What Drives the Strength of Monetary Policy Transmission?*

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This paper analyzes the cross-country and time variation in monetary policy transmission from short-term interest rates to price level. Using Bayesian TVP-VAR models where the structural monetary policy shocks are identified using zero and sign restrictions, the results suggest that monetary policy transmission has become stronger over time and sacrifice ratios have decreased. Exploring the cross-country and time variation in monetary policy responses using panel regressions, I show that stronger monetary policy transmission and lower sacrifice ratios were associated with an inflation-targeting regime. In periods of banking crises, the transmission was weaker and output costs were higher.

JEL Codes: E52, C54.

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 their decisions about policy interest rates affect the economy. How large is the expected impact of an 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 quantitative summary

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of studies estimating the monetary transmission in various countries, over different time periods and using different modeling strategies, see Havránek and Rusnák (2012). The current consensus is that the response of price level to a monetary policy shock reaches its peak in four to eight quarters. Some studies (Canova, Gambetti, and Pappa 2007; Koop, Leon-Gonzalez, and Strachan 2009) show that monetary policy has changed over time in some countries. Other studies illustrate the cross-country heterogeneity in monetary transmission (Elbourne and de Haan 2006; Jarocinski 2010). A natural policymakers' question would be: what are the drivers of the strength and speed of monetary transmission?

This paper aims to explain the cross-country and time variation in the strength of monetary transmission focusing on the possible role of monetary regime and the characteristics of the economy and financial sector. I start by estimating time-varying impulse responses to monetary policy shocks on a sample of thirty-three OECD and EU countries, keeping the model specification fixed across countries. Having obtained the panel of impulse responses to monetary policy shocks (monetary policy shock is identified by a mixture of short-term and sign restrictions in the framework of Bayesian time-varying parameter vector autoregression, or TVP-VAR; see the methodological part for details), I illustrate the time evolution of impulse responses over the last four decades. Specifically, the results show that the lags of price-level responses to monetary policy shocks have shortened during the observed period, which may reflect the changes in monetary policy strategies and smoother functioning of financial markets. Further, using panel fixed-effects regressions, I show the differences in monetary transmission for different monetary policy regimes: when a country adopted an inflation-targeting monetary policy regime, the transmission from monetary policy interest rates to prices became significantly stronger (by 0.1–0.2 percentage point in a response to a 1 pp shock to policy interest rate). On the other hand, inflation targeters as a whole have a marginally weaker transmission than euro-area countries. Further, a part of the time variation in a fixed-effects model is explained by variables linked to the functioning of the financial sector: while higher leverage in the economy (with higher domestic private credit) is related to stronger transmission, the occurrence of a banking crisis decreases the magnitude of the response of prices to a monetary policy shock.

In a banking crisis, the response of prices to a 1 pp monetary policy shock is lower by 0.05–0.1 pp. The between-effects regressions show that euro-area member countries and countries more open to international trade have stronger transmission.

Finally, I 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 the last decades from their peak in the 1970s (which coincides with the U.S. disinflation under Volcker chairmanship of the Federal Reserve). A monetary policy regime switch to an inflation-targeting regime was typically followed by lower output costs of disinflation. In the periods of stress in the banking sector the sacrifice ratios were higher.

Still, the 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. The analysis relies on the identification strategy based on a mixture of short-term (zero) and sign restrictions, using the established understanding of the nature of monetary policy shock. 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 by avoiding the time-invariant endogeneity, but other types of endogeneity may be still present.

Following the Introduction, 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, and 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 before (Ehrmann 2000; Mojon and Peersman 2001) and after euro adoption (Angeloni and Ehrmann 2003; Ciccarelli and Rebucci 2006) with mixed conclusions regarding prior euro adoption heterogeneity of transmission and its homogenization in euro-area countries after the adoption of the single currency. Weak conclusions are largely caused by wide confidence intervals of the estimates. The heterogeneity of transmission in euro-area countries has been explored by Ciccarelli, Maddaloni, and Peydró (2013), showing the importance of the credit channel during the crisis. Another cross-country study, by Aysun, Brady, and Honig (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 and Fuerst 1997; Bernanke, Gertler, and Gilchrist 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, Montiel, and Spilimbergo (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 is that of Georgiadis (2012), who attributes the cross-country differences in transmission estimated through VAR impulse responses to differences in the financial sector, labor market, and industrial mix. However, his work is restricted to a cross-country analysis only and so it cannot control for the country fixed effects. There might be an omitted-variable bias present in such estimations. For better identification of the effects, this paper explores also the time variation in monetary policy transmission. A Bayesian methodology for multi-country estimation of time-varying parameter VARs was proposed by Canova and 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 thirty-three now-developed countries, with the time span from 1970 to 2010 where the data permit. This to some extent restricts the set of possible explanatory variables of 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. The analysis presented here sticks to variables available in a longer time series for most countries.

3. Empirical Methodology

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

[1]Because I estimate the TVP-VARs separately for each country, the international spillovers of monetary policy are not analyzed.

[2]Although 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 (the VAR system with exogenous variables has been called VARX). See Lütkepohl (2007) for details.

The process can be summarized as follows:

(i) Assemble data set of thirty-three OECD+EU countries (where the data coverage permits), including the endogenous and exogenous variables of the VAR and possible determinants of the strength of monetary transmission.

(ii) Estimate Bayesian TVP-VAR with stochastic volatility, identify structural shocks using short-term and sign restrictions, and compute impulse response functions (IRFs).

(iii) Plot the impulse response functions, exploring both the time and cross-country patterns in monetary transmission, including the "sacrifice ratios."

(iv) 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, I use a quarterly data set consisting of the seasonally adjusted log-GDP index in constant prices, log-CPI, and money market interest rate—a market-based proxy for the monetary policy target rate and a logarithm of nominal effective exchange rate. Further, I include the logarithm of the oil price index as an exogenous variable.

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

3.2 TVP-VAR Estimation and Identification

3.2.1 Reduced-Form TVP-VAR

I estimate the reduced-form time-varying parameter vector autoregressive model with stochastic volatility, similarly to Primiceri (2005) and Koop, Leon-Gonzalez, and Strachan (2009). In models with stochastic volatility, not only the coefficients but also the covariance matrix of residuals are allowed to change over time. Therefore, these models are able to distinguish between the structural changes in the parameters of monetary policy—the "good/bad policy" story (Cogley and Sargent 2002; Lubik and Schorfheide 2004; Boivin and Giannoni 2006)—and changes in the magnitude of shocks—the "good/bad luck" story (Sims and 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, the interest rate, and the log of the nominal effective exchange rate), Z_t is a vector of explanatory variables consisting of the lags of endogenous variables, an exogenous variable (the log of the commodity price index), and the intercept. I use one lag of endogenous variables in the TVP-VAR system to reduce the number of coefficients to be estimated.[3] The coefficients are time varying, and I assume they follow a random-walk process

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

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

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

[3] Although Bayesian estimation principally avoids the dimensionality problem, the set of parameters to be estimated consists of 4×6 time-varying coefficients in VAR equations (including coefficients on the exogenous variables and the intercept), plus the $4 \times 4 + 4$ elements of time-varying variance-covariance matrices and a number of time-invariant parameters. To maintain a reasonable degree of estimation efficiency, I use one lag of the endogenous variables in the VAR system, which is sufficient for capturing the impulse response dynamics.

where A_t is a 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 iid $\mathcal{N}(0,1)$. 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 iid $\mathcal{N}(0,S)$ and η_t is iid $\mathcal{N}(0,W)$. 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 each model parameter are assumed to be independent across model parameters.

For the technical details of Bayesian MC^2 estimation (Gibbs sampler), see Primiceri (2005) or Koop and Korobilis (2009). The priors on the parameters of the model, as well as the hyperparameters (see appendix 1 for details) are held constant across the cross-section of countries for which the TVP-VARs are estimated, and I take them from Primiceri (2005).

3.2.2 Sign Restrictions

Subsequently to estimating the reduced-form TVP-VAR, I identify structural shocks using a mixture of short-term and sign restrictions (Fry and Pagan 2011). Sign-restrictions identification has been frequently used for the analysis of monetary policy (Canova and Nicolo 2002; Uhlig 2005; Rafiq and Mallick 2008; Scholl and Uhlig

2008; Jarocinski 2010). Due to computing-time reasons, this paper focuses only on the identification of monetary policy shock. I restrict the monetary policy shock to have the following pattern:

$$\begin{bmatrix} \text{Response to MP Shock} & \text{Log-GDP} & \text{Log-CPI} & \text{IR} & \text{ER} \\ \text{On Impact} & 0 & 0 & + & + \\ \text{In the Short Run (1–4 quarters)} & ? & ? & + & + \\ \text{On the MP Horizon (4–6 quarters)} & - & - & ? & ? \\ & & & & \end{bmatrix},$$

i.e., I search for such structural transformation of (transitory) reduced-form shocks where output and price level react to a monetary policy shock only with a lag, and on the monetary policy horizon (four to six quarters) the response of prices and output is negative. Interest rate and exchange rate can react on impact, while the direction of their responses is positive in the short run (up to four quarters) and unrestricted further on. The set of restrictions may appear exhaustive, but as Matthias (2007) shows on data simulated from a structural model, a large number of sign restrictions is needed to correctly identify shocks.[4] The sign pattern used here is consistent with the theoretical consensus of New Keynesian general equilibrium models (Smets and Wouters 2003; Christiano, Eichenbaum, and Evans 2005; Galí and Gertler 2007).[5] The structural shocks are identified according to Fry and Pagan (2011). First, the candidate structural shocks are obtained from orthogonal (Givens) rotations of a set of uncorrelated shocks which come from the recursive (Choleski) identification. Specifically, in this case the candidate structural shocks are created by multiplying a set of uncorrelated shocks by a Givens matrix $Q(\theta)$, which takes the following form:

[4]Canova and Paustian (2011) even show that a large number of restrictions can make up for modest model misspecifications. Another reason for using the mixture of sign and short-run restrictions is that using the sign restrictions alone leads to a bias in estimates of the impulse responses, as the posterior distribution of estimated IRFs is effectively truncated by the sign restriction. The size of the truncation bias was estimated by Liu and Theodoridis (2012), who show that it increases with IRF horizons and VAR lags and amounts to up to 0.5 pp.

[5]However, a number of assumptions such as habit formation, capital installment costs, persistent autoregressive shocks, etc. need to be made to generate hump-shaped responses in those models.

$$Q(\theta) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos\theta & -\sin\theta \\ 0 & 0 & \sin\theta & \cos\theta \end{pmatrix},$$

where the parameters θ are drawn from $U[0, \pi]$. That way, I obtain candidate structural (uncorrelated) shocks. Among the candidate shocks, only those which satisfy the sign restrictions are picked. This identification strategy does not deliver exact model identification, because I generally find multiple candidate sets of structural shocks which satisfy the restrictions. We follow the consensus (Fry and Pagan 2011) to report the median impulse response of the ones which satisfy sign restrictions. As I identify only one structural shock, the choice of median model is straightforward.

The shocks are normalized to a 1 pp increase in interest rate on impact.

3.3 Panel of Impulse Responses

As a result, I obtain a panel of impulse responses of price level to (transitory) monetary policy shocks. I examine the cross-country and time variation first graphically (showing, for example, that the lag of monetary transmission has gradually decreased over the 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), I use the value of impulse response function at the conventional monetary policy horizons ($h = 4, 6, 8$ quarters). Different horizons generally yield similar conclusions, so I show only the results for the cumulative response from the impact to $h = 6$ quarters after the initial shock. Using panel regressions, I 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, or the occurrence of banking crises. The standard errors are heteroskedasticity robust and clustered at the country level.

Using panel fixed effects and between estimators, I am able to distinguish which of the factors capture the cross-country variation and which are better at capturing 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 monetary policy shocks than inflation targeters, the fixed-effects estimator (explaining the time variation) shows that when a country adopted inflation targeting, its transmission on average strengthened. Moreover, the results suggest that in the periods of elevated financial stress (captured by the occurrence of banking crises), monetary policy transmission is relatively weaker. On the other hand, a part of the cross-country variation can be explained by the degree of openness: more open economies have on average stronger transmission, probably because of the exchange rate channel. The transmission is also stronger with increasing financial leverage.

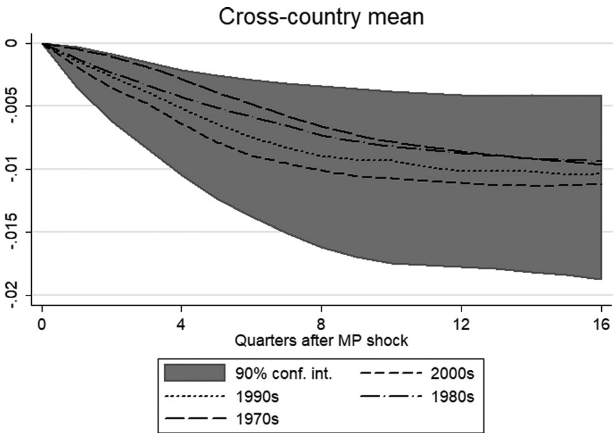
Finally, I compute and analyze the behavior of the monetary policy sacrifice ratios in the spirit of Jarocinski (2010). The sacrifice ratios measure the output cost of disinflation, i.e., how much output needs to be sacrificed to deliver lower inflation after a monetary tightening, and are defined as $\frac{IRF^{GDP}(h)}{IRF^{P}(h)}$ on the horizon h. According to the results, sacrifice ratios have decreased over time, reaching their maximum values during the 1980s. The figures below also show that an inflation-targeting regime of monetary policy is related to lower output costs of disinflation. Moreover, the sacrifice ratios increase in the periods of financial stress in the banking sector.

In this section, the impulse responses from the TVP-VAR on the sample of thirty-three countries are presented, illustrating both cross-country and time variation in the impulse responses to a monetary policy shock of a magnitude of 1 pp. In the main text I focus on the impulse response functions of CPI. Responses of other variables are in the appendix.

Figure 1 shows the mean impulse response (IRF) of CPI to a monetary policy (MP) shock averaged across countries (data permitting) as it evolved during the last four decades. Note that the panel of impulse responses is unbalanced because of the short time series for some countries, affecting the first two decades of the sample.[6]

[6]Confidence intervals for the estimates are not explicitly presented, as the uncertainty consists of both model uncertainty (generally more impulse responses satisfy the restrictions) and parameter uncertainty. However, the parameter

Figure 1. Evolution of IRFs of CPI to an MP Shock over Decades



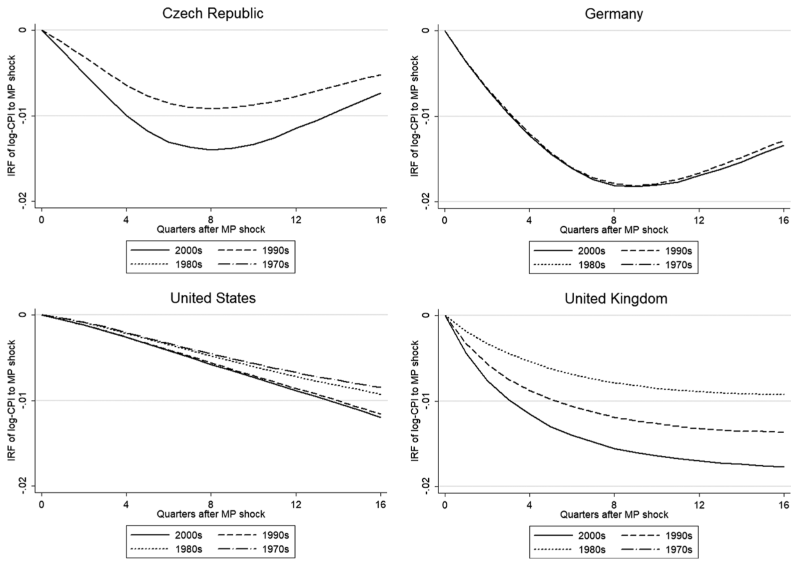
Notes: Response of log-CPI to a 1 pp monetary policy interest rate shock, estimated within a VAR model and identified using sign restrictions. Confidence bands are derived from the cross-country sample distribution, and do not explicitly reflect parameter or model uncertainty.

Although the changes are relatively small to be statistically significant, the figure suggests that monetary transmission has strengthened gradually over the last forty years. At the same time, the hump shape of the IRF of log-CPI to a monetary policy restriction has become more pronounced, with the peak response now occurring earlier after the initial shocks. This illustrates that the lags of the response of prices to monetary policy shocks have become shorter.[7]

uncertainty around mean impulse responses is fairly stable across countries, periods, and horizons and amounts to about 0.5–0.8 pp.

[7]Note 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 illustrate 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 than reaction implied by the policy rule (or stronger, or even in the opposite direction). The (time-varying) monetary policy rule is estimated as a part of the TVP-VAR model, constituting one of the equations of the VAR system. The model allows for immediate reaction of the monetary policy rate to developments in all endogenous variables and the exogenous variable, and as such it can be considered a generalization of the simple empirical Taylor (1993) rule.

Figure 2. Evolution of IRFs of CPI to an MP Shock in Different Countries

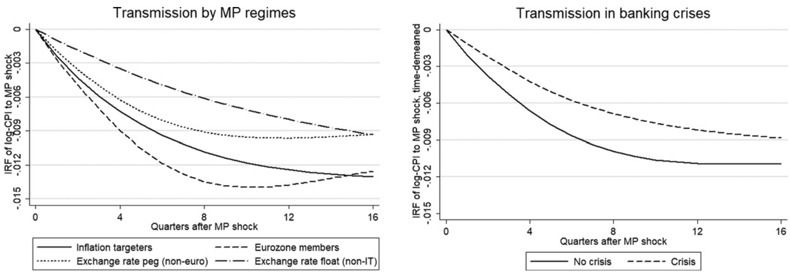


Notes: Response of log-CPI to a 1 pp monetary policy interest rate shock, estimated within a VAR model and identified using sign restrictions.

Figure 2 shows the evolution of impulse responses in several selected countries. The Czech Republic is chosen to represent (historically) developing inflation-targeting countries, the United Kingdom represents a developed inflation-targeting economy, Germany represents a major euro-area economy, and the United States represents the world's leading economy. The development of monetary transmission in these four countries represents the overall trends in the last decades. The transmission from short-term interest rates to prices became stronger, and the duration between the initial shock and the peak response in CPI (where there is one) became shorter.

Figure 3 (left panel) illustrates the different strength and speed of monetary transmission under different monetary policy regimes. The figure presents a typical (mean) impulse responses of price level to 1 pp 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

Figure 3. IRFs of CPI to an MP Shock under Different MP Regimes and In/Out of Banking Crises



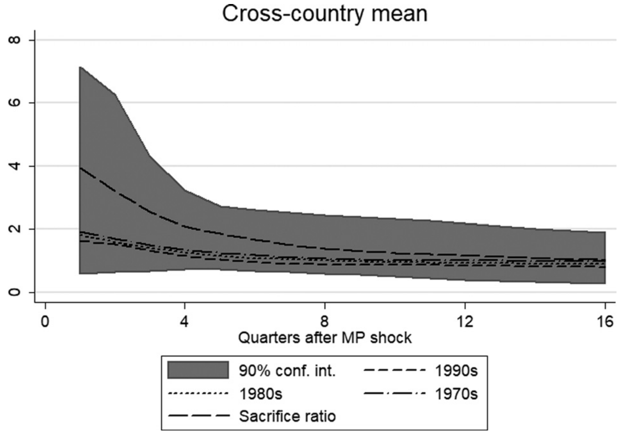
Notes: Response of log-CPI to a 1 pp monetary policy interest rate shock, estimated within a VAR model and identified using sign restrictions.

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 (cross-country mean for each time period) from the values of IRFs in respective periods. Still, the differences come from both the cross-country variation and the time variation, as there have been changes of monetary policy regimes during the sample period.

Interestingly, transmission of (non-systematic) monetary policy is the strongest in euro-area countries, even after controlling for the time effects of generally stronger transmission in more recent time periods. This finding may not be that surprising given that 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 larger and more frequent. As Matthias (2007) and Castelnuovo (2012) show, when the variance of shocks is large, their identification using sign restrictions is better. Another explanation may be that euro-area countries are among the ones with the most developed financial sectors in the sample, which may be related to a better functioning of transmission.

Figure 3 (right panel) illustrates the mean IRFs for countries going through a banking crisis. Again controlling for the time effects,

Figure 4. Evolution of the Monetary Policy Sacrifice Ratios over Decades

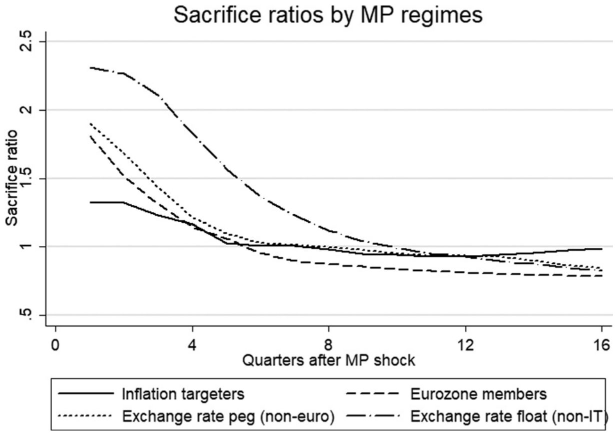


Notes: Sacrifice ratio is defined as a share of IRFs of output and CPI in percentage points to a 1 pp monetary policy interest rate shock, estimated within a VAR model and identified using sign restrictions. Confidence bands are derived from the cross-country sample distribution, and do not explicitly reflect parameter or model uncertainty.

the figure shows that during banking crises the transmission is marginally weaker. It is important to note that the presented typical responses for different regimes do mix two sources of variation coming from different dimensions: cross-country variation and time variation. For example, transmission can become weaker when a country enters a banking crisis, but it may be stronger in countries which generally experience crises more frequently. The presented figures are, pooling the two dimensions together. As the identification of pure cross-country effects is a rather difficult task because of possibly many omitted variables (unobserved country-specific endogeneity), more reliable relationships can be obtained from the time variation in each. To distinguish between the two dimensions of variation, I run both between-effects and fixed-effects panel estimators in the following section.

Figure 4 illustrates the evolution of the sacrifice ratios of monetary policy over the last decades. As defined earlier, the sacrifice ratios show how much output (in %) on average has to be sacrificed

Figure 5. Sacrifice Ratios under Different MP Regimes



Notes: Sacrifice ratio is defined as a share of IRFs of output and CPI in percentage points to a 1 pp monetary policy interest rate shock, estimated within a VAR model and identified using sign restrictions.

to induce a 1 percent decrease in price level at a desired horizon, given the estimated impulse response functions of (real) log-GDP and log-CPI to a monetary policy shock. In other words, the sacrifice ratios measure the output costs of disinflation. Although the changes are again too small to be significant, the results illustrate that the monetary policy sacrifice ratios might have decreased since the 1970s. Finally, figure 5 shows that the sacrifice ratios are marginally lower for inflation targeters at the short horizons. Possible determinants of lower sacrifice ratios are also analyzed in the next section.

It is important to relate these findings to the literature on the slope of the Phillips curve. Several influential studies have suggested that the Phillips curve has flattened (Simon, Matheson, and Sandri 2013; Blanchard, Cerutti, and Summers 2015), partly relating this phenomenon to better anchoring of short-term inflation expectations. This may suggest that monetary policy needed to do more to affect inflation and that sacrifice ratios have increased.[8]

[8]There are several methodological questions regarding the findings of declining Phillips-curve slope, often related to the single-equation estimation and the

Taking a closer look, this does not directly contradict findings of this paper.[9] First recall that sacrifice ratios here are defined as the ratio of the impulse responses of output and inflation. The finding of decreasing sacrifice ratios rather indicates a growing importance of other channels of monetary policy (than the standard interest rate channel), those affecting inflation directly with a relatively weaker effect on economic activity. The exchange rate channel is one of the candidates, as are other asset price channels (such as housing, directly reflected in CPI measures of many countries). Another one may be the expectation channel, which affects inflation directly through managing expectations without the need to force changes in output.

To sum up, the above-presented findings indicate gradual, structural improvements in the strength and efficiency in monetary policy transmission, which can be related to changes in monetary policy frameworks. This process may be disrupted or delayed by banking crises.

4. Results: Factors Associated with the Characteristics of Monetary Transmission

Finally, I examine the cross-country and within-country variation in using panel regressions. While the above-presented IRF plots mix these two dimensions of variation together, in this section I show that when controlling for country fixed effects, the results can be somewhat different.

In the fixed-effects regressions the following equation is estimated:

$$IRF^P(h)_{i,t} = \alpha_i^{FE} + \beta^{FE} X_{i,t} + \varepsilon_{i,t}^{FE}, \tag{1}$$

possible effects of omitted variables. As Jarocinski and Bobeica (2017) suggest, the "missing inflation" puzzles attributed to flattening Phillips curves disappear once using a VAR with full endogenous relationships. Further, other studies have suggested that Phillips curves may not have flattened if using different measures of slack.

[9] Additionally, the effects presented in this paper are conditional on non-systematic monetary policy shock, which may be substantially different from unconditional relationships such as the Phillips-curve slope.

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. I focus on the typical monetary policy horizon and present the results for $h = 6$.

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

$$IRF^P(h)_i = \alpha^{BE} + \beta^{BE} X_i + \varepsilon_i^{BE}, \tag{2}$$

where both the left- and the right-hand-side variables are within-country averages. The between-effects regression may be largely influenced by the problem of omitted variables, as there are possibly many country-specific factors not explicitly included in the regression. I believe that there is more information value in the fixed-effects model which filters out this time-invariant endogeneity, while the coefficients of the between-effects model can be interpreted rather as correlations.

It is important to note that the dependent variable is estimated and comes with a potentially large measurement error into the regression. This does not bias the estimates (as opposed to the estimated explanatory variable) but may pose inference problems, as the errors might be heteroskedastic. To account for this, Lewis and Linzer (2005) for most applications suggest using robust standard errors, e.g., the standard Hubert-White. Additionally, I use robust standard errors clustered at the country level, as the errors might well be correlated within country.

The results presented in table 1 suggest that when a country adopted an inflation-targeting regime of monetary policy, the transmission of monetary policy to price level became stronger by 0.1–0.2 pp in a response to a 1 pp shock to monetary policy rate. For comparison and the evaluation of the economic significance of this effect, as figure 1 shows, the mean cumulative response at the monetary policy horizon has amounted to 1 pp. The relationship between inflation targeting and stronger transmission can be attributed to an increased transparency, more careful communication, and increased credibility of monetary policy, typical features of an

Table 1. Correlates of the Cumulative Response of Inflation to an MP Shock after Six Quarters

	FE	BE	FE Full	BE Full
InflTargeters	−0.176***		−0.137***	−0.0172
	(−4.52)		(−3.81)	(−0.06)
DomPrivCredit	−0.00151***		−0.00132***	−0.000994
	(−4.12)		(−2.84)	(−0.41)
BankCrisis	0.0725***		0.0759***	0.862
	(3.69)		(3.58)	(0.99)
Eurozone		−0.844***	−0.0152	−0.568
		(−3.25)	(−0.47)	(−1.41)
Openness		−0.00353*	−0.00139	−0.00208
		(−1.75)	(−1.27)	(−0.83)
MktCapitalization			6.07e-16	1.18e-14
			(0.07)	(0.21)
GovtDebt			0.000507	0.00248
			(0.69)	(0.71)
Constant	−0.579***	−0.364*	−0.564***	−0.666*
	(−17.05)	(−2.02)	(−6.34)	(−1.78)
Observations	3,256	3,284	2,631	2,631
Adjusted R^2	0.274	0.262	0.194	0.055

Notes: t-statistics are in parentheses. The dependent variable is the cumulative response of inflation in percentage points to a 1 pp MP shock. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

inflation-targeting regime. Transparency has been found crucial for monetary transmission also in the empirical study by Neuenkirch (2011), while theoretical work of Amato, Morris, and Shin (2002) emphasized the role of public information for coordination. For a survey on the evolution and the role of central bank communication, see Blinder et al. (2008).

Further, the stress in the banking sector seems to disrupt the functioning of monetary policy transmission. The occurrence of banking crises shows a significant relationship to the weaker effect of monetary policy interest rate shocks on prices. In the periods of banking crises, the response of price level to a 1 pp monetary policy shock has been lower by about 0.05–0.1 pp on average. This is likely because of disrupted pass-through from the policy rates to client interest rates on loans, caused by elevated risk premiums on both interbank market and client loans. The disruptions to the monetary policy transmission mechanism related to financial stress (Adrian and Shin 2009) seem to overweight the potential amplification effects of the financial accelerator, which would predict stronger transmission when frictions in financial markets are more substantial (which is likely during banking crises). On the other hand, a higher ratio of domestic private credit to GDP is related to stronger monetary policy transmission, as more leveraged economies respond more strongly to changes in interest rates through credit and balance sheet channels, while also the wealth effects of interest rate changes are larger. This finding is in line with the suggestions of the financial accelerator literature (Carlstrom and Fuerst 1997; Bernanke, Gertler, and Gilchrist 1999) and the related empirical studies (Ciccarelli, Maddaloni, and Peydró 2013).[10]

The fixed-effects regression using the full set of explanatory variables (third column in table 1) shows that other variables are of lower relevance.

The cross-country variation suggests that more open economies (with a higher share of the volume of trade to GDP) seem to feature stronger monetary policy transmission, which is likely an effect of a stronger exchange rate channel. Euro-area members have also seen a stronger transmission, which may be an effect of country-specific unobserved factors, as euro-area countries are among the most developed financial sectors in the sample.

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. Again, this can be attributed to higher credibility and transparency related to inflation targeting, although a similarly favorable (albeit slightly weaker) result applies to euro-area members. In addition to a generally weaker monetary policy transmission in banking crises, the analysis shows that banking stress (both the crisis occurrence and the increased

[10] It is important to note that the presented effects might come from two sources, namely change in monetary policy strategy or a structural change in the economy/financial sector, affecting the transmission mechanism. Ciccarelli and Rebucci (2006) explore this distinction while analyzing changes in transmission after the establishment of EMU. However, this distinction would require a different modeling strategy than I use here.

Table 2. Correlates of the MP Sacrifice Ratios at the Horizon of Six Quarters

	FE	FE Full	BE Full
InflTargeters	−0.108***	−0.0862***	−0.863
	(−4.95)	(−4.57)	(−0.96)
Eurozone	−0.0507***	−0.0301	−1.307
	(−3.75)	(−1.62)	(−1.11)
BankCrisis	0.0865	0.0521**	0.221
	(1.46)	(2.31)	(0.09)
MktCapitalization		−2.41e-16	−8.17e-14
		(−0.08)	(−0.49)
DomPrivCredit		0.0000692	0.0000552
		(0.27)	(0.01)
GovtDebt		0.00217	0.00314
		(1.32)	(0.31)
Openness		−0.000140	−0.00817
		(−0.33)	(−1.11)
Constant	1.452***	1.319***	2.469**
	(147.19)	(11.98)	(2.26)
Observations	3,311	2,631	2,631
Adjusted R^2	0.085	0.152	−0.117

Notes: t-statistics are in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

non-performing loans ratio) is 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.

5. 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, it has documented the role of financial-sector characteristics and the monetary policy regime on the strength and efficiency of monetary policy transmission. The aggregate approach allows for the quantification of the effects.

I have constructed a panel of time-varying impulse response functions for thirty-three countries, with the time span ranging from 1970 to 2010 where the data permitted. Estimating Bayesian TVP-VAR models with the same specification for all countries and identifying the monetary policy interest rate shock using a mixture of short-term and sign restrictions, I have obtained the time-varying impulse responses of price level and GDP to a monetary policy shock for each country in the sample. The time-varying model suggests that the transmission of monetary policy has strengthened over time and the lags of transmission became shorter, while the monetary policy sacrifice ratios have gradually decreased.

Further, I have analyzed the possible determinants of the strength of monetary policy transmission. Exploiting both the cross-country and the within-country variance using panel regressions, the role of various financial and institutional characteristics of economies for the strength of monetary policy transmission has been examined. 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 pp policy interest rate shock became on average stronger by 0.1–0.2 pp. 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 pp shock was lower by about 0.05–0.1 pp. Further, a higher ratio of domestic private credit to GDP is related to stronger transmission, as a higher leverage ratio implies that interest rate changes have a larger impact through the credit and balance sheet channels. Finally, more open economies feature stronger responses to monetary policy shocks, likely due to the exchange rate channel.

Finally, note that the observed relationships cannot be interpreted as causalities, as various forms of endogeneity may still be present even when time and country fixed effects are controlled for. Further work addressing the endogeneity issues, as well as exploring the quantitative implications of financial and institutional factors for transmission in a more structural framework, could be valuable topics for future research.

Appendix 1. Bayesian TVP-VAR Estimation: Technical Annex

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 10,000 burn-in draws and 2,000–10,000 effective draws depending on whether a reasonable degree of convergence was reached. Convergence was diagnosed using autocorrelation functions of the Markov chain and Raftery and 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, and 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 percent of the uncertainty around the time-invariant OLS estimate to time variation. Further $k_W = 0.01$ and $k_S = 0.1$, we again follow Primiceri (2005) here.

Appendix 2. Additional Results

Figure 6 illustrates the impulse response functions of remaining variables to a monetary policy shock, including their estimated evolution over time and the confidence bands. Figure 7 shows three-dimensional plots of the impulse response functions of log-CPI to a 1 pp monetary policy shock in selected countries.

Figure 6. IRFs of Log-Output, Interest Rate (pp), and Log-Effective Exchange Rate to a Monetary Policy Shock (normalized to 1 pp to interest rate on impact)

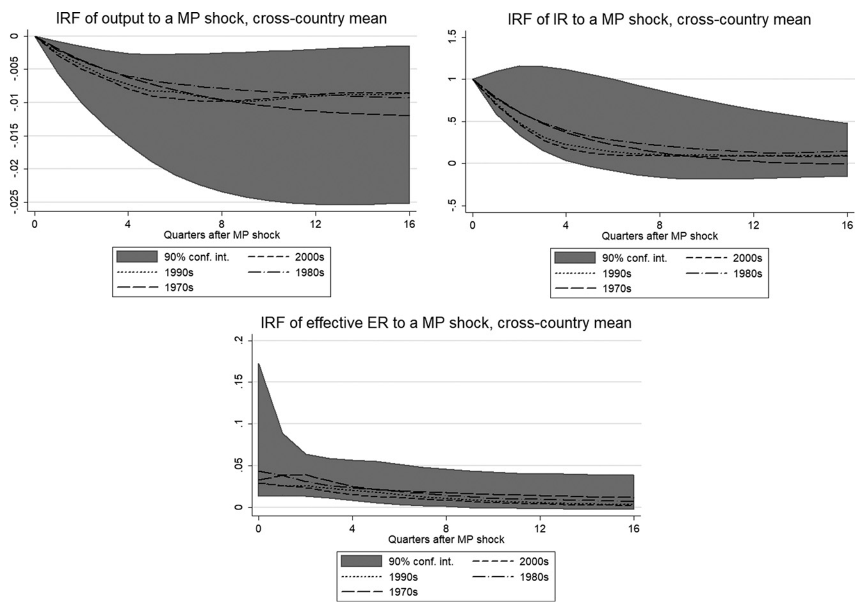
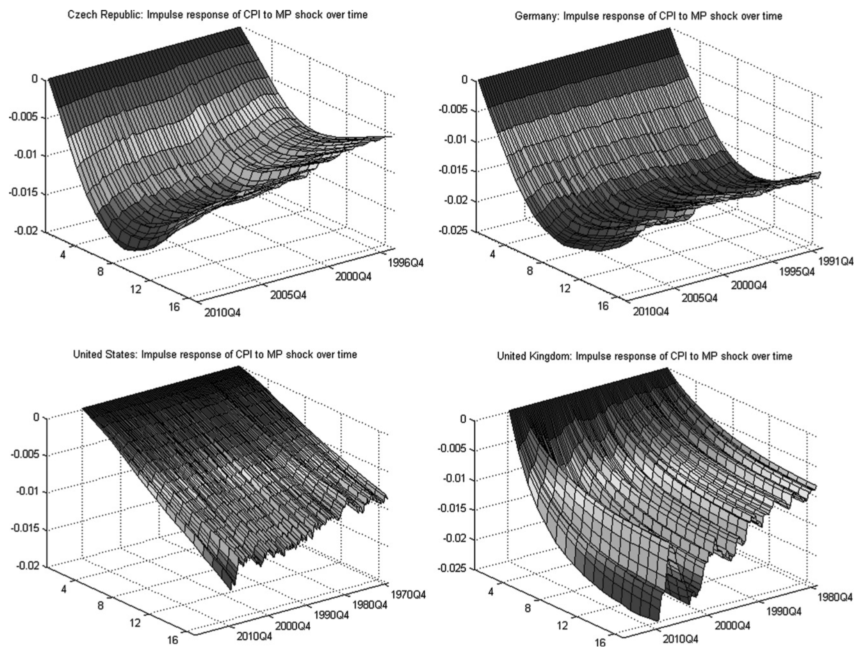


Figure 7. Evolution of IRFs of CPI to an MP Shock in Selected Countries



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