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Monetary Policy and Exchange Rate Dynamics: The Exchange Rate as a Shock Absorber*

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Abstract
We analyze the contribution of the real exchange rate to the macroeconomic volatility of Czech economy and its role in cushioning economic disturbances. Results from a two-country structural VAR model do not allow us to reject a shock-absorbing role of the real exchange rate for the Czech economy. This result is robust to model extensions. Further analysis shows that domestic monetary policy and the real exchange rate are responsive to asymmetric and real exchange rate shocks in the short term, while the contribution of non-policy shocks is prevailing in the long term. This supports the view that the Czech National Bank's policy is predictable. Low transmission of a real exchange rate shock to output and price volatility is consistent with the theoretical role of the exchange rate as a shock absorber.

1. Introduction

A seminal paper by Clarida and Gali (1994) initiated increasing interest in research on the sources of real exchange rate fluctuations and their propagation to the rest of the economy. The ensuing studies include Thomas (1997) and Amisano *et al.* (2009), who assess the shock-absorbing role of the real exchange rate. Theoretical models often support the shock-absorbing role of the real exchange rate. However, a number of empirical studies, e.g. Farrant and Peersman (2006) and Peersman (2011), consider the real exchange rate to be a source of volatility instead of a shock absorber.

The potential of the real exchange rate to absorb shocks becomes an even more important topic to study when the nominal exchange rate is fixed. Such study is often motivated by exploring the effects of eurozone entry or adoption of a common monetary policy. Movements in the real exchange rate can be attributed to nominal exchange rate shocks and differences in productivity levels. In the fixed exchange rate regime, nominal exchange rate shocks are absent and real exchange rate fluctuations reflect structural differences between the economies. Berka *et al.* (2012, 2014) show that the real exchange rate becomes an effective shock-absorbing mechanism when the nominal exchange rate is fixed.

In this work, we analyze the sources of the Czech koruna-euro real exchange rate volatility, focusing on the role of both nominal shocks and real shocks. Our approach is based on structural vector autoregression (SVAR) models and a sign restriction identification scheme is used for identification.

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Structural VAR models have become one of the most widely used tools for identifying structural shocks. Using VAR models with a triangular identification scheme, Clarida and Gali (1994) question the importance of nominal shocks for real exchange rate fluctuations. They show that a demand shock is able to explain most of the variance in the real exchange rate, which was therefore claimed to be a shock absorber. More recently, Juvenal (2011) supports their findings that demand shocks are more important in generating real exchange rate fluctuations. However, this view has been challenged by a number of studies, where alternative approaches for shock identification were used. Rogers (1999), Eichenbaum and Evans (1995) and Bluedorn and Bowdler (2005) have found that nominal shocks (in the models based on Clarida and Gali (1994), this covers monetary policy and the exchange rate) contribute significantly to business cycle volatility.

In comparison with the above-mentioned studies, we have to cope with the limited data span in the case of the Czech economy. Therefore, we rely on the sign restriction method for converting a VAR model into a structural VAR model. The advantage of this method is that it does not require short-run zero constraints to be imposed on the contemporaneous impact as the triangular identification schemes do. Nor does it require restrictions on the long-run effects of shocks, as these are unclear for an economy in transition. Instead of these requirements, only the signs of the impulse responses are restricted. The sign restriction method was introduced by Uhlig (2005) and has been continually developed since then. Furthermore, the sign restriction method is used in Farrant and Peersman (2006), Scholl and Uhlig (2008) and Mallick and Rafiq (2008) to analyze the contribution of nominal shocks to macroeconomic volatility. Corsetti *et al.* (2009) use the sign restriction approach to identify the effects of productivity and demand shocks on the US economy. A thorough description of the method and its possible applications and shortcomings are presented in Fry and Pagan (2011).

The imposed sign restrictions are collected from theoretical studies and are consistent with the structural model of the Czech economy as presented by Andrle *et al.* (2009). Therefore, the dynamics of the estimated model are in line with the results of the structural model estimation for the Czech economy.

We consider the model formulated in relative terms by Clarida and Gali (1994) as a baseline specification. The baseline model does not separate monetary policy and real exchange rate shocks; therefore we extend the baseline specification to account for the influence of monetary policy. This extended model is used to check the robustness of the baseline model predictions by assessing the distributions of the initial responses of the model variables to shocks. The analysis of these distributions suggests that accounting for monetary policy in the extended model improves shock identification. The explicit role of policy improves the recovery of the signs of the impulse responses and slightly lowers the uncertainty in the variables' responses.

After the structural model is identified, we decompose the variance of the model's variables, focusing on the contributions of real exchange rate shocks to volatility. The analysis of the volatility contributions explores the nature of the exchange rate. The results of the variance decomposition allow us to consider the exchange rate as a shock absorber rather than as a shock generator.

Unlike in the aforementioned studies for other countries, we find that real shocks play an ample role in real exchange rate fluctuations. While the real exchange rate shock is still found to be an important source of exchange rate volatility, its impact is comparable to a combination of real and demand shocks. Moreover, a real exchange rate shock does not generate a large portion of the variance in real output and inflation in the two relative models.

As our baseline and extended models are specified in relative terms, they do not identify the source of shocks (domestic or foreign). Therefore, we introduce a more complex model that follows studies by Artis and Ehrmann (2006) and Peersman (2011). Using this model and implied forecast error variance decomposition, we conclude that symmetric and asymmetric monetary policy shocks strongly affect the volatility of the exchange rate. Also, we find that exchange rate shocks are not the main source of inflation and output volatility, so the shock-absorbing nature of the exchange rate prevails.

As the Czech Republic has a floating exchange rate regime, real exchange rate volatility reflects shocks to nominal exchange rate and productivity differences between the country and the eurozone. Without evidence on a fixed exchange rate regime, determining through decomposition what share of volatility is attributed to the nominal exchange rate is not a straightforward process. Therefore, the question of how much the volatility would have been reduced if the Czech Republic had entered eurozone is beyond the scope of this paper.

The rest of the paper is organized as follows: In Section 2, we briefly describe the implementation of the sign restriction method and discuss the properties of the data. A presentation of the setup of the models and the utilized identification restrictions follows in Section 3. Section 4 presents our estimation results. Finally, Section 5 summarizes our findings and concludes the paper.

2. Implementing Sign Restrictions

Assume that a general VAR model of order p with n variables, where $\mathbf{X_t}$ is a vector of endogenous variables, can be stated as:

$$\mathbf{BX_t} = A(L)\mathbf{X_{t-1}} + \boldsymbol{\varepsilon}_\mathbf{t}$$

Here $A(L)$ is a polynomial of order p of matrices of size $n \times n$; $\mathbf{B}$ is a matrix of size $n \times n$; and $\boldsymbol{\varepsilon}_\mathbf{t}$ is an $n \times 1$ vector of normally i.i.d. shock disturbances with zero mean and variance-covariance matrix $\mathbf{\Sigma}$. The reduced form of the structural VAR can be then written:

$$\mathbf{X_t} = \Pi(\mathrm{L})\mathbf{X_{t-1}} + \mathbf{e_t}$$

where $\Pi(L) = \mathbf{B}^{-1}A(L)$ and $\mathbf{e_t}$ is an $n \times 1$ vector of normally i.i.d. shock disturbances with zero mean and variance-covariance matrix $\mathbf{V}$. While VAR estimation is now a standard procedure in the literature, the interpretation of shocks e_t, is subject to discussion. The aim is to assess the reaction of model variables to shocks, as our goal is to decompose the prediction errors to structurally meaningful innovations. Note that the general-form shocks, $\boldsymbol{\varepsilon}_\mathbf{t}$, and their covariance structure are related to the structural shocks, e_t, of the model in the following manner:

$$\mathbf{e_t} = \mathbf{B}^{-1}\boldsymbol{\varepsilon}_t$$
$$\mathbf{V} = \mathrm{E}(\mathbf{e_t}\mathbf{e_t}^{\mathbf{T}}) = \mathbf{HH}^{\mathbf{T}}$$

To assess the impulse responses of the structural representation, one needs to pin down impulse matrix $\mathbf{B}^{-1}$. The only restriction on $\mathbf{B}^{-1}$ is, however, covariance structure $\mathbf{V}$. The identification problem arises because there are not enough restrictions to pin down $\mathbf{V}$ as $\mathbf{HH^T} = \mathbf{B}^{-1}\mathbf{\Sigma}\mathbf{B}^{-1\mathbf{T}}$. The multiplicity is delivered by the orthonormal property of matrices, as for any orthonormal matrix $\mathbf{Q}$, $\mathbf{V} = (\mathbf{HQ})(\mathbf{HQ})^{\mathbf{T}}$. Thus e_t has the same variance matrix but is associated with different impulse responses generated by impulse matrix $\mathbf{B}^{-1}\mathbf{Q}$.[1]

Before Uhlig's (2005) seminal paper, common approaches to identifying matrix $\mathbf{B}^{-1}$ relied on imposing long-run restrictions on some of its elements. The popular approach, known as the Cholesky scheme, assumes a recursive identification scheme and imposes a triangular structure on matrix $\mathbf{V}$. An example of this is presented in Gali (1994), where restrictions imply that output reacts only to supply shocks, inflation reacts only to supply and demand shocks, etc. Though, some such restrictions are usually theoretically justified, it is often hard to defend this sort of timing. Furthermore, for the scheme based on the long-term restrictions, Farrant and Peersman (2006) and Uhlig (2005) show that long-term zero response restrictions can deliver biased results. This bias often leads to the emergence of anomalies such as the price puzzle or delayed overshooting puzzles.

To avoid the emergence of bias, we employ the sign restriction identification method pioneered by Faust (1998) and developed by Uhlig (2005). The sign restriction approach identifies shocks by imposing restrictions only on the signs of the impulse responses to structural shocks. These restrictions are usually imposed in the short or medium term to represent the structural effects of the shocks. The restrictions applied to the impulse responses can be set up so that the different puzzles are ruled out. Also, to avoid the use of strong restrictions on the variable relationships, long-term restrictions are not applied. Thus, the main advantage of the applied methodology is that it imposes relatively few restrictions on the results, making the impulse response correspond more to patterns found in the data and less to assumptions imposed by the researcher.

However, sign restriction identification has certain shortcomings (for a comprehensive analysis of the method's advantages and disadvantages, we refer the reader to Fry and Pagan (2011)). First, one has to be careful to uniquely identify the shocks with restrictions. For example, if both supply and demand shocks result in a positive output response, and only the output reaction is restricted to be positive, then the researcher cannot distinguish between demand and supply shocks. Therefore, additional restrictions are needed on inflation, which responds negatively to supply shocks and positively to demand shocks. Clearly, if there is no information to distinguish between shocks (i.e. variables respond to them with similar signs), the method cannot distinguish between them. In this case, the response to one shock is contaminated by the other shock.

Second, one must be careful with interpreting the identification results. By producing multiple response matrices, $\mathbf{B}^{-1}$, multiple model parameterizations are

[1] For a discussion of the parameter estimates, see Uhlig (2005).

delivered. Simple averaging among multiple $\mathbf{B}^{-1}$ to get a representative impulse response and variance decomposition is inadequate. Another limitation of the sign restriction scheme, in general, is its inability to recover the true parameters and quantitative responses of the model, as shown by Fry and Pagan (2011). The impulse response functions obtained with such weak identification are responses of the variables to a scaled shock with the size of one standard deviation. However, as Berg (2010) claims, the ability to generate multiple impulse responses makes the sign restriction approach advantageous in comparison with recursive identification schemes, as it provides a larger number of factorizations.

In this work, we are interested in variance decomposition, where the relative contribution of shocks is important. Therefore, we are interested in the delivered impulse responses rather than in parameter analysis. The reported impulse responses demonstrate the properties of the model and we are interested in the sign of the responses but not in the quantitative aspects. At the same time, using the least restrictive identification scheme, we impose little bias in the results.

Used for our analysis, the IRIS toolbox implements the following algorithm for sign restrictions: First, the reduced-form VAR model is estimated to obtain matrix $\mathbf{V}$. Second, the lower triangular factor of $\mathbf{V}$ is computed. Third, a random $n \times n$ matrix $\mathbf{W}$ is drawn from the multivariate standard normal distribution. Furthermore, $\mathbf{W}$ is decomposed so that $\mathbf{W} = \mathbf{QR}$ and $\mathbf{QQ}^\mathbf{T} = \mathbf{Q}^\mathbf{T}\mathbf{Q} = \mathbf{I}$. Fourth, the impulse response matrix $\mathbf{B}^{-1}\mathbf{Q}$ is created and responses are calculated. Finally, the restrictions are checked and if all are fulfilled the draw is kept; otherwise it is discarded. A large number of $\mathbf{W}$s are considered so that we can draw an inference from the collected draws. Thus, identification is achieved by imposing sign restrictions on the response matrix $\mathbf{B}^{-1}\mathbf{Q}$. As there are multiple random matrices $\mathbf{W}$ and many of them satisfy the imposed restrictions, there could be an infinite number of response matrices and corresponding structural parameters. Usually in the literature 1,000 successful draws is considered satisfactory to cover the space of the parameters.

As the sign restrictions—similarly to Bayesian methods—deliver a large set of models, there is no unique set of parameters representing the estimation. Therefore, the general approach is to report the median response for the impulse response function for the considered variable. However, this approach does not provide consistent results. Fry and Pagan (2011) criticize this procedure, as the median responses may be infeasible because they originate from different models (different parameterization).

To avoid this inconsistency, we employ the closest-to-median approach, proposed by Fry and Pagan (2011), to report the results of identification. For period i the median impulse $\bar{\varphi}_i$ over all successful draws φ_j is computed, where $\bar{\varphi}_i$ and φ_j s are $n \times n$ matrices. The objective is to find the draw that is closest to the median, i.e. solves the following problem:

$$M(j) = \sum_{i=1}^{q} \left(\bar{\varphi}_i - \varphi_j\right)\left(\bar{\varphi}_i - \varphi_j\right)^T$$

where the search runs over all successful draws j. As noted above, we do not report structural parameters because the method is unable to identify them.

In order to analyze the role of the exchange rate in generating economic volatility, we decompose the variance of the model variables. Forecast error variance decomposition indicates how much of the forecast error variance of each of the variables can be explained by exogenous shocks to the other variables. In accordance with the Fry and Pagan (2011) critique of the multiplicity of parameterization, the variance decomposition of the closest-to-median model is analyzed. This choice ensures that the shocks in the calculation are truly uncorrelated.

3. Data Description

The time series used are retrieved from the Czech National Bank's (CNB) ARAD database, the Czech Statistical Office and Eurostat. The sample period covers the period from the first quarter of 1998 (when the CNB launched the inflation-targeting policy) to the last quarter of 2011 (the last available data point), representing an era of a consistent type of monetary policy (avoiding significant policy breaks). All of the time series are collected at quarterly frequency, producing a sample of 56 observations.

The description of the foreign counterpart in the two country model is based on the effective indicators. These effective indicators are constructed from the raw euro-area country data[2] by using the weights of Czech exports to the Eurozone countries.

Short-term interest rates are described by the 3M PRIBOR and 3M EURIBOR interbank rates, whereas the source for the data is the CNB database.

Domestic output is described by the seasonally adjusted domestic real GDP series, which originates from nominal GDP deflated by its deflator. The exchange rate time series are taken from the ARAD database. The exchange rate is defined as the price of one euro in Czech koruna; therefore, a decrease of the exchange rate equates to appreciation of the koruna. Domestic inflation is represented by the adjusted net inflation time series, as this measure excludes the primary impacts of tax changes.

Figure 7[3] shows the data used in the estimation of the relative models. During the 1998–2011 period, various trends are observed in the data documenting the Czech Republic's economic convergence process. The observation of trends justifies the removal of trends before estimation. The nature of the relative variables removes common trends and the use of time series differencing removes remaining trends in the relative variables. For non-relative models, linear detrending is used to remove domestic trends originating from the convergence process and subsequent differencing delivers stationarity.

4. Models and Estimation

The discussion by Obstfeld *et al.* (1985) and the studies by Artis and Ehrmann (2006) and Amisano *et al.* (2009) on the role of the real exchange rate provide the theoretical basis of our analysis. As in Amisano *et al.* (2009), we also follow the approach of Clarida and Gali (1994) by setting up a small open economy model

[2] Source: Statistical Data Warehouse of the European Central Bank.

[3] All figures are presented in the *Appendix*.

and relating it to a VAR model specified in relative terms.[4] We believe that the relative form is also appropriate for the case of the Czech Republic, where the large neighbor is replaced by the effective eurozone aggregate. This assumption can be justified by the fact that the Czech Republic is a relatively small economy within the European Union. As the baseline structural model is specified in detail by Clarida and Gali (1994), derivation of the structural model is beyond the scope of our analysis.

Motivation for the relative form originates from focus on the real exchange rate, which itself is a “relative” variable. As the theoretical background suggests, the real exchange rate itself does not respond to symmetric shocks, e.g. the symmetric increase of the price level in the considered pair. This property of the real exchange rate justifies the setup of relative models that focus on asymmetric shocks. As the relative form rules out symmetric shocks by definition of variables, it provides focus on identification of asymmetric shocks. Also, the model in relative terms remains parsimonious. As only asymmetric shocks are present in the model, the significant contribution of relative supply and demand shocks to volatility of the real exchange rate will signal that an independent exchange rate can help stabilize the economy.

The vector error correction (VEC) model is not considered, as we did not identify statistically significant and well-reasoned co-integrating relationships in the relative time series.

4.1 Baseline Model Estimation

In general, we estimate the reduced form VAR model:

$$\mathbf{X_t} = \mu + \Pi(L)\mathbf{X_{t-1}} + \mathbf{e_t}$$

where $\mathbf{X_t}$ is a vector of endogenous variables and $\mathbf{e_t}$ is a vector of reduced-form shocks. As the baseline model specification, we follow Clarida and Gali (1994) and estimate the baseline VAR model in the first differences: $\Delta\mathbf{X_t}=\{\Delta y_t, \ \Delta p_t, \ \Delta q_t\}$, where y_t is the logarithm of real relative GDP, p_t is the logarithm of the relative consumer price index, and q_t is the logarithm of the real exchange rate in direct quotation (negative values reflect domestic currency appreciation). Here the relative real output and the relative price index are defined as domestic variables relative to foreign (effective eurozone) variables. In the baseline model specification, we prefer to refer to the nominal shock instead of monetary shock as Clarida and Gali (1994) did. In our view, the monetary shock in their work covers disturbances originating from the nominal exchange rate and the nominal interest rate. As the model is in the form of differences, the sign restrictions are applied to the differences.

As Uhlig (2005) points out, reasonable impulse response functions are the goal of the sign restriction identification scheme. The baseline model identifies three structural shocks: a relative supply shock, a relative demand shock and a relative nominal shock.[5] Structural shocks are identified by the sign restrictions imposed.

[4] As the relative formulation has become popular, Artis and Ehrmann (2006) list studies which apply the methodology of Clarida and Gali (1994) in specifying the variables under consideration (e.g. output or inflation) as relative to the corresponding variable of a large neighboring country.

[5] When considering the results of the relative model, by reference to supply, demand and nominal shocks we refer to relative form of the shocks.

Table 1 Sign Restrictions—Baseline Model

Variable Structural Shock	Δy_t	Δp_t	Δq_t
Relative supply	> 0	< 0	
Relative demand	> 0	> 0	< 0
Relative nominal	< 0	< 0	< 0

The inference is drawn by considering the properties of the impulse response; we therefore leave out presentation of the estimated parameters.

The applied restrictions follow from previous theoretical and empirical studies such as Berg (2010), Liu (2010), Juvenal (2011) and Clarida and Gali (1994). *Table 1* lists the restrictions used simultaneously in the identification of structural shocks in the baseline model. These restrictions are in line with the impulse responses of the structural model for the Czech Republic presented by Andrle *et al.* (2009). We identify the supply shock as increasing output growth. Furthermore, we assume that it is not associated with a positive response of inflation. The response of the real exchange rate is left unrestricted, as the short-run effect is uncertain in the Clarida and Gali (1994) model.

The demand shock is identified using the relationship from the model in Clarida and Gali (1994). Following the theoretical model, the demand shock increases relative inflation and appreciates the real exchange rate. Also, we assume that the response of relative output is positive.

The last set of restrictions considers the negative nominal shock as defined in the model by Clarida and Gali (1994). A negative nominal shock causes real appreciation and this lowers relative output growth (an immediate loss of competitiveness) and relative inflation (a decrease in the growth of prices of the imported consumption component). In line with empirical studies, e.g. María-Dolores (2010), it is assumed that the Czech Republic is characterized by incomplete exchange rate pass-through. This assumption rules out cases where a positive response of domestic and foreign prices can lead to a decrease in the relative price change.

For the identification, we consider 1,000 successful draws of rotations delivered by a total of 82,220 draws. *Figure 1* summarizes the responses of the baseline model. In this figure, each chart shows the response of the variable to all identified shocks. As the sign restriction approach does not identify the magnitude of shocks, as Fry and Pagan (2011) discuss, confidence intervals are not plotted in the impulse response charts.

As can be observed, the responses comply with the short-run restrictions summarized in *Table 1*. First, the positive supply shock accelerates relative output growth. This results in an immediate drop in relative inflation, which lasts for several periods. The real exchange rate depreciates with the supply shock. An initial real depreciation in response to a supply shock is also found by Clarida and Gali (1994) for Canada and the UK. The low levels of relative inflation correct the actual and expected relative output growth. The initial depreciation is quickly changed into appreciation. After the correction of the initial response of relative output, the real exchange rate responds by depreciating and the initial shocks are quickly absorbed.

When relative variables are considered, the movements in domestic variables could be offset by the foreign counterpart. However, the responses of relative variables originate from the fact that the Czech Republic is a small open economy and its behavior does not affect the rest of the world. Specifically, the subsequent real depreciation (a positive nominal shock) increases domestic exports, but this does not cause a drop in eurozone output.

A positive demand shock leads to an immediate increase in relative inflation and in real appreciation in line with the theory. The demand shock also results in higher relative output growth.

Finally, a negative nominal shock causes real appreciation and suppresses Czech output relative to foreign output due to the loss of competitiveness in international markets. However, this effect is short-lived. After a short period of appreciation, the low relative growth puts upward pressure on the real exchange rate, leading to a very short period of growth of relative output and prices. The dynamics and duration of the response to the nominal shock are in line with the findings of the structural model for the Czech economy.

The reversal in the impulse response of the real exchange rate for relative supply and nominal shocks is in line with our expectations of the real exchange rate returning to its trend. Here our results differ from Thomas (1997) and Clarida and Gali (1994), who identified long-run effects of supply shocks that are puzzling for most countries.

To assess the amount of variance in the variables that can be attributed to the nominal shock, we employ forecast error variance decomposition. The decompositions are presented in *Figure 2*. As the chart for the real exchange rate illustrates, the relative nominal shock accounts for slightly more than half of the real exchange rate variance. The relative demand shock generates less volatility of the real exchange rate than does the relative nominal shock, yet it still accounts for about 40% of real exchange rate volatility. This means that a large fraction of real exchange rate volatility originates from fundamentals. Moreover, real exchange rate volatility is driven more by the nominal shock than by the real ones.

From the decomposition of relative output and prices it can be concluded that the real exchange rate fuels less than 15% of their volatility.

When comparing our results with studies analyzing the driving forces of exchange rates before the formation of the common European currency, the following conclusions can be drawn: Contrary to the cases of Austria, Belgium, and France (studied by Thomas, 1997), the supply shock does not play a significant role in real exchange rate volatility. However, our findings are similar to the cases of Sweden and the Netherlands, where demand and nominal shocks are the main driving force of the real exchange rate, as reported by Thomas (1997).

The nominal shock accounts for a much greater fraction (approx. 55%) of the forecast errors in the real exchange rate for the Czech Republic than for countries such as France or the Netherlands (approx. 15%). However, the nominal shock's contribution is much lower than for Sweden (approx. 60%). The cumulative contribution of supply and nominal shocks to the movement of the real exchange rate is comparable to the core eurozone countries with the exception of the Netherlands, when compared to Thomas (1997). Therefore, losing the exchange rate as a shock

Table 2 Sign Restrictions—Extended Model

Variable Structural shock	Δy_t	Δp_t	Δq_t	i_t
Relative supply	> 0	< 0		< 0
Relative demand	> 0	> 0	< 0	> 0
Exchange rate	< 0	< 0	< 0	< 0
Relative monetary policy	< 0	< 0	< 0	> 0

absorber could be as costly for the Czech Republic as for the core eurozone countries.

To assess the impact of a supply shock, Hodson (2003) uses the measure of coincidence, which is a simple ratio of the supply shock's contribution to the real exchange rate and the supply shock's contribution to relative output. If the real exchange rate and relative output are motivated by a different variety of shocks, this measure of coincidence will be zero. In the extreme case, if both variables are stimulated by the same shocks, it will be one. In the case of the Czech Republic, the coincidence measure is approximately 0.14, which puts the Czech Republic in a group with Austria, Netherlands and Spain.

Keeping in mind the differences in methodologies and historical periods from the international comparison presented, there are similarities with Austria and Belgium when it comes to the source of real exchange rate volatility. When the importance of supply shocks is considered, countries such as Sweden and the Netherlands are the most similar ones.

As the nominal shock identified in the baseline model may be affected by the monetary policy response, we extend the model to include the policy rate. This extension also allows us to disentangle monetary and exchange rate shocks.

4.2 Extended Model Shock Identified

The model of Clarida and Gali (1994) can be extended to include monetary policy, as the base-line model lacks any direct interaction between monetary policy and real variables. The relative interest rate is defined as the ratio of the domestic interest rate to the foreign interest rate. We do not include the term structure (which can be based on relative longer-term interest rates), as the problem of mismatched interest rate expectations and realizations would significantly complicate the setting of the restrictions.

The following extended VAR model is estimated: $\Delta \mathbf{X_t} = \{\Delta y_t, \ \Delta p_t, \ \Delta q_t, \ i_t\}$. In the extended version, i_t is the relative interest rate (the domestic to foreign three-month interest rate). The extended model is converted to a structural VAR with the set of impulse restrictions summarized in *Table 2*. The additional restrictions describe the response of the interest rate and follow the nature of the inflation-targeting regime. For the relative demand shock, the relative interest rate increases in response to rising inflation. For the appreciation shock, the drop in inflation is followed by an easing of monetary policy. As the last restriction, a tightening of domestic monetary policy is followed by a decrease in output and inflation.

The above-mentioned sign restrictions deliver the impulse responses summarized in *Figure 3*, where each chart shows the response of a given variable to all identified shocks.[6] As can be seen from the closest-to-median responses, the real exchange rate reacts to the relative demand shock by appreciating. This can be explained by the strong response of the monetary authority to inflation.

The appreciation of the real exchange rate in response to the increasing interest rate is in line with the standard international macroeconomic theory. Here, with the increase in the relative interest rate, the real exchange rate appreciates despite the decline in relative output and this delivers real depreciation in the following periods. As monetary policy is gradually eased (the relative interest rate decreases), relative output growth recovers and the depreciation returns the real exchange rate to its trend.

Figure 4 summarizes the forecast error variance decomposition of the extended model for the parameterization that delivers the impulse responses closest to the median response.

The extended model delivers results close to the baseline model. In the baseline model, the nominal shock accounts for more than 50% of real exchange rate volatility. In the extended model, the contribution is now distributed between the real exchange rate shock, accounting for less than 50%, and the relative policy shock, accounting for roughly 10%. The demand and supply shocks still account for more than 40% of real exchange rate volatility. Notably, the influence of the supply shock is more pronounced in the extended model. Its share in the variance decomposition is now about 15%, while the impact of the demand shock is reduced to about 30% (see *Figure 2* for a comparison). The decline in the demand shock's contribution to volatility can be explained by the introduction of relative interest rate in our model. Therefore, it can be concluded that the monetary policy response to relative inflation contaminated the relative demand shock's contribution in the case of the baseline model.

The share of the nominal shock in generating relative output and inflation volatility is almost unchanged. With an explicit role for monetary policy, the real exchange rate accounts for about 15% for both of the variables.

The share of the supply shock in generating volatility in the variables of interest decreases to 10%. This suggests that some portion of the interest rate shock's contribution is attributed to the supply shock in the baseline model.

Note that the demand shock does not contribute significantly to the volatility of the relative interest rate. This originates from the fact that the demand shock does not significantly contribute to the variance of relative inflation and output (10% and 20%, respectively). This finding might imply that inflation expectations are well-anchored and a demand shock does not increase inflation expectations in the Czech Republic. The small reaction of the policy rate to the demand shock is then consistent with the Czech National Bank's inflation-targeting regime.

The variance decomposition of the real exchange rate and its relatively small share in relative output growth and inflation volatility suggest that the behavior of Czech koruna is consistent with the shock-absorbing nature of the exchange rate.

[6] We report the results of 1,000 successful draws out of 2,511,244 total draws.

The response of the real exchange rate to the relative supply shock is intentionally left unrestricted; therefore, we compare the distribution of the responses across these models, as in Uhlig (2005) and Jääskelä and Jennings (2010), to assess the identification properties. By incorporating monetary policy into the model, we observe an increase in the kurtosis of the initial responses distributions. This suggests that the inclusion of the relative monetary policy shock delivers additional features that are left unidentified in the parsimonious specification. It also suggests that the richer model and sign restriction identification improve the recovery of the true impulse responses.

4.3 Monetary Policy and the Exchange Rate

Our last model explores the response of the exchange rate to monetary policy shocks. As Rogers (1999) and Artis and Ehrmann (2006) suggest, there are reasons to care about the nature of shocks that drive exchange rate volatility. Firstly, Rogers (1999) shows that knowledge about the nature of shocks is relevant for the decisions of monetary policymakers. Rogers (1999) also asserts that evidence on the nature of exchange rate volatility is relevant for the literature on dynamic stochastic general equilibrium models that include the exchange rate. This knowledge helps to replicate the observed real exchange rate patterns that follow monetary shocks. Furthermore, Artis and Ehrmann (2006) discuss the link between monetary policy and the nominal exchange rate. They analyze the situation in which asymmetric shocks, as opposed to symmetric shocks, were found to have the dominant influence on the exchange rate. This would inform policymakers that there are potential drawbacks associated with maintaining a system of fixed exchange rates. In this case, a flexible exchange rate system may be preferable to fixed rates.

The following analysis also originates from the work of Clarida and Gali (1994), where the variables are specified as relative to the corresponding variables of the large neighbor. However, as Artis and Ehrmann (2006) and Peersman (2011) note, models formulated in relative terms are unable to disentangle the reactions of domestic and foreign variables themselves. Also, the relative formulation can identify only asymmetric shocks and thus yields no information on the comparative frequency of symmetric and asymmetric shocks.

This does not allow one to identify which country has to bear the adjustment to a shock. As the assumption of a small open economy is used, it is implicitly assumed that the small country is the one that bears the adjustment costs. In this case, if exchange rate volatility is mainly generated by the response to asymmetric shocks (one-country shocks), we conclude that it can help stabilize the economy. Also, this part of the analysis helps us to assess what portion of exchange rate volatility is being bred by its own shocks and whether these shocks turn out to be destabilizing to the rest of the economy. To explore the response of monetary policy to symmetric and asymmetric shocks and the relationship thereof to the real exchange rate, we employ the approach presented by Peersman (2011). This approach includes the implicit assumption that fiscal policy is too rigid to be an effective tool for stabilizing exchange rate shocks. Therefore, the policy response is fully assigned to monetary policy in the framework used.

Table 3 Sign Restrictions for Impulse Responses—Agnostic Scheme

	Output	Prices	Int. rate	F. int. rate	Ex. rate
Symmetric policy shock	< 0	< 0	> 0	> 0	
Asymmetric policy shock	< 0	< 0	> 0	< 0	< 0
Exchange rate shock	> 0	> 0	> 0	< 0	> 0

Following the studies by Artis and Ehrmann (2006) and Peersman (2011), we estimate the following VAR $\Delta\mathbf{X_t}=\{\Delta y_t, \Delta p_t, i_t, i_t^*, \Delta q_t\}$, where Δy_t denotes domestic output growth, Δp_t is domestic inflation, i_t is the domestic short-term interest rate, and i_t^* is the foreign interest rate. Also, as in the previous models, Δq_t denotes changes in the real exchange rate, where positive values signal domestic currency depreciation. Here, all variables except the interest rates are in logs and the linear trend is removed before differencing. As we focus on the effects of the exchange rate and symmetric and asymmetric monetary policy shocks, the corresponding vector of shocks is defined as $\boldsymbol{\varepsilon}_\mathbf{t} = \left\{\varepsilon_t^{\Delta y}, \varepsilon_t^{\Delta p}, \varepsilon_t^{\Delta iA}, \varepsilon_t^{\Delta iS}, \varepsilon_t^{\Delta q}\right\}$.

With the focus on the interaction of symmetric and asymmetric monetary policy shocks and the real exchange rate, the identification scheme is an alternative to the agnostic identification scheme originally applied by Uhlig (2005) and used in recent studies such as Scholl and Uhlig (2008) and Rafiq and Mallick (2008). The intention of this analysis is to follow the minimalist approach of those studies.

Our goal is to identify the response to symmetric and asymmetric policy shocks, $\varepsilon_t^{\Delta iS}$ and $\varepsilon_t^{\Delta iA}$ respectively, and to analyze the contribution of real exchange rate shocks, $\varepsilon_t^{\Delta q}$. The sign restrictions imposed to identify these shocks are summarized in *Table 3*.

To identify the symmetric monetary policy shocks, we impose the restrictions that domestic inflation and output growth slow down after a monetary tightening. As the shock is symmetric, the foreign monetary authority also increases its policy rate. The response of the real exchange rate is left unrestricted. However, in the case of the asymmetric policy shock, the foreign monetary authority eases its policy in response to the shock and in this case the real exchange rate appreciates in response to the interest rate differential. Finally, in the case of the real exchange rate depreciation shock, the domestic policy authority has to increase interest rates as domestic inflation and output growth increase in response to the sudden demand from abroad. As in Peersman (2011), in response to the domestic currency depreciation the foreign monetary policy authority eases its policy to reestablish competitiveness on international markets. The response to the rest of the shocks is left unrestricted. The closest-to-median impulse responses that result from imposing the restrictions in *Table 3* are shown in *Figure 5*. In this figure, each chart shows the response of the variables to the three identified shocks.

In the case of the symmetric policy shock, the real exchange rate depreciates sharply. The size of the responses suggests that there is a permanent effect on prices, as the response of inflation is positive in the medium term. The profile of the real exchange rate change shows that there may be a permanent shift in the nominal exchange rate. However, the effect on real output growth seems to be only temporary. When comparing the persistence of deviations, the responses of $\varepsilon_t^{\Delta y}$ and $\varepsilon_t^{\Delta p}$ show less persistency than the response of the interest rate.

The inflation-targeting nature of the monetary policy regime is also responsible for the responses (marked by the blue solid line) to the shock to the exchange rate, $\varepsilon_t^{\Delta q}$. The positive exchange rate shock delivers depreciation and leads to an increase in inflation. As the monetary authority responds to this shock by increasing the interest rate, some decrease in output is observed due to a loss of competitiveness. The strong response of monetary policy and the peak response of inflation after three periods suggest the presence of rigidities. Due to these rigidities, the policy rate only slowly returns to the steady state. This could imply that the domestic economy experiences real exchange rate depreciation as the initial response to a symmetric shock.

In the case of the asymmetric shock, output growth reacts negatively to the worsened competitiveness and the shape of the response identifies some long-term effects. Also, a negative response of inflation can be observed, and the peak in the second period suggests the presence of rigidities. The main results here are that domestic monetary policy reacts strongly and immediately to asymmetric shocks. This is further reflected in the variance decomposition. Also, the rest of the shocks considered show responses similar to the structural shocks in the previous model.

A central question of this analysis is the relative importance of symmetric and asymmetric monetary shocks for business cycle fluctuations. The forecast error variance decompositions of the variables of interest are shown in *Figure 6*.

The analysis of the forecast error variance shows that the volatility of output growth and inflation is mostly generated by the rest of the shocks. In the case of output growth, the symmetric monetary policy shock explains approximately 30% of the volatility. This suggests that there is quite a strong link between the countries considered, and this is consistent with the nature of the Czech economy. In the case of inflation, unidentified shocks are the main drivers of its volatility.

The main contributor to real exchange rate volatility is its idiosyncratic shock, which accounts for 50% of the volatility. The asymmetric and symmetric monetary policy shocks account for approximately 40% of real exchange rate volatility. This is in line with the results from both relative models. Here, the contribution of the symmetric shock is almost twice as large as the contribution of the asymmetric shock. This suggests relatively lower importance of the real exchange rate in handling asymmetric shocks. The evidence presented in *Figure 6* indicates that policy and idiosyncratic shocks are important for real exchange rate movements. This conclusion resembles that of Rogers (1999) and Clarida and Gali (1994) for the US and the UK, Japan and Germany, where monetary shocks were found to account for approximately half of the forecast error variance of the real exchange rate over short horizons. Taking into account that the asymmetric and symmetric shocks represent the influence of monetary policy, these results are also similar (comparing the sum of the contributions of foreign and domestic policy shocks) to those of Scholl and Uhlig (2008) who analyze the influence of monetary policy on the real exchange rate in a two-country model for pairs of developed economies.

From the decomposition of interest rate volatility, it turns out that the symmetric monetary policy shock accounts only for a small fraction of the forecast error variance. The domestic interest rate responds to asymmetric shocks mostly in the short term. The fact that in the long term the volatility of domestic policy is explained by the response to non-policy shocks supports the view that the Czech National Bank's policy is predictable. According to Uhlig (2005), predictability is a property of good policy, so we can conclude that over the time span analyzed the monetary policy of the CNB was generally successful in not generating extra volatility.

Based on the variance decompositions, policy shocks and real exchange rate shocks are the main contributors to the variance of the relative real exchange and interest rates in the short term. Also, variance decomposition identifies a significant contribution of the idiosyncratic shock to real exchange rate volatility and this contribution is stable. However, for the remaining variables, the contribution of the real exchange rate shock and asymmetric policy shock is decreasing over the horizon of responses. This is consistent with the shock-absorbing nature of the real exchange rate over the considered horizon. As the contribution of real exchange rate shocks is minor for output growth and price change, the real exchange rate is not considered to be a shock generator. Furthermore, the structure of the domestic interest rate variance reveals that the real exchange rate shock is responsible for 20–30% of volatility, so a significant response of the domestic interest rate to real exchange rate shocks is present.

As the sign restriction method produces a lot of alternative parameterizations, we can also check how representative the parameterization of the model closest to all the median responses is (robustness of results). The distribution of the variance decomposition shows that the chosen model puts greater weight on the idiosyncratic exchange rate shock than the median response in favor of the rest of the shocks (see *Figure 8*). However, the results are still within a reasonable band and the ratio of symmetric to asymmetric shocks also seems to be stable.

5. Conclusions

The aim of our work is to shed light on the role of the real exchange rate in the macroeconomic volatility of the Czech economy. We find that the shock-absorbing role of the koruna-euro exchange rate is consistent with the data.

At first, we analyze the contributions of the shocks to the variance of variables describing the Czech economy within the model in relative terms as described by Clarida and Gali (1994). Furthermore, for a robustness check of the results, the original model is extended to capture the behavior of monetary policy. We find that the extension of the model improves shock identification, thus delivering stronger inference about the unrestricted variables. In addition to the models in relative terms, we further consider the relationship between monetary policy and the real exchange rate in a model that is not formulated in relative terms. The results of this model imply that the behavior of the real exchange rate responds to monetary policy actions. The moderate response of output growth to monetary policy shocks is also identified. All three considered models show that the real exchange rate can be seen as a shock absorber. Similarly to other studies for various developed economies, we find that real exchange rate shocks drive real exchange rate volatility. However, in contrast to those studies, we find that almost half of its variance is driven by relative supply and demand shocks.

Our results may be biased toward a stronger role of the shock-absorbing nature of the real exchange rate for the Czech Republic. This bias may originate from the choice of identification scheme and due to the short data sample. This motivates us to use the sign restriction method, as it belongs to the class of Bayesian estimation methods that are able to handle this limitation. We believe that this study is a useful exercise in assessing the stabilizing role of the real exchange rate under the inflation-targeting regime. In this respect, this work provides useful guidance even though its results are dependent on various aspects of the estimation and identification procedures. Our sensitivity analysis supports the robustness of the results obtained.

APPENDIX

Figure 1 Impulse Response Function—Baseline Model

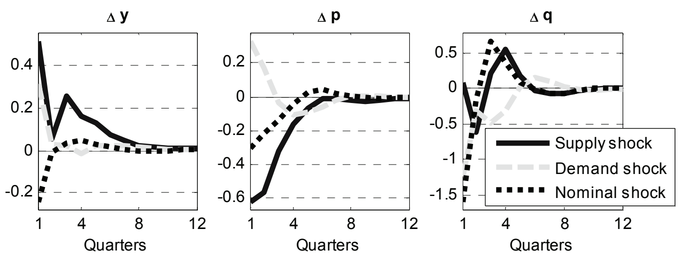


Figure 2 Variance Decomposition—Baseline Model

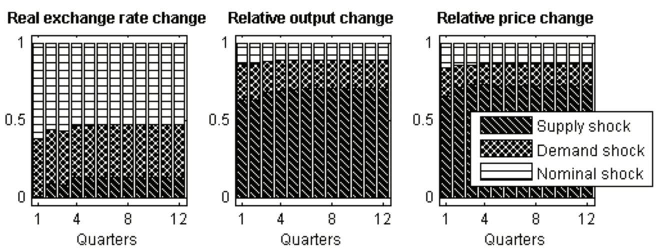


Figure 3 Impulse Response Functions—Extended Model

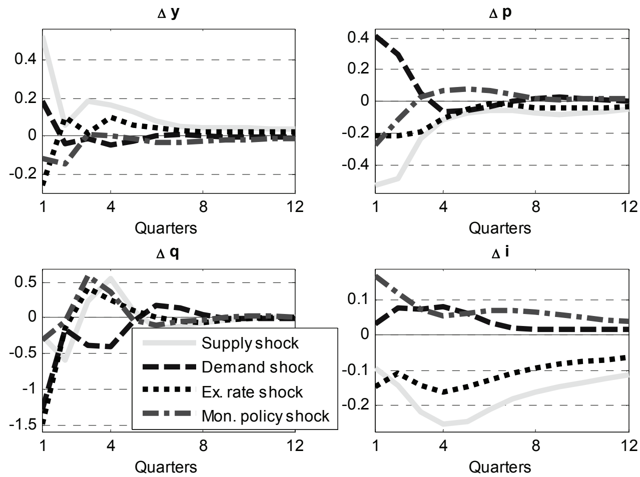


Figure 4 Variance Decomposition—Extended Model

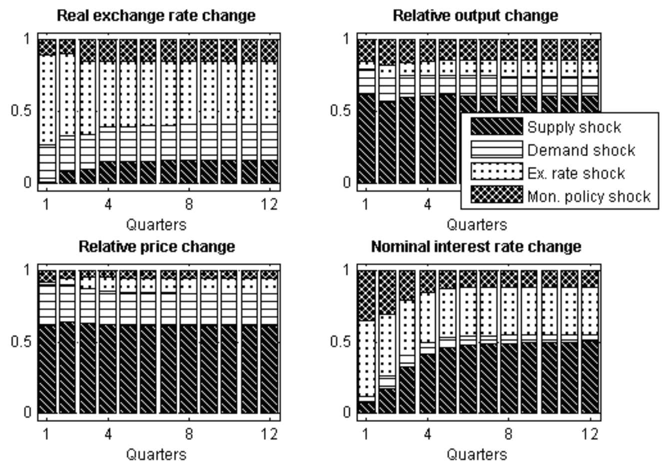


Figure 5 Impulse Response Functions—Agnostic Scheme

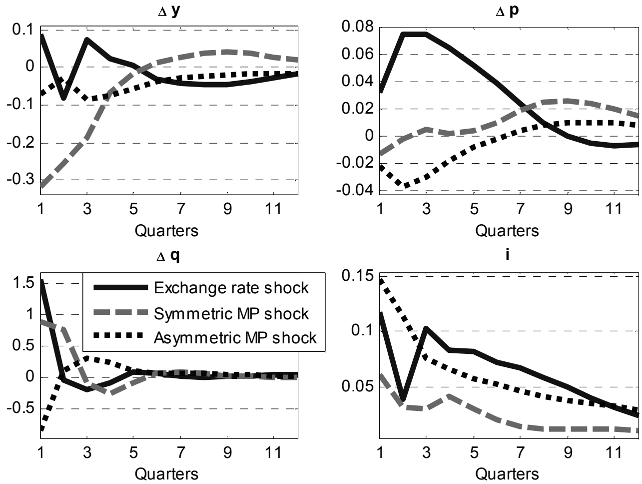


Figure 6 Variance Decomposition—Agnostic Scheme

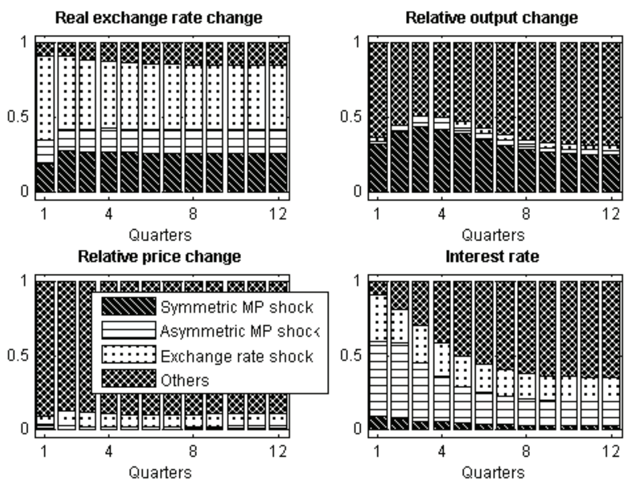


Figure 7 Trends in Relative Variables

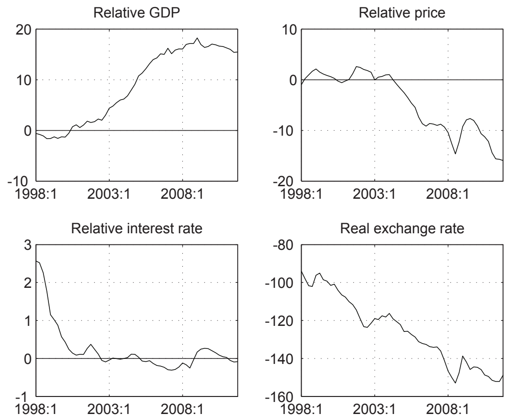
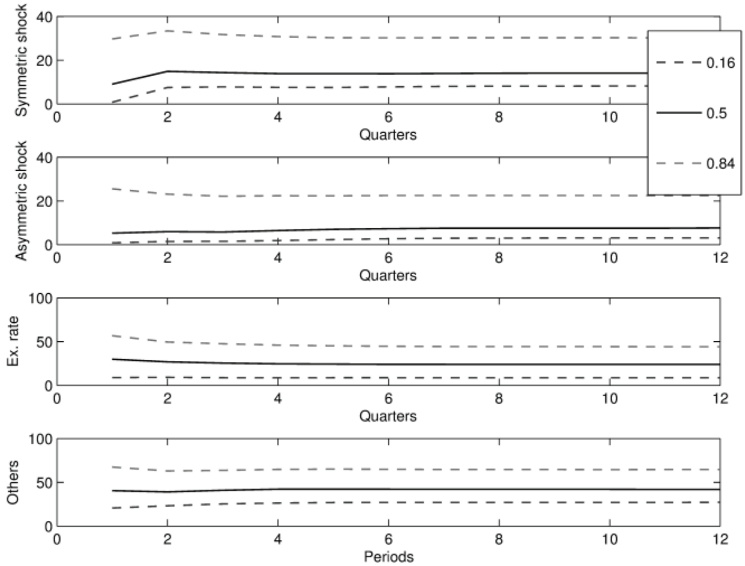


Figure 8 Distribution of Variance Decomposition—Exchange rate



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