of interest rate cut on output and price level? What is the time profile of the response of targeted variables? Obviously, these questions have been frequently addressed in the academic literature. For the meta-analysis of studies estimating the monetary transmission in various countries, over different time periods and using different modeling strategies see Havranek & Rusnak (2012). The current consensus is that the response of price level to a monetary policy shock reaches its peak in 4-8 quarters. Some studies (Canova *et al.*, 2007; Koop *et al.*, 2009) show that monetary policy has changed over time in some countries. Other studies illustrate the cross-country heterogeneity in monetary transmission (Jarocinski, 2010; Elbourne & de Haan, 2006). A natural policymakers' question would be: what are drivers of the strength and time profile of monetary transmission?

We aim to explain the cross-country and time variation in the strength of monetary transmission focusing on the possible role of monetary regime, financial sector characteristics and institutional factors. We start by consistently estimating time-varying impulse responses to monetary policy shocks in a set of 33 OECD and EU countries. Having obtained the panel of impulse responses to a monetary policy shock (monetary policy shock is identified by sign-restrictions in the framework of Bayesian time-varying parameter vector autoregression (TVP-VAR), see the methodological part for details), we illustrate the time evolution of impulse responses over last four decades in 33 countries. Specifically, the results show the shortening lag of monetary policy transmission during the observed period, which may reflect the changes in monetary policy strategies and better functioning of financial markets. Further, using panel fixed effects regressions we show the differences in monetary transmission for different monetary policy regimes: when a country adopted inflation targeting monetary policy regime, the transmission from monetary policy interest rates to prices became significantly stronger (by 0.8% in a response to a 1% shock to policy interest rate). On the other hand, inflation targeters as a whole have weaker transmission in comparison to euro area countries, even after correcting for time effects. Further, the time-variation in a fixed-effects model is well captured by variables linked to the functioning of financial sector: both the occurrence of banking crisis and ratio of non-performing loans decrease the magnitude of the response of prices to a monetary policy shock. In a banking crisis, the response of prices to a 1% monetary policy shock is lower by 1%. Further, the between-effects regressions show that countries with high domestic credit to GDP ratio have stronger transmission while the economies with high external debt are less influenced by domestic monetary policy.

Finally, we examine the “sacrifice ratios” of monetary policy in the spirit of Jarocinski (2010), measuring the ratio of output losses to price level decrease as a result of non-systematic monetary policy tightening. The results suggest that the sacrifice ratios have decreased during last decades, being the highest during the 1980s (which coincides with the U.S. disinflation

under Volcker chairmanship of the Federal Reserve). A change to inflation targeting regime is typically followed by lower output costs of disinflation. In the periods of stress in banking sector, the sacrifice ratios are higher.

Still, standard shortcomings of small-size VAR analysis apply. Due to the limited number of variables in the VAR system, the observed responses may be influenced by shocks to omitted or unobserved variables. We believe that the identification strategy relying on sign restrictions is appropriate here, as we do not want to impose any zero restrictions and thus force the impulse response into particular “shape”. Further, one has to be cautious about interpreting the obtained relationships between the transmission strength and the explanatory variables as causalities. The fixed-effects model mitigates the identification problem to some extent, but various types of endogeneity may be still present, most notably the omitted variable bias or spurious relationships.

Following the Introduction, the Section 2 describes the empirical methodology in more detail, Section 3 presents the estimated time-varying impulse responses illustrating the time-evolution and cross-country heterogeneity of monetary transmission, Section 4 examines the role of monetary policy regime, financial sector characteristics and other economic factors in explaining the cross-country and time-variation in the strength of monetary transmission. Finally, Section 5 concludes.

2 Relation to Existing Literature

Early attempts to explain cross-country heterogeneity in monetary policy transmission have often focused on the differences in transmission among the members of the European Economic and Monetary Union, both prior (Mojon & Peersman, 2001; Ehrmann, 2000) and after euro adoption (Angeloni & Ehrmann, 2003; Ciccarelli & Rebucci, 2002) with mixed conclusions regarding prior euro adoption heterogeneity of transmission and its homogenization in euro area countries after euro adoption. Weak conclusions are largely caused by wide confidence intervals of the estimates. Recently, the heterogeneity of transmission in euro area countries has been explored by Ciccarelli *et al.* (2013), showing the importance of the credit channel during the crisis. Another recent cross-country study by Aysun *et al.* (2013) has focused on the impact of financial structure on transmission, similarly showing that in economies with higher financial frictions, the credit channel is stronger as the theory of financial accelerator (Carlstrom & Fuerst, 1997; Bernanke *et al.*, 1999) would predict. The role of financial system and banks in transmission has been examined by Ehrmann *et al.* (2001) using bank-level data. A paper by Mishra *et al.* (2012) focuses on the role of financial sector development in transmission differences among low income countries, stressing the role of the degree of development of financial markets and the exchange rate arrangements. Berben *et al.* (2004) have examined the heterogeneity in transmission through the lens of forecasting and policy evaluation models of national central banks of the euro area, concluding that the differences stem from the heterogeneity of economic conditions rather than from the differences in modeling strategies.

A work close to the analysis conducted here would be the recent paper by Georgiadis (2012),

who attributes the cross-country differences in transmission estimated through VAR impulse responses to differences in financial sector, labor market and industrial mix. However, this is a cross-country analysis only and so it cannot control for the country fixed effects. There is inherently a strong omitted variable bias present in such estimations. For better identification of the effects, we need to explore the time-variation in monetary policy transmission. A Bayesian methodology for multi-country estimation of time-varying parameter VARs was proposed by Canova & Ciccarelli (2009). Due to better control over the estimation process, we stick to a set of single-country TVP-VAR models using the methodology of Primiceri (2005), which allows for time-varying (stochastic) volatility.¹ The sample used in this paper is considerably broader than in any previous work, using the data for 33 now developed countries, with the time span from the 1970 to 2010 where the data permits. This to some extent restricts the set of possible explanatory variables for the strength of monetary transmission, notably many financial and labor market indicators started to be collected in a broader set of economies only after 2000.

3 Empirical Methodology

To be able to analyze both the cross-country and time-variation in the strength of monetary transmission, we need to estimate the impulse responses of monetary policy shocks in the respective countries and periods. For this purpose, we make use of the time-varying parameter vector-autoregressive model (TVP-VAR) with stochastic volatility as proposed by Primiceri (2005). We include the standard set of variables: output, price level, exchange rate, interest rate (endogenous variables) and oil prices (exogenous variable²). The reduced-form TVP-VAR is estimated using Bayesian Monte Carlo Markov chain (MC^2) technique (the Gibbs sampler) based on Primiceri (2005). The structural monetary policy shocks are then identified using theory-based sign restrictions. After obtaining impulse responses to monetary policy shock, we examine the determinants of cross-country and time-variation using stylized facts and panel regressions.

The workflow can be summarized as follows:

1. Assemble dataset of 36 OECD+EU countries, including the endogenous and exogenous variables of the VAR and other possible determinants of the strength of monetary transmission
2. Estimate Bayesian TVP-VAR with stochastic volatility for 33 (data permitting) countries, identify structural shocks using sign restrictions and compute impulse response functions
3. Illustrate the time and cross country patterns in monetary transmission, including the “sacrifice ratios”

¹Because we estimate the TVP-VARs separately for each country, the international spillovers of monetary policy are not captured and foreign demand and credit shocks are regarded as a part of error term.

²Although the original contribution by Sims (1980) defines VAR with endogenous variables only, the later empirical applications have frequently used the restrictions that some variables are exogenous to the system (sometimes called VARX). See Lütkepohl (2007) for details.

4. Test whether monetary policy regime and financial sector characteristics matter for the strength of monetary transmission using panel regressions

3.1 Data

For the estimation of TVP-VARs, we use a quarterly dataset consisting of seasonally adjusted log-GDP in constant prices, log-CPI, money market interest rate – a market-based proxy for the monetary policy target rate and a logarithm of nominal effective exchange rate. Further, we include the log of oil price index as an exogenous variable.

For the examination of possible covariates of strength of monetary transmission and the sacrifice ratios, we use a set of variables consisting of characteristics of financial sector, institutional setup of the monetary policy regime and other economic characteristics such as trade openness. Majority of the data have been downloaded through Thomson Datastream. Data on the exchange rate arrangements and monetary policy regimes were taken from the updated dataset of Reinhart & Rogoff (2004). The data on the occurrence of banking crises is taken from Babecký *et al.* (2012), where an aggregation of crises listed in academic papers is complemented by a survey among central bank experts in respective countries.

The full dataset, including Datastream variable codes, is available from the online appendix.³

3.2 TVP-VAR Estimation and Identification

Reduced-form TVP-VAR We estimate the reduced-form time-varying parameter vector-autoregression model with stochastic volatility, similarly to Primiceri (2005) and Koop *et al.* (2009). In models with stochastic volatility, not only the coefficients, but also the covariance matrix of residuals is allowed to change. Therefore, these models are able to distinguish between the structural changes in monetary policy: the “bad policy” story (Boivin & Giannoni, 2006; Cogley & Sargent, 2002; Lubik & Schorfheide, 2004), and changes in the magnitude of shocks: the “bad luck” story (Sims & Zha, 2006). We estimate the reduced-form system of equations

$$y_t = Z_t \beta_t + u_t$$

where y_t is a vector of endogenous variables (consisting of the logs of output and price level, interest rate and nominal effective exchange rate), Z_t is a vector of explanatory variables consisting of the lags of endogenous variables, an exogenous variable (commodity price index) and the intercept. We use 2 lags of endogenous variables in the TVP-VAR system to reduce the number of coefficients to be estimated⁴, while still capturing the important dynamics. The

³The online appendix is accesible through <http://home.cerge-ei.cz/jakubm/transmission>

⁴Although Bayesian estimation mitigates the dimensionality problem, we still have to estimate $2 \times 5 + 1$ time-varying coefficients in each equation, plus the $4 \times 4 + 4$ elements of time-varying variance-covariance matrices and a number of time-invariant parameters. Along with Primiceri (2005) we consider the usage of 2 lags of endogenous variables to be the optimal trade-off between descriptive accuracy and estimation efficiency, as longer lags are supposed to have lower information value.

coefficients are time-varying, and we assume they follow a random walk process

$$\beta_t = \beta_{t-1} + \nu_t$$

where ν_t is i.i.d. $\mathcal{N}(0, Q)$. The error term u_t has a potentially time-varying distribution $\mathcal{N}(0, \Omega_t)$. Similarly to Primiceri (2005) we use a triangular reduction of Ω_t such that

$$A_t \Omega_t A_t' = \Sigma_t \Sigma_t'$$

where A_t is lower triangular matrix consisting of elements $\alpha_{ij,t}$ for $i > j$, ones on the diagonal ($i = j$) and zeros elsewhere ($i < j$). Σ_t is a diagonal matrix with $\sigma_{ii,t}$ elements. It follows that

$$\Omega_t = A_t^{-1} \Sigma_t \Sigma_t' (A_t^{-1})'$$

and consequently

$$y_t = Z_t \beta_t + A_t^{-1} \Sigma_t \epsilon_t$$

where ϵ_t is i.i.d. $\mathcal{N}(0, 1)$. The elements of A_t and Σ_t matrices follow

$$\alpha_{ij,t} = \alpha_{ij,t-1} + \xi_t$$

$$\log \sigma_{ii,t} = \log \sigma_{ii,t-1} + \eta_t$$

where ξ_t is i.i.d. $\mathcal{N}(0, S)$ and η_t is i.i.d. $\mathcal{N}(0, W)$. The matrix describing the whole covariance structure of the model,

$$V = \begin{pmatrix} I_n & 0 & 0 & 0 \\ 0 & Q & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & W \end{pmatrix}$$

is block-diagonal, i.e. the shocks in each random walk equation governing the time-variation of the model parameters are assumed to be independent across equations.

For the technical details of Bayesian MC^2 estimation (Gibbs sampler) see Koop & Korobilis (2009) or Primiceri (2005). The priors on the on the parameters of the model, as well as the hyperparameters (see Appendix A for details) are held constant across the cross-section of countries for which the TVP-VARs are estimated, and we use the same values as Primiceri (2005).

Sign-restrictions Subsequently to estimating the reduced-form TVP-VAR, we identify structural shocks using sign-restrictions (Fry & Pagan, 2011). Sign restrictions identification has been frequently used for the analysis of monetary policy (Canova & Nicolo, 2002; Uhlig, 2005; Rafiq & Mallick, 2008; Scholl & Uhlig, 2008; Jarocinski, 2010). The major advantage of this identification strategy is that it stays agnostic about the shape of the impulse response function, most importantly it does not restrict the on-impact response to equal zero as it is the case while

using the recursive identification.⁵ We believe that for the analysis done in this paper it is important not to impose restrictions on the shape of impulse response functions, and therefore the sign restrictions are the appropriate strategy. Due to computing time reasons, in this paper we focus only on the identification of monetary policy shock. We restrict the monetary policy shock to have the following pattern:

$$\begin{bmatrix} \text{variable} & \text{log-GDP} & \text{log-CPI} & \text{IR} & \text{ER} \\ \text{response to MP shock} & - & - & + & + \end{bmatrix}$$

i.e. we search for such structural transformation of shocks where output and price level react negatively, and the interest rate and exchange rate positively to a non-systematic monetary policy tightening. This sign pattern is consistent with the theoretical consensus of New Keynesian general equilibrium models (Smets & Wouters, 2003; Christiano *et al.*, 2005; Gali & Gertler, 2007). The structural shocks are identified according to Fry & Pagan (2011). Specifically, the candidate structural shocks are computed as those orthogonal (Givens) rotations of uncorrelated shocks which fulfill the imposed sign restrictions. The candidate structural shocks are created by multiplying the (normalized) any set of uncorrelated shocks (obtained for example using recursive identification) with matrix $Q(\theta)$, which is a multiple of Givens matrices $Q_{ij}(\theta_k)$ for various values of $\theta_k \in [0, \pi]$ and positions i, j . For the example where $i = 2, j = 3$, the Givens matrix takes the following form:

$$Q_{23}(\theta_k) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \theta_k & -\sin \theta_k & 0 \\ 0 & \sin \theta_k & \cos \theta_k & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where the parameters θ_k are drawn from $U[0, \pi]$. Then

$$Q(\theta) = Q_{12}(\theta_1) \times Q_{13}(\theta_2) \times Q_{14}(\theta_3) \times Q_{23}(\theta_4) \times Q_{24}(\theta_5) \times Q_{34}(\theta_6)$$

That way, we obtain candidate structural (uncorrelated) shocks. Among these, only those which satisfy the sign restrictions are chosen. This identification strategy does not deliver exact model identification, because we generally find multiple candidate sets of structural shocks which satisfy the restrictions. We follow the consensus (Fry & Pagan, 2011) to report the median impulse response of the ones which satisfy sign restrictions. As we identify only one structural shock, the choice of median model is straightforward.

⁵New Keynesian models with forward-looking rational expectations apply multiple assumptions on investment delays, habit formation, autoregressive processes of shocks, etc. to generate hump-shaped responses matching the impulse responses from VARs, while these may be driven more by the recursive identification strategy than by the actual data. Sign restrictions identification relaxes this assumption, often showing that the responses are faster with the peak response coming earlier.

3.3 Panel of Impulse Responses

As a result, we obtain a panel of impulse responses of price level to monetary policy shocks. We examine the cross-country and time variation first graphically (showing, for example, that the lag of monetary transmission has gradually decreased over last decades) and then test for the possible correlates of stronger monetary transmission using panel regressions. As a measure of the transmission strength (the explained variable), we use both the value of impulse response function (IRF) at the conventional monetary policy horizons ($h = 4, 6, 8$ quarters) and the cumulative sum of the impulse response functions:

$$\sum_{k=0}^h IRF_{\pi}(k)$$

As all these measures generally yield similar conclusions, we show only the results for the cumulative response from the impact to $h = 6$ quarters after the initial shock. Using panel regressions, we proceed by testing the relationships between the strength of the impulse responses and various characteristics of the economy and financial sector, such as monetary policy regime, the stock market capitalization, trade openness, the occurrence of banking crisis, non-performing loans ratio, structure of the economy, and central bank independence and credibility. We use clustered standard errors at country level.

Using panel fixed effects and between estimators we are able to distinguish which of the factors contribute most to explaining the cross-country variation and which capture the time variation in the strength of monetary transmission. For example, the results suggest that although euro area countries generally feature stronger monetary transmission of non-systematic monetary policy shocks than inflation targeters, the fixed-effects time variation shows that when a country adopted inflation targeting, its transmission strengthened. Moreover, the results suggest that in the periods of financial distress (occurrence of banking crises, high ratio of non-performing loans) the monetary policy transmission is relatively weaker. On the other hand, the cross-country variation can be explained by the structure of credit: higher domestic private credit is correlated with the stronger transmission while in countries with large foreign debt the transmission is weaker, possibly because such economy is more influenced by foreign monetary policy.

Finally, we evaluate the monetary policy sacrifice ratios in the spirit of Jarocinski (2010). The sacrifice ratios measure the output cost of disinflation, i.e. how much output needs to be sacrificed to deliver lower inflation after (unexpected) monetary tightening, and is defined as

$$\frac{\sum_{k=0}^h IRF_{GDP}(k)}{IRF_{\pi}(h)}$$

on the horizon h . According to the results, sacrifice ratios have decreased over time, reaching their maximum values during the 1980s. Below we show that inflation targeting regime of monetary policy is related to lower output costs of disinflation, and that the sacrifice ratios increase in the periods of financial stress in the banking sector.

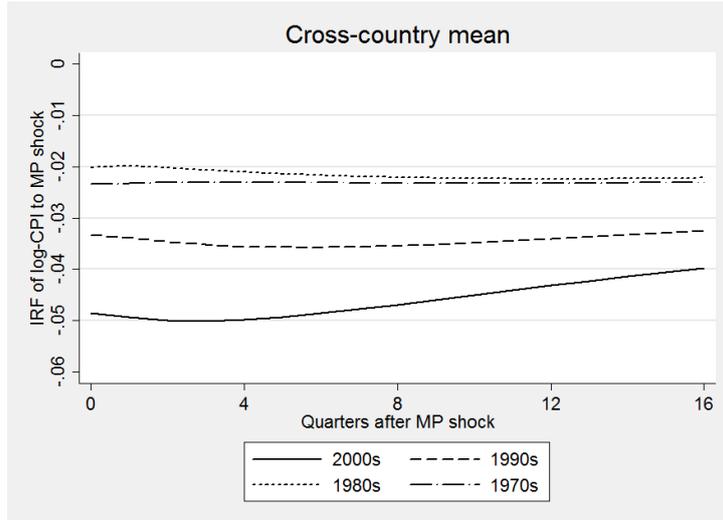


Figure 1: Evolution of IRFs of CPI to an MP shock over decades

4 Results: Cross-country characteristics and time evolution of monetary transmission

In this section, we present the results from the TVP-VAR on the sample of 33 countries. We illustrate both the cross-country and time variation in the impulse responses to a monetary policy shock.

First, we present the time evolution of the response of log-CPI to a monetary policy shock. Figure 1 shows the mean impulse responses averaged across countries (data-permitting) as it evolved during last 4 decades. The figure shows that monetary transmission has strengthened considerably over the last 40 years. At the same time, the hump-shape of the IRF of log-CPI to a monetary policy restriction became more pronounced, with the peak response now occurring earlier after the initial shocks. We interpret this as shorter lag of the response of prices to non-systematic monetary policy shocks.

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Figure 2 shows the evolution of impulse responses in several selected countries. Czech Republic is chosen to represent (historically) developing inflation-targeting countries, Sweden and UK represent developed inflation targeters and US as the world's leading economy (not explicitly targeting inflation until 2012). The development of monetary transmission in these four countries represents the overall trends in last decades. The transmission from short term

⁶Note that all referred shocks represent deviations from a systematic monetary policy rule rather than actual actions of monetary policy. In other words, the presented IRFs may refer to the responses to non-systematic shocks. These could represent either a situation where the policy rule would imply no reaction, but the monetary policy reacted, or an opposite situation where the monetary policy should have reacted according to the rule, but it did not, or the reaction was weaker (or stronger, or even go in the opposite direction) than it was implied by the rule. The (time-varying) monetary policy rule is estimated as a part of the TVP-VAR model, constituting one of the dynamic equations of the VAR system. The model allows for immediate reaction of monetary policy rate to developments in all endogenous variables and the exogenous variable, and as such it can be considered as a generalization of the simple empirical Taylor (1993)-rule.

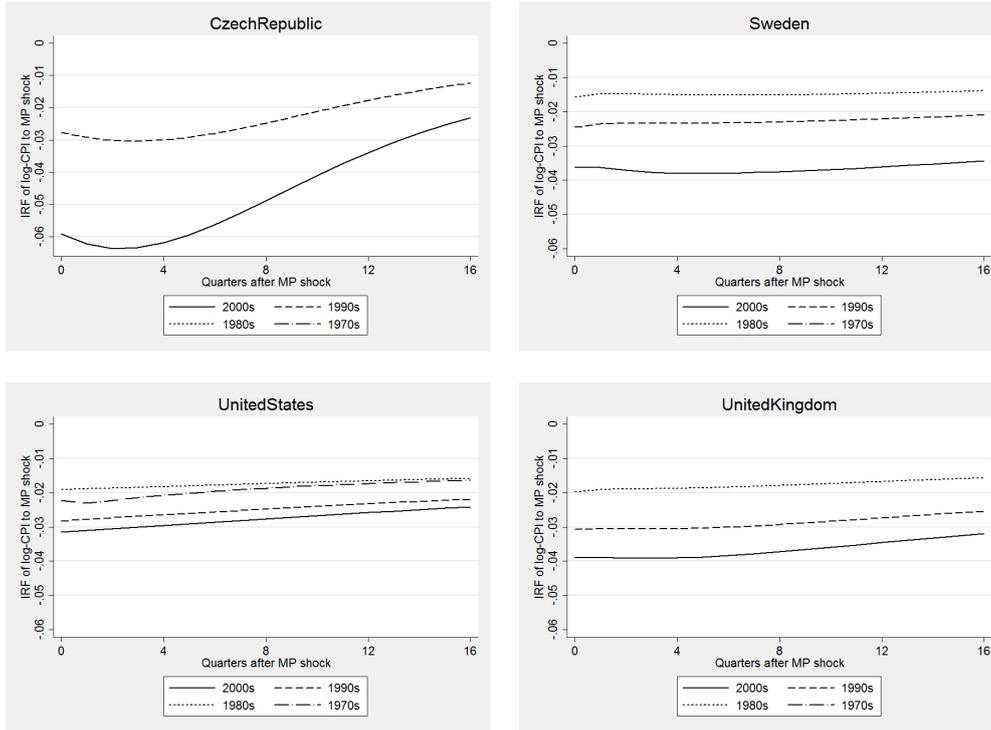


Figure 2: Evolution of IRFs of CPI to an MP shock in different countries

interest rates to prices became stronger, and the duration between the initial shock and the peak percentual response in CPI became shorter.

The relatively flat response observed in the United States (and, to a lower extent in the United Kingdom and Sweden) may refer either to lower occurrence of non-systematic shocks, so it is difficult to identify pronounced dynamics of impulse response functions. It may also be that the inflation expectations are well anchored by the inflation target and any monetary policy actions are considered to lead to the achievement of inflation target. In other words, due to high credibility of monetary policy, even non-systematic shocks may be perceived as systematic response, mitigating their impact on prices. We will test for the role of inflation targeting in the following section. Further, the fact that we do not use zero restrictions on impact makes the hump-shape of impulse response less pronounced in comparison to the ones from standard recursively identified VARs. As noted in the introduction, theoretical models typically need many assumptions to achieve hump-shaped response and match the IRFs from VARs, which may be driven mainly by the assumption of recursive identification while the true response may come faster.

We also illustrate the different strength and speed of monetary transmission under different monetary policy regimes. Figure 3 (left panel) presents a typical (mean) impulse responses of price level to 100 b.p. monetary policy restriction for countries operating under inflation targeting, members of the euro area, non-euro pegged exchange rate regimes and non-inflation-targeting floaters. As the monetary policy transmission has changed over time (as illustrated in Figure 1), and, at the same time, countries were adopting inflation targeting and entering

the euro area, spurious relationships are likely to arise. We control for the time trends here by subtracting time-effects from the values of IRFs in respective periods. Still, the variance comes both from the cross-country and time dimensions, as there have been changes of monetary policy regimes during the sample period.

Interestingly, inflation targeters seem to feature the most flat impulse responses, which may be the result of firmly anchored inflation expectations. A deviation from a systematic monetary policy rule may be interpreted as a policy measure to achieve target, keeping the inflation expectations anchored and resulting in only muted deviations of inflation from the targeted rate. On the other extreme, monetary transmission is the strongest in countries using the euro, even after controlling for the time effects of generally stronger transmission. This finding is not surprising, as euro area members face common monetary policy, which may not be fully suited for the needs of individual economies. Therefore the deviations from country-specific, idiosyncratic monetary rules (represented by the VAR equation with interest rate as the explained variable) are generally more substantial, allowing for better identification of non-systematic monetary policy shocks, and the corresponding responses. Coupled with weaker definition of inflation target and its imperfect fulfillment in the individual countries (ECB's "definition of price stability" relates to the euro area average), the more frequent non-systematic monetary policy shocks generate more pronounced responses in terms of price level.

Explicit inflation targeters and euro area members aside floating exchange rate regimes show marginally stronger monetary transmission compared to exchange rate pegs (including managed floats), mainly at longer monetary policy horizons. This is in line with the textbook Mundell-Fleming model (Mundell, 1962; Fleming, 1962) of the inefficiency of domestic monetary policy under fixed exchange rate regimes.

We also illustrate the mean IRFs for countries going through a banking crisis. Again controlling for the time effects, Figure 3 (right panel) does not provide a strong evidence about different functioning of monetary transmission during banking crises. However, it is important to note that the presented typical responses for different regimes do mix two sources of variation coming from different dimensions: the cross-country variation and the time-variation. For example, countries which are in general characterized by inflation targeting may feature weaker responses to non-systematic monetary policy shocks for other reasons, while the change from non-IT to IT in a given country may still be related to strengthening of transmission. Similarly, transmission can become weaker when a country enters a banking crisis, but may be stronger in countries which generally experience crises more frequently. The presented figures are, however, pooling the two dimensions together. As the identification of pure cross-country effects is a rather difficult task because of possibly many omitted variables (country characteristics), more reliable relationships can be obtained from the intra-country time variation. To distinguish between the two dimensions of variation, we later run both between effects and fixed effects panel estimators.

Finally, we illustrate the evolution of the sacrifice ratios of monetary policy over last decades. As defined earlier, the sacrifice ratios show how much output (in %) has to be on average

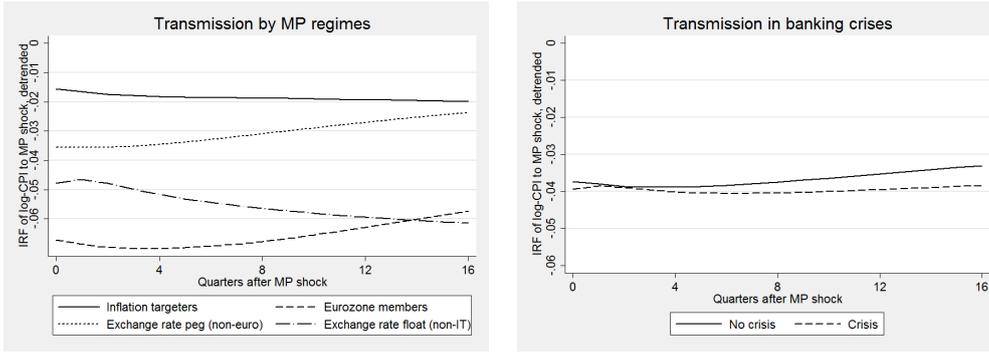


Figure 3: IRFs of CPI to an MP shock under different MP regimes and in banking crises

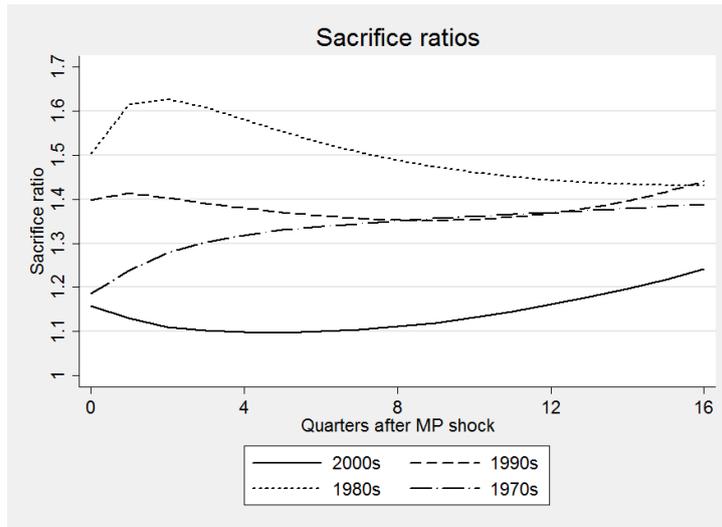


Figure 4: Evolution of the monetary policy sacrifice ratios over decades

sacrificed to induce a 1% decrease in price level at a desired horizon, given the estimated impulse response functions of log-GDP (real) and log-CPI to a monetary policy shock. The sacrifice ratios in other words measure the output costs of disinflation. We illustrate that the monetary policy sacrifice ratios have substantially decreased since the 1970s. Possible determinants of lower sacrifice ratios are analyzed in the next section.

5 Results: Factors Associated with the Characteristics of Monetary Transmission

Finally, we examine the cross-country and within-country variation in the framework of panel regressions. While the above presented IRF plots are mixing these two dimensions of variation, in this section we show that when controlling for country fixed-effects, the results can be different, sometimes even opposite.

In the fixed effects regressions we estimate the following equation:

$$\left(\frac{1}{h} \sum_{k=0}^h IRF_{\pi}(k)\right)_{i,t} = \alpha_i^{FE} + \beta^{FE} X_{i,t} + \varepsilon_{i,t}^{FE} \quad (1)$$

where $X_{i,t}$ captures possible explanatory variables for the strength of monetary policy transmission. The fixed effects regression measures the correlation of within-country variation in explanatory variables with the cumulative response of price level to a monetary policy shock. We present results for $h = 6$. We use clustered standard errors at the country-level, as the standard errors are likely correlated within country.

The between effects regression explains the cross-country variation, which is filtered out in the above fixed effects regression. The between effects equation is the following:

$$\left(\frac{1}{h} \sum_{k=0}^h IRF_{\pi}(k)\right)_i = \alpha^{BE} + \beta^{BE} X_i + \varepsilon_i^{BE} \quad (2)$$

where both the left- and the right-hand side variables are country averages. The between effects regression may be influenced by the problem of omitted variable, as there are possibly many country-specific factors not explicitly included in the regression. Therefore we believe that there is more information value in the fixed effects model, and we interpret the coefficients of the between effects model only as correlations.

The results presented in Table 1 suggest that when a country adopted inflation targeting regime of monetary policy, the transmission of monetary policy became stronger by 0.8 percentage points in price level response to a 1% shock to monetary policy rate. For comparison and the evaluation of economic significance of this effect, as Figure 1 shows, the mean response is 5 percentage points. We attribute this effect to an increased transparency, more careful communication and increased credibility of monetary policy which is typically connected to inflation targeting regime. Transparency has been found crucial for monetary transmission also in the empirical study by Neuenkirch (2011), while teoretical work of Amato *et al.* (2002) emphasized the role of public information for coordination. For survey on the evolution and the role of central bank communication see Blinder *et al.* (2008).

Further, the stress in banking sectors seems to disrupt the functioning of monetary policy transmission. Both the increased ratio of non-performing loans and the recorded occurrence of banking crises are significantly related to lower impact of monetary policy interest rate shocks on prices. In the periods of banking crises, the response of price level to a 1% monetary policy shock has been lower by about 1%. This is likely because of disrupted pass-through from the policy rates to client interest rates on loans. Because of the credit crunch typically related to banking crises, the client interest rates rise despite the low policy rates and while also interbank market rates may be low. We are convinced that the disruptions to monetary policy transmission mechanism related to financial stress (Adrian & Shin, 2009) overweight the amplification effects of financial accelerator, which would predict stronger transmission when frictions in financial

Table 1: Correlates of the cumulative response of inflation to MP shock after 6 quarters

	FE	BE	FE full	BE full
InfTgrs	-0.00763*** (-3.71)	0.0231*** (2.85)	-0.00715** (-2.05)	0.0215* (1.96)
NonPrfLoans	0.000401** (2.39)	-0.00406** (-2.16)	0.000115 (0.78)	-0.00396 (-1.44)
BankCrisis	0.00971*** (3.38)	-0.0817* (-1.81)	0.00771*** (3.16)	-0.0267 (-0.44)
DPrivCredit		-0.000462*** (-3.67)	-0.0000541 (-0.89)	-0.000341* (-1.84)
MktSize		4.85e-15*** (2.91)	4.33e-16 (0.48)	3.40e-15 (1.55)
FrgnDebt		0.000123*** (3.36)	0.0000133 (0.88)	0.000112** (2.22)
BankCapital			0.000865 (0.78)	0.00199 (0.61)
BankLiqdty			-0.000226 (-0.41)	-0.000817 (-0.28)
GovtDebt			-0.00000594 (-0.06)	-0.000183 (-1.05)
Openness			0.0000949 (0.71)	-0.0000934 (-0.55)
Const	-0.0496*** (-45.86)	-0.0133 (-0.80)	-0.0599*** (-4.23)	-0.0228 (-0.57)
<i>N</i>	1352	1023	903	903
adj. <i>R</i> ²	0.066	0.391	0.065	0.287

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

markets are higher (likely during banking crises). The effects of financial accelerator become significant when explaining the cross-country variation in the between effects model. The fixed effects regression using the full set of explanatory variables (3rd column in Table 1) shows that other variables are of lower relevance.

The cross-country variation in the strength of transmission is more explained by variables related to the structure of financing. Countries with higher domestic private credit have stronger transmission, which is in line with financial accelerator theory (Bernanke *et al.*, 1999; Carlstrom & Fuerst, 1997) and the related empirical studies (Ciccarelli *et al.*, 2013), which would predict stronger response to monetary policy shocks in more leveraged economies, as higher leverage implies larger effects of interest rates through credit and balance sheet channels. The results also show that foreign indebtedness is related to weaker transmission, as an economy with high

Table 2: Correlates of the MP sacrifice ratios at the horizon of 6 quarters

	FE	FE full	BE full
InflTgtrs	-0.152 (-1.49)	-0.0824* (-1.91)	-0.279 (-0.93)
BankCrisis	0.149** (2.63)	0.0485 (1.48)	-1.134 (-0.68)
Openness	-0.00818*** (-4.64)	-0.00528** (-2.40)	0.000746 (0.16)
MktSize		-7.38e-15 (-0.79)	6.38e-14 (1.06)
BankCapital		-0.0103 (-0.52)	-0.0984 (-1.10)
BankLiqdty		0.000994 (0.05)	0.0988 (1.25)
NonPrfLoans		0.00526 (0.99)	-0.124 (-1.64)
DPrivCredit		-0.000699 (-0.54)	-0.00695 (-1.37)
GovtDebt		-0.000188 (-0.10)	0.00278 (0.58)
FrgnDebt		0.000427 (1.34)	0.000416 (0.30)
Const	1.920*** (14.31)	1.643*** (7.79)	2.657** (2.41)
<i>N</i>	3113	903	903
adj. <i>R</i> ²	0.176	0.083	-0.071

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

external debt is possibly more influenced by foreign monetary policy.

Table 2 shows the correlates of monetary policy sacrifice ratios with the explanatory variables. Notably, inflation targeting is shown to be related to more favorable sacrifice ratios, i.e. lower output losses are needed for disinflation. This can be again attributed to higher credibility and transparency related to inflation targeting. In addition to a generally weaker monetary policy transmission in banking crises, we show that banking stress (both the crisis occurrence and the increased non-performing loans ratio) are related also to higher output costs of monetary policy-induced disinflation. As these effects are symmetric, this result also offers an optimistic interpretation: during banking crises, monetary policy can help to recover the real economy using monetary stimulus without increasing inflation much.

6 Concluding Remarks

This paper has mapped the monetary policy transmission across time and space. Taking an aggregate view on the transmission from monetary policy interest rates to price level, we have documented the role of financial sector characteristics and monetary policy regime on the strength and efficiency of transmission. The aggregate approach allows us to quantify the effects.

We have constructed a panel of time-varying impulse response functions for 33 countries, the time span ranging from the 1970 to 2010 where the data permitted. Estimating consistent Bayesian TVP-VAR models and identifying the monetary policy interest rate shock using sign restrictions, we have obtained the time-varying impulse responses of price level and GDP to a monetary policy shock for each country in the sample. We have illustrated the overall strengthening and shorter transmission lags over time and documented the gradually decreasing monetary policy sacrifice ratios.

Further we have analyzed the possible determinants of the strength of monetary policy transmission. Exploiting both the cross-country and within-country variance using panel regressions, we have examined the role of various financial and institutional characteristics of economies for the strength of monetary policy transmission. The results suggest, that inflation targeting is related to stronger transmission and more favorable sacrifice ratios of monetary policy. When a country adopted inflation targeting, the response of prices to a 1% policy interest rate shock became on average stronger by 0.8 percentage points. On the other hand, stress in the banking sector is related to disrupted monetary policy transmission and higher sacrifice ratios. In a banking crisis, the response of CPI to a 1% shock was lower by 1 percentage point. The cross-country comparisons show that countries with higher domestic private credit have stronger transmission, as higher leverage ratio implies that interest rate changes have larger impact through the credit and balance sheet channels. Finally, economies with higher external debt seem to be more influenced by foreign than by domestic monetary policy, making the responses weaker.

We are well aware that the observed relationships cannot be interpreted as causalities, as various forms of endogeneity may be still present even when time and country fixed effects are controlled for. Further work addressing the endogeneity issues, as well as establishing finer quantifications of the incremental changes of financial variables and institutional factors could be valuable topics for future research.

References

- ADRIAN, T. & H. S. SHIN (2009): “Prices and quantities in the monetary policy transmission mechanism.” *International Journal of Central Banking* **5(4)**: pp. 131–142.
- AMATO, J. D., S. MORRIS, & H. S. SHIN (2002): “Communication and monetary policy.” *Oxford Review of Economic Policy* **18(4)**: pp. 495–503.
- ANGELONI, I. & M. EHRMANN (2003): “Monetary transmission in the euro area: early evidence.” *Economic Policy* **18(37)**: pp. 469–501.
- AYSUN, U., R. BRADY, & A. HONIG (2013): “Financial frictions and the strength of monetary transmission.” *Journal of International Money and Finance* **32(0)**: pp. 1097 – 1119.
- BABECKÝ, J., T. HAVRÁNEK, J. MATĚJŮ, M. RUSNÁK, K. ŠMÍDKOVÁ, & B. VAŠÍČEK (2012): “Banking, debt and currency crises: early warning indicators for developed countries.” *Working Paper Series 1485*, European Central Bank.
- BERBEN, R.-P., A. LOCARNO, J. MORGAN, & J. VALLES (2004): “Cross-country differences in monetary policy transmission.” *Working Paper Series 400*, European Central Bank.
- BERNANKE, B. S., M. GERTLER, & S. GILCHRIST (1999): “The financial accelerator in a quantitative business cycle framework.” In J. B. TAYLOR & M. WOODFORD (editors), “Handbook of Macroeconomics,” volume 1 of *Handbook of Macroeconomics*, chapter 21, pp. 1341–1393. Elsevier.
- BLINDER, A. S., M. EHRMANN, M. FRATZSCHER, J. D. HAAN, & D.-J. JANSEN (2008): “Central bank communication and monetary policy: A survey of theory and evidence.” *Journal of Economic Literature* **46(4)**: pp. 910–45.
- BOIVIN, J. & M. P. GIANNONI (2006): “Has monetary policy become more effective?” *The Review of Economics and Statistics* **88(3)**: pp. 445–462.
- CANOVA, F. & M. CICCARELLI (2009): “Estimating multicountry var models.” *International Economic Review* **50(3)**: pp. 929–959.
- CANOVA, F., L. GAMBETTI, & E. PAPPÀ (2007): “The structural dynamics of output growth and inflation: Some international evidence.” *Economic Journal* **117(519)**: pp. C167–C191.
- CANOVA, F. & G. D. NICOLO (2002): “Monetary disturbances matter for business fluctuations in the g-7.” *Journal of Monetary Economics* **49(6)**: pp. 1131–1159.
- CARLSTROM, C. T. & T. S. FUERST (1997): “Agency costs, net worth, and business fluctuations: A computable general equilibrium analysis.” *American Economic Review* **87(5)**: pp. 893–910.
- CHRISTIANO, L. J., M. EICHENBAUM, & C. L. EVANS (2005): “Nominal rigidities and the dynamic effects of a shock to monetary policy.” *Journal of Political Economy* **113(1)**: pp. 1–45.
- CICCARELLI, M., A. MADDALONI, & J.-L. PEDRÓ (2013): “Heterogeneous transmission mechanism: Monetary policy and financial fragility in the euro area.” *Working Paper Series 1527*, European Central Bank.
- CICCARELLI, M. & A. REBUCCI (2002): “The transmission mechanism of european monetary policy: Is there heterogeneity? is it changing over time?” *IMF Working Papers 02/54*, International Monetary Fund.
- COGLEY, T. & T. J. SARGENT (2002): “Evolving post-world war ii u.s. inflation dynamics.” In “NBER Macroeconomics Annual 2001, Volume 16,” NBER Chapters, pp. 331–388. National Bureau of Economic Research, Inc.

- EHRMANN, M. (2000): “Comparing monetary policy transmission across european countries.” *Review of World Economics (Weltwirtschaftliches Archiv)* **136(1)**: pp. 58–83.
- EHRMANN, M., L. GAMBACORTA, J. MARTINEZ-PAGES, P. SEVESTRE, & A. WORMS (2001): “Financial systems and the role of banks in monetary policy transmission in the euro area.” *Working Paper Series 105*, European Central Bank.
- ELBOURNE, A. & J. DE HAAN (2006): “Financial structure and monetary policy transmission in transition countries.” *Journal of Comparative Economics* **34(1)**: pp. 1–23.
- FLEMING, J. M. (1962): “Domestic financial policies under fixed and under floating exchange rates.” *IMF Staff Papers* **9(3)**: pp. 369–380.
- FRY, R. & A. PAGAN (2011): “Sign restrictions in structural vector autoregressions: A critical review.” *Journal of Economic Literature* **49(4)**: pp. 938–60.
- GALI, J. & M. GERTLER (2007): “Macroeconomic modeling for monetary policy evaluation.” *Journal of Economic Perspectives* **21(4)**: pp. 25–46.
- GEORGIADIS, G. (2012): “Towards an explanation of cross-country asymmetries in monetary transmission.” *Technical report*.
- HAVRANEK, T. & M. RUSNAK (2012): “Transmission lags of monetary policy: A meta-analysis.” *Working Papers 2012/10*, Czech National Bank, Research Department.
- JAROCINSKI, M. (2010): “Responses to monetary policy shocks in the east and the west of europe: a comparison.” *Journal of Applied Econometrics* **25(5)**: pp. 833–868.
- KOOP, G. & D. KOROBILIS (2009): “Bayesian multivariate time series methods for empirical macroeconomics.” *MPRA Paper 20125*, University Library of Munich, Germany.
- KOOP, G., R. LEON-GONZALEZ, & R. W. STRACHAN (2009): “On the evolution of the monetary policy transmission mechanism.” *Journal of Economic Dynamics and Control* **33(4)**: pp. 997–1017.
- LUBIK, T. A. & F. SCHORFHEIDE (2004): “Testing for indeterminacy: An application to u.s. monetary policy.” *American Economic Review* **94(1)**: pp. 190–217.
- LÜTKEPOHL, H. (2007): *New Introduction to Multiple Time Series Analysis*. Springer, 1st ed. 2006. corr. 2nd printing edition.
- MISHRA, P., P. J. MONTIEL, & A. SPILIMBERGO (2012): “Monetary transmission in low-income countries: Effectiveness and policy implications.” *IMF Economic Review* **60(2)**: pp. 270–302.
- MOJON, B. & G. PEERSMAN (2001): “A var description of the effects of monetary policy in the individual countries of the euro area.” *Working Paper Series 092*, European Central Bank.
- MUNDELL, R. A. (1962): “The appropriate use of monetary and fiscal policy for internal and external stability.” *IMF Staff Papers* **9(1)**: pp. 70–79.
- NEUENKIRCH, M. (2011): “Monetary policy transmission in vector autoregressions: A new approach using central bank communication.” *Technical report*.
- PRIMICERI, G. E. (2005): “Time Varying Structural Vector Autoregressions and Monetary Policy.” *Review of Economic Studies*, Vol. 72, No. 3, pp. 821-852, July 2005 .
- RAFIQ, M. & S. MALLICK (2008): “The effect of monetary policy on output in emu3: A sign restriction approach.” *Journal of Macroeconomics* **30(4)**: pp. 1756–1791.

- RAFTERY, A. E. & S. LEWIS (1992): “How many iterations in the gibbs sampler?” In “Bayesian Statistics 4,” pp. 763–773. Oxford University Press.
- REINHART, C. M. & K. S. ROGOFF (2004): “The modern history of exchange rate arrangements: A reinterpretation.” *The Quarterly Journal of Economics* **119**(1): pp. 1–48.
- SCHOLL, A. & H. UHLIG (2008): “New evidence on the puzzles: Results from agnostic identification on monetary policy and exchange rates.” *Journal of International Economics* **76**(1): pp. 1–13.
- SIMS, C. A. (1980): “Macroeconomics and reality.” *Econometrica* **48**(1): pp. 1–48.
- SIMS, C. A. & T. ZHA (2006): “Were there regime switches in u.s. monetary policy?” *American Economic Review* **96**(1): pp. 54–81.
- SMETS, F. & R. WOUTERS (2003): “An estimated dynamic stochastic general equilibrium model of the euro area.” *Journal of the European Economic Association* **1**(5): pp. 1123–1175.
- TAYLOR, J. B. (1993): “Discretion versus policy rules in practice.” *Carnegie-Rochester Conference Series on Public Policy* **39**(1): pp. 195–214.
- UHLIG, H. (2005): “What are the effects of monetary policy on output? results from an agnostic identification procedure.” *Journal of Monetary Economics* **52**(2): pp. 381–419.

A Bayesian TVP-VAR Estimation: Some Technical Details

We use one lag in the VAR system, to keep the space of estimated (time varying) coefficients reasonably sized. The number of Gibbs sampler iterations varies across countries. Those with longer time series typically need more draws for reaching convergence, as there are longer paths of time-varying parameters (or, equivalently, the respective errors) to be estimated. Generally we have used 10000 burn-in draws and 2000-10000 effective draws depending on whether a reasonable degree of convergence was reached. Convergence was diagnosed using autocorrelation functions of the Markov chain and Raftery & Lewis (1992) convergence diagnostics. The priors on the parameters of the model and the hyperparameters are set according to Primiceri (2005). Specifically,

$$\beta_0 \sim \mathcal{N}(\hat{\beta}_{OLS}, 4.\text{var}[\hat{\beta}_{OLS}])$$

$$A_0 \sim \mathcal{N}(\hat{A}_{OLS}, 4.\text{var}[\hat{A}_{OLS}])$$

$$\log \sigma_0 \sim \mathcal{N}(\log \hat{\sigma}_{OLS}, 4I_n)$$

i.e. the prior distributions are normal for matrices Z and A and log-normal for vector σ , where the means are the OLS estimates of Z , A and σ from a time-invariant VAR. Prior variances on Z and A are set at four times the variances from a time-invariant VAR, while the prior variance on $\log \sigma$ is four times the identity matrix. The priors on the hyperparameters are set as follows:

$$Q \sim \mathcal{IW}(k_Q^2.\tau.\text{var}[\hat{Z}_{OLS}], \tau)$$

$$W \sim \mathcal{IG}(k_W^2.(1 + \dim(W)).I_n, (1 + \dim(W)))$$

$$S_\tau \sim \mathcal{IW}(k_S^2.(1 + \dim(S_\tau)).\text{var}[\hat{A}_{\tau,OLS}], (1 + \dim(S_\tau)))$$

where τ is the size of training sample, S_τ and $\hat{A}_{\tau,OLS}$ are the corresponding parts of the respective matrices. We use the whole time series as the training sample. The prior hyperparameter mean factors are set to $k_Q = 0.01$, so that we attribute 1% of the uncertainty arounds the time-invariant OLS estimate to time-variation. Further $k_W = 0.01$ and $k_S = 0.1$, we again follow Primiceri (2005) here.

B Additional Results

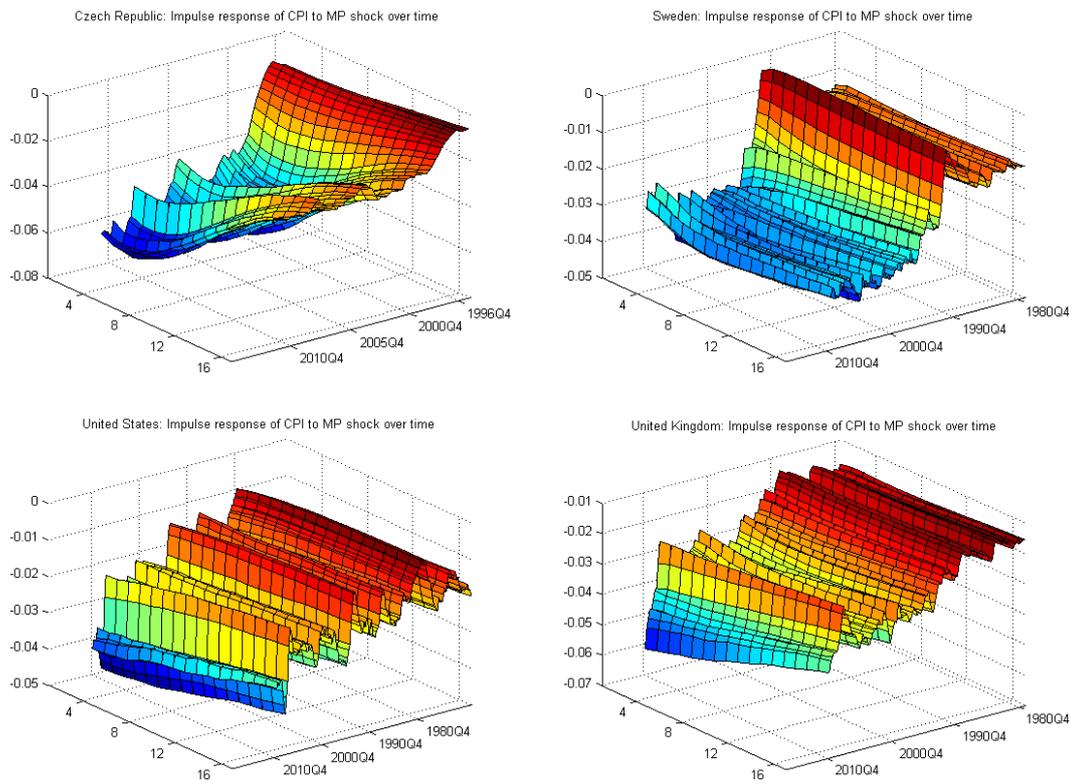


Figure 5: Evolution of IRFs of CPI to an MP shock in different countries