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Sources of Real Exchange Rate Fluctuations: The Role of Supply Shocks Revisited[☆]

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Abstract

We re-examine the role of supply shocks in driving real exchange rates. In contrast to previous studies, our structural VAR identifies a second supply shock beyond the productivity shock. This cost-push shock is identified simultaneously with productivity, real demand and two nominal disturbances by imposing sign restrictions derived from a new open economy macro model. Cost-push and productivity shocks are differentiated through the impulse response of hours worked. Using time series of the US vis-à-vis an aggregate of industrialized countries, we find that cost-push shocks account for up to one third of real exchange rate fluctuations. Overall, our results assign a more prominent role to real than to nominal shocks.

Keywords: real exchange rate, supply shock, structural vector autoregression, sign restriction

JEL Classification: C32, F31, F32, F41

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1 Introduction

The roots of real exchange rate fluctuations have received substantial attention in international economics. One of the major concerns in designing exchange rate policy is whether movements in the real exchange rate are optimal responses to asymmetric real shocks or are distortionary due to nominal disturbances in the exchange rate itself (Devereux and Engel, 2007).

The empirical debate on whether nominal or real shocks are the main driving force of real exchange rate movements has not been settled. Some studies argue in favor of real demand shocks, which makes the exchange rate an important shock absorber;¹ others highlight the importance of nominal disturbances from financial markets and monetary policy rendering exchange rate movements undesirable and distortionary.² Thus far, only supply shocks have been uniformly rejected as a main contributor to real exchange rate variability.³

In this paper, we reassess the role of real supply shocks. There are ample and widely accepted theoretical arguments for an important role of real supply shocks (e.g., Balassa, 1964 and Samuelson, 1964). Recently, using an open-economy DSGE model, Steinsson (2008) shows that various sources of cost-push shocks are necessary to explain the persistent and hump-shaped impulse response of the real exchange rate observed in the data. In this spirit and in contrast to previous empirical literature, we extend the concept of real supply shocks beyond the standard productivity shock. In particular, we additionally consider cost-push factors that affect a firm's marginal costs of production. This comprises factors such as labor market institutions, demographics, and international competition. To be specific, we focus on the empirical question of whether cost-push shocks are also an important driver of volatility in the real exchange rate. In particular, we propose a novel identification scheme for identifying cost-push shocks, along with productivity shocks, real demand shocks and nominal shocks, in a structural vector autoregression (SVAR) analysis.

Our SVAR identification is based on the sign restriction approach advanced by Faust (1998), Uhlig (2005), and Canova and De Nicoló (2002). Sign restrictions are well-suited for identifying cost-push shocks. These supply factors affecting the cost of production may well have only temporary and not long-run effects. Long-run restrictions as commonly employed in the literature to

¹Clarida and Gali (1994), Chadha and Prasad (1997), and Juvenal (2011) find a strong role of real demand shocks in driving variations in the real exchange rate. Mumtaz and Sunder-Plassmann (2013) also argue in favor of real demand shocks in a VAR setting with time-varying parameters and stochastic volatility.

²Recent studies by Artis and Ehrmann (2006) and Farrant and Peersman (2006) conclude that exchange rate fluctuations primarily reflect nominal shocks.

³One exception stressing the empirical relevance of supply shocks is Alexius (2005), who examines the long run effects of productivity shocks on the real exchange rate in a vector error correction model.

identify supply shocks assume that only shocks that have long-run effects on output are supply shocks. Thus, prior studies using long-run restrictions neglect supply shocks that necessarily do not have long-run effects by construction. These supply shocks will instead be considered demand shocks instead. An underestimation of the true role of supply shocks is a likely result.

We construct a new open economy macro (NOEM) model, in which movements of the real exchange rate are driven by real shocks due to the pricing-to-market assumption and nominal disturbances, such as risk premium and monetary policy shocks. Using robust impulse responses of the NOEM model to derive sign-restrictions, we identify the different sources of variability of the real exchange rate in the data. The key identification is based on the insight, highlighted by Galí (1999) in a closed-economy context, that the hours differential falls after a positive (relative) productivity shock but rises in response to cost-push shocks.⁴ The intuition behind this difference is as follows: after a positive relative productivity shock, domestic households choose to substitute labor for leisure, as they can meet higher demand by taking advantage of more efficient production technology. By contrast, after a favorable relative cost-push shock, as labor productivity in this case remains constant, higher demand can only be met by working more.

The sign restriction SVAR approach suffers from the well-known problem of interpreting the multitude of identified models. The widely applied method of using the median across admissible draws has been heavily criticized (e.g., Fry and Pagan, 2011). We are one of the first studies to contrast the median approach with a recent approach suggested by Inoue and Kilian (2013). Instead of mixing structural models, we interpret the most likely model given the data and sign restrictions based on the mode of the posterior distribution of the impulse responses. In particular, this allows for a more straightforward interpretation of explained variance shares.

Our main findings based on time series data on the US vis-à-vis an aggregate of industrialized countries show that cost-push shocks provide a new and important source of real exchange rate fluctuations. In particular, cost-push shocks account for up to 30% of the variability of the real exchange rate. Moreover, to support our results and identification we show that our identified cost-push shock series comoves with important determinants of a firm's cost of production (i.e., total labor costs). The results for the other identified shocks are consistent with findings in the existing literature. While productivity shocks are not an important driver of real exchange rate volatility (3-10%), real demand shocks explain up to 36%. Regarding nominal shocks, risk premium shocks account for up to 25%, and monetary policy shocks only contribute approximately

⁴The impact of productivity shocks on hours worked remains a controversial issue in the empirical literature. Galí (1999), Basu, Fernald, and Kimball (2006), Francis and Ramey (2005) and others argue that hours fall, whereas Christiano, Eichenbaum, and Vigfusson (2004) and Dedola and Neri (2007), among others, find the opposite. In this paper, we impose sign restrictions consistent with the predictions of sticky-price models.

10% to real exchange rate fluctuations.

Our analysis is closely related to a growing body of SVAR studies on exchange rate dynamics using sign restrictions. This development is motivated by the contradictory results of earlier SVAR studies based on different identification schemes. [Farrant and Peersman \(2006\)](#) argue that both short-run and long-run zero restrictions suffer from theoretical and methodological shortcomings. The sign-restriction approach circumvents these problems as it allows for the identification of structural shocks based on qualitative predictions of theoretical models, while allowing the data to speak to the quantitative effects. Our study is most closely related to [Juvenal \(2011\)](#), who identifies productivity, preference and monetary policy shocks from an open-economy DSGE model. She concludes that real demand shocks are the main driver of real exchange rate movements. This paper extends these findings, as we identify not only a larger set of structural shocks in a unified framework but also implement the most recent sign restriction methods.

The remainder of this paper is organized as follows. Section 2 briefly describes the theoretical model and derives sign restrictions by applying a robust calibration strategy. Section 3 presents the SVAR approach and discusses the data and our results. Section 4 provides validity and robustness checks. Section 5 concludes.

2 The structural model

In this section, we derive sign restrictions on impulse responses of key macroeconomic variables which are studied in our SVAR analysis. We consider a two-country new open economy macroeconomic model in the spirit of [Chari, Kehoe, and McGrattan \(2002\)](#). The world economy consists of two symmetric countries with equal sizes. In each country, the representative household supplies labor to firms, invests in state-contingent bonds and consumes a non-traded final good. The final good is produced by competitive firms that composite varieties of intermediate goods produced in both countries. Intermediate good producers (firms) are assumed to be monopolistic competitors and set prices in a staggered fashion à la [Calvo \(1983\)](#). In addition, we assume that firms denominate their prices in the unit of the buyer's currency, so that real asymmetric shocks cause movements in the real exchange rate. In addition, we introduce two nominal factors that move the real exchange rate through their effects on the nominal exchange rate. In particular, we introduce monetary policy shocks to a Taylor rule and risk premium shocks as deviations from uncovered interest rate parity, i.e., a nominal shock originating from irrational

behavior in financial markets.⁵

In our model, three sources of real structural shocks affect international relative prices. Productivity shocks and government spending shocks represent supply and demand factors, widely considered in the literature. In addition, we use labor supply shocks, modeled as time-varying disturbances to the marginal utility of leisure, to capture the cost-push factors emphasized in our empirical analysis.⁶ As shown in Steinsson (2008), various cost-push disturbances including labor supply shocks affect our model's dynamics in a similar fashion, therefore incorporating one is sufficient to capture the qualitative effects of various cost-push factors.

To derive the impulse response functions, we loglinearize the model around a deterministic steady state. To limit the number of variables in the SVAR model, we focus on impulse responses of differential variables to relative shocks, i.e. home variables minus the foreign counterparts. Key loglinearized equations of the model are as follows:⁷

$$\sigma E_t [\hat{c}_{t+1}] = \sigma \hat{c}_t + \hat{i}_t - E_t [\hat{\pi}_{t+1}] \quad (1)$$

$$\hat{\pi}_t = \beta E_t [\hat{\pi}_{t+1}] + \kappa(1 - 2\alpha)\widehat{mc}_t + 2\kappa\alpha q_t \quad (2)$$

$$\text{where } \kappa = \frac{(1 - \theta)(1 - \theta\beta)}{\theta}$$

$$\widehat{mc}_t = \sigma \hat{c}_t + \phi \hat{y}_t + \hat{\xi}_t - (1 + \phi)\hat{z}_t \quad (3)$$

$$\hat{i}_t = \omega \hat{i}_{t-1} + (1 - \omega) [\eta_\pi \hat{\pi}_t + \eta_y (\hat{y}_t - \hat{y}_t^n)] + \hat{e}_t \quad (4)$$

$$\hat{y}_t^n = \frac{(1 - 2\alpha)(1 + \phi)}{\sigma + \phi(1 - 2\alpha)} \hat{z}_t - \frac{1 - 2\alpha}{\sigma + \phi(1 - 2\alpha)} \hat{\xi}_t + \frac{\sigma G}{C[\sigma + \phi(1 - 2\alpha)]} \hat{g}_t. \quad (5)$$

$$y_t = (1 - \alpha) \frac{C}{Y} c_t + \alpha \frac{C}{Y} \tilde{c}_t + \eta(1 - \alpha) \frac{C}{Y} (p_t - p_t^H) + \eta\alpha \frac{C}{Y} (\tilde{p}_t - \tilde{p}_t^H) + \frac{G}{Y} g_t \quad (6)$$

$$\tilde{y}_t = \alpha \frac{C}{Y} c_t + (1 - \alpha) \frac{C}{Y} \tilde{c}_t + \eta\alpha \frac{C}{Y} (p_t - p_t^F) + \eta(1 - \alpha) \frac{C}{Y} (\tilde{p}_t - \tilde{p}_t^F) + \frac{G}{Y} \tilde{g}_t \quad (7)$$

$$\hat{y}_t = y_t - \tilde{y}_t \quad (8)$$

$$nx_t = \alpha \frac{C}{Y} [\hat{c}_t - \eta(\tilde{p}_t^H - \tilde{p}_t - p_t^F + p_t)] \quad (9)$$

$$q_t = \sigma \hat{c}_t - f_t \quad (10)$$

⁵Fratzscher, Juvenal, and Sarno (2010) have recently shown that such shocks have important spillovers on the international business cycle.

⁶In the macroeconomic literature, the labor supply shock can be motivated with different micro-foundations. For example, Chari, Kehoe, and McGrattan (2007) show that time-varying marginal disutility of labor can be caused by changes in labor tax rates; Benhabib, Rogerson, and Wright (1991) associate this shock to changes in home production technology.

⁷This is not a complete list of equations we use in our numerical exercise. A detailed exposition of the model is written in the supplementary technical notes, which are available on authors' website: <http://www.makro.phil.uni-erlangen.de/LehrstuhlMA/ModelsupplementaryNotes.pdf>.

All variables except for nx_t are expressed in terms of log deviations from the steady state. Variables with a caret (“^”) denote differentials between home and foreign variables. Equation (1) is the standard intertemporal IS curve, in which \hat{c}_t is consumption, \hat{i}_t is the nominal rate of interest and $\hat{\pi}_t$ is the rate of inflation. Equation (2) and (3) together define the open economy new Keynesian Phillips curve, where $\hat{m}c_t$ and q_t denote real marginal costs and the real exchange rate, respectively. As we can see in Equation (3), both relative productivity shock (\hat{z}_t) and labor supply shocks ($\hat{\xi}_t$) affect real marginal cost. Equation (4) describes the differential of interest rate feedback rules, as proposed by Taylor (1993). We assume that both home and foreign central banks set the short-run nominal interest rates (\hat{i}_t) in response to inflation deviations from the targets and output gaps ($\hat{y}_t - \hat{y}_t^n$) with interest rate smoothing. Potential output is defined in Equation (5) as equilibrium output under flexible prices, where \hat{g}_t denote the relative government spending shock. Equation (6) and (7) summarize the open-economy aggregate resource constraints, i.e., output is equal to the sum of consumption, net exports and government expenditures. Equation (9) describes the net exports to GDP ratio in terms of the consumption differential and terms of trade. Equation (10) determines the real exchange rate through the uncovered interest rate parity, where f_t denotes a time-varying risk premium shock from the financial markets.⁸ As discussed in Berka, Devereux, and Engel (2012), if final consumption prices are set in the buyer’s currency and are sticky, nominal exchange rate fluctuations by themselves contribute to deviations from the law of one price across countries.

2.1 Calibration

To obtain robust sign restrictions, we consider a broad range of plausible values for our model’s parameters. In the following, we proceed in three steps. First, we specify a plausible range of values for each parameter based on microeconomic and macroeconomic evidence. Second, we assume uniform and independent distributions over all ranges of specified values and draw 50,000 sets of realizations on the parameter space. Last, we compute impulse response functions (IRFs) for each set of parameter values.

We choose the range of parameter values following the calibration exercise set forth by Kydland and Prescott (1982). A period in the model is a quarter. The consumption to GDP ratio in steady state is set in the range $[0.56, 0.66]$, which is consistent with the long-run grand ratios considered in the real business cycle literature. We choose the subjective discount factor β

⁸This shock can be motivated as a systematic failure of exchange rate expectations (Kollmann, 2002) or it is a result from noise trading in the foreign exchange market (Mark and Wu, 1998 and Jeanne and Rose, 2002).

over the range $[0.982, 0.99]$, which implies a steady state real return on financial assets of 4.2 to 7.5 percent per annum. This range is consistent with various estimates for the US after tax real return (Gomme and Rupert, 2007). The Frisch elasticity of labor supply ϕ is set over the range between 0.5 and 3 (Blundell and Macurdy, 1999). For the relative risk aversion parameter (σ), we consider $[1, 6]$ as a plausible range of values. The upper bound is motivated by Chari et al. (2002), who choose this value to match the relative volatility between the real exchange rate and consumption in US data. In the steady state, the consumption home bias α is equal to the ratio of imports to GDP. We calculate the average ratio of US imports to GDP between 1960Q1 to 2012Q2,⁹ which yields the lower bound of 0.025. In the literature, values as high as 0.25 are also frequently used (e.g., Cooke, 2010), therefore, we choose the range $[0.025, 0.25]$ for this parameter. Following Backus, Kehoe, and Kydland (1994), we set the elasticity of substitution between home and foreign goods between 1 and 2.

Proceeding with the sticky price parameter θ , which denotes the average probability of not adjusting prices, we choose a range between 0.75, a value commonly used in sticky price models, and 0.55, reflecting the lower bound of estimates based on the micro-level price data (e.g., Bils and Klenow, 2004 and Nakamura and Steinsson, 2008 among others). For monetary policy parameters, we choose values commonly associated with the simple Taylor rule. Following Taylor (1993) and estimates by Clarida, Galí, and Gertler (2000), we choose the inflation response parameter ϕ_π to be in the range $[1.5, 2.15]$. The output-gap-response parameter ϕ_y is set between 0.5 and 0.93. We consider values of the interest rate smoothing parameter ω between 0.4 (Rudebusch, 2006) and 0.8, which covers estimates commonly found for the Volcker-Greenspan period.

We choose values of persistence parameters for the shock processes according to estimated DSGE models (e.g., Smets and Wouters, 2007 and Lubik and Schorfheide, 2006). For the relative productivity process, we choose a range between 0.94 and 0.97.¹⁰ We set the persistence parameter for the risk premium shock according to the posterior distribution of interest rate premium disturbances, estimated by Smets and Wouters (2007). The 90% interval of this parameter lies between 0.07 – 0.36. For the monetary policy shock, the estimated interval is between 0.04 and 0.24. We set the range of the persistence parameter of labor supply shocks according to estimates in Chang and Schorfheide (2003). The values are between 0.797 and 0.933. Finally, following Lubik and Schorfheide (2006), values of the persistence parameter for the relative gov-

⁹Data source: US Department of Commerce: Bureau of Economic Analysis, Series ID: BOPMGS and GDP.

¹⁰Here, we assume that the shock processes between the US and the rest of world have the same persistence, so that the evidence of the estimated shocks for the US can be used to calibrate the relative shocks in our theoretical model.

ernment expenditure shock vary between 0.83 and 0.97. Because our focus in this exercise is only on the sign of the impulse response functions, standard deviations of innovations are normalized to one. The values of parameters discussed above are listed in Table 1.

[Insert Table 1 here.]

2.2 Deriving robust sign restrictions

Given the parameter regions discussed above, we solve for the theoretical impulse responses of the output, inflation, hours, and interest rate differential and the real exchange rate to our five different structural shocks for 50,000 parameter realizations. The signs of the impulse responses based on the 90% interval across realizations are summarized in Table 2. Figure 2 in the Appendix shows the theoretical impulse responses between the 5th and 95th quantiles across impulse responses.

[Insert Table 2 here.]

The qualitative predictions of our NOEM model are consistent with conventional wisdom. After a positive relative supply shock (either a productivity shock or a labor supply shock), the output differential rises and the inflation differential falls. After a positive relative demand shock (either a government spending shock or a monetary policy shock) both output and inflation differential rise. In addition, our theoretical model also predicts that the real exchange rate depreciates as a result of an expansionary monetary policy shock, while it appreciates due to a positive real demand shock. These signs are exactly the same as in [Clarida and Galí \(1994\)](#) and [Farrant and Peersman \(2006\)](#).

Besides these standard impulse responses, our fully fledged NOEM model sheds light on impulse responses of a larger set of macroeconomic variables. This allows us to explore the information of more time series data than was applied in earlier studies. In the following, we discuss in detail our identification scheme with regard to identifying cost-push shocks and risk premium shocks.

First, as seen in the first two rows of Table 2, using only the responses in output, inflation and the real exchange rate, one can not distinguish between the two sources of supply shocks. This is, however, not true for impulse responses of hours worked. Our theoretical model predicts that the hours differential rises after a favorable labor supply shock, but falls in response to a positive relative productivity shock. These different responses of hours worked to the supply shocks is a robust feature of NOEM models. The economic intuition is as follows: first, both relative

supply shocks cause the marginal costs to fall in home country relative to the foreign country, this effect in turn stimulates the demand for the home products. Second, due to price rigidities in both markets, demand for home goods does not increase so much that allows the income effect to dominate the substitution effect. As a result, after a positive relative productivity shock, the home households optimally choose to substitute labor with leisure, while meeting higher demand by taking advantage of more efficient production technology.¹¹ By contrast, after a favorable relative labor supply shock, labor productivity does not change, therefore higher demand can be only met by increasing hours worked.

Second, in our SVAR model, we include the nominal interest rate differential. We find from the robust impulse responses that the nominal interest rate is informative for disentangling monetary policy shocks and risk premium shocks. As seen in the last two rows of Table 2, these two sources of disturbances produce the same sign of impulse responses of all variables except for the nominal interest rate. The theoretical reason is that, on the one hand, the relative nominal interest rate falls after an expansionary monetary policy shock because of the Taylor rule, on the other hand, the nominal interest rate differential rises after a positive risk premium shock due to uncovered interest parity. A positive risk premium shock amounts to an expected depreciation of the nominal exchange rate. Therefore, in order to reestablish interest rate parity, home nominal interest rates need to rise faster than the foreign rate.

Third, our NOEM model distinguishes real demand shocks from risk premium shocks. In the literature, a more common way to introduce a real demand shock is through a preference shock to the household utility function (e.g., Juvenal, 2011). In this case, the preference shock would affect the consumption Euler equation exactly in the same way as the risk premium shock in our model. Thus, it is not clear which shock is identified. Our specification avoids this observational equivalence problem, as we introduce government spending shocks as a real demand shifter, which affects the model's dynamics through the goods market clearing conditions. As shown in the third and fourth rows of Table 2, we distinguish the government spending shock from the risk premium shock through the responses of the real exchange rate.

¹¹This insight is analogous to the one discussed by Galí (1999) in a closed-economy New Keynesian model.

3 Empirical analysis

3.1 Methodology

The general VAR setup is based on a reduced-form estimation of

$$Y_t = B(L)Y_{t-1} + u_t, \quad t = 1, \dots, T, \quad (11)$$

where Y_t is a $N \times 1$ vector of endogenous variables, and the lag polynomial $B(L)$ represents $N \times N$ coefficient matrices for each lag up to the maximum lag length k . The reduced-form innovations are denoted by the $N \times 1$ vector u_t , which are independent and identically distributed with mean zero and covariance Σ_u . We obtain the underlying structural shocks e_t by transforming the reduced-form innovations u_t with a matrix A such that $A^{-1}u_t = e_t$.

Identification sets A such that the structural innovations e_t are orthogonal and economically interpretable. The variance of each structural innovation is normalized to one which yields $\Sigma_e = E[e_t e_t'] = I_n$. While specifying A it is important that the transformation preserves the covariance structure of the VAR, such that $\Sigma_u = E[u_t u_t'] = AE[e_t e_t']A' = AA'$.

In contrast to the identification schemes commonly applied in the SVAR literature, the sign restriction approach does not set a single transformation matrix A , but it accepts all transformation matrices that satisfy the imposed sign restrictions. We construct random candidate draws for transformation matrix A based on householder transformations as described in [Fry and Pagan \(2011\)](#).¹² For each candidate draw, we compute the implied impulse response functions and only retain those draws that satisfy the sign restrictions.

We estimate our VAR with Bayesian methods to account for parameter uncertainty in the decision to accept or reject the identification. As emphasized by [Uhlig \(2005\)](#), by basing the sign restriction solely on the point estimates, one leaves parameter uncertainty unaddressed. We consider 10,000 draws from the posterior distribution of the reduced-form VAR parameters and, for each draw, check the signs of the impulse responses of 200,000 candidate transformation matrices A . We follow [Uhlig \(2005\)](#) and choose a weak Normal-Wishart prior that gives the simple OLS estimates for $B(L)$ and Σ_u as the mean of our closed-form Normal-Wishart posterior.

Due to the nature of the sign restriction approach, one obtains a number of accepted impulse responses that are each characterized by a different transformation matrix A . Each accepted

¹²Using a householder transformation in constructing candidate draws for A ensures that Σ_e is an identity matrix and $\Sigma_u = AA'$. Alternatively, one commonly observes the use of Givens rotation matrices as proposed by [Canova and De Nicoló \(2002\)](#). We selected the former, as the two methods yield equivalent results, while the former is computationally superior ([Fry and Pagan, 2011](#)).

draw corresponds to one structural model. It is very likely that these models will generate conflicting results regarding the research question. Consequently, to obtain a clearly interpretable result, one must decide which of these models is “best” given the data. Most existing studies report the median of all accepted impulse responses as a summary statistic. However, this procedure is problematic, as the median impulse response most likely stems from different models *A*.¹³ Thus, the median model lacks structural interpretability. To address this multiple-models problem (Fry and Pagan, 2011), we follow Inoue and Kilian (2013), who construct the posterior distribution of the impulse responses of all accepted models and use the mode of the resulting posterior as a summary statistic of the most likely model given the data and the sign restrictions. To check the robustness of our results, we report our findings using the mode measure and the conventional median measure. The posterior approach of Inoue and Kilian (2013) also addresses a second problem as it allows a straightforward construction of uncertainty bands around the impulse responses using the highest posterior credible set by ranking IRFs according to their posterior density.¹⁴

3.2 Data

In the empirical analysis, we use data for the US vis-à-vis an aggregate of industrialized countries (rest of the world, ROW). We construct the ROW data by aggregating time series from the G7 countries excluding the US (Japan, Germany, the UK, Italy, Canada, and France). While aggregating, we weight each country according to the Bank of International Settlements (BIS) narrow weighting matrix with the most recent trade shares covering the period 2008 to 2010. We obtain aggregate ROW series for real GDP per capita, inflation, hours worked, and interest rates. Nominal GDP per capita is converted to real terms using the consumer price index (CPI) with base year 2005. Next, we convert real GDP in local currency to US dollars using the average market exchange rate from the year 2005. As discussed in Juvenal (2011), this strategy distinguishes movements in real GDP from exchange rate fluctuations. The data on hours worked are

¹³Several studies follow Uhlig (2005)’s proposition to minimize a penalty function to reduce the number of admissible models. The intuition is to give a reward to large responses of the right sign and penalize those of the wrong sign. However, the penalty function has been criticized for arbitrariness and a lack of economic interpretability. An interesting extension is developed by Liu and Theodoridis (2012). They propose selecting the model that minimizes the distance of the response to the responses of an estimated DSGE model. Naturally, this renders the results much more dependent on model choice. The model then also restricts the quantitative results. As we wish to be agnostic with respect to this dimension, we do not follow this approach.

¹⁴Fry and Pagan (2011) proposed considering a structural model with the IRFs closest to the median IRFs to ensure structural interpretability. However, as argued by Inoue and Kilian (2013), as the median of a vector is in general not the vector of the marginal medians, the median IRF as applied in the literature is not a well defined concept. This criticism also applies to the optimal median proposed by Fry and Pagan (2011).

provided by [Ohanian and Raffo \(2012\)](#), who construct an internationally comparable data set of hours worked that allows us to account for both the intensive and extensive margin of labor adjustment.¹⁵ Detailed data sources for all series and for each country are summarized in Appendix (A).

When calculating the real effective exchange rate (REER) for the US vis-à-vis the ROW, we construct a geometric weighted average of the bilateral exchange rates adjusted by the CPI. To make measurement comparable to our theoretical model, we define our data series as the differential between the home and the foreign country, i.e., the ROW aggregate is subtracted from the US data.¹⁶ Figure 1 depicts the time series used in the VAR estimation.¹⁷ All of the data are in quarterly frequency and cover the period from 1978Q4 to 2010Q4. We adjust all series for seasonal effects using Census-X12-ARIMA.

[Insert Figure 1 here.]

We estimate the VAR using first differences in GDP, hours and the real exchange rate in our benchmark specification.¹⁸ Ljung-Box tests for residual autocorrelation indicate that $k = 4$ lags in the estimation are appropriate.¹⁹

3.3 Results based on a generic identification of supply shocks

To contrast our results with those in the literature, we first apply the identification scheme and the VAR setting of [Farrant and Peersman \(2006\)](#) to our data set. We estimate a three-variable-SVAR with the output differential, the inflation differential, and the real effective exchange rate. To identify generic supply, demand and nominal shocks, we set the same sign restrictions as in [Farrant and Peersman \(2006\)](#). Although these restrictions are derived from a different theoretical model, they are fully in accordance to the sign restrictions of our NOEM model. The restrictions are summarized in Table 3.

[Insert Table 3 here.]

¹⁵The dataset of [Ohanian and Raffo \(2012\)](#) uses data from a number of different sources, including national statistical offices and establishment and household surveys.

¹⁶For GDP and hours worked, we consider the log differential, inflation and interest rate differentials are measured in absolute terms.

¹⁷We take the log of the real exchange rate series.

¹⁸In accordance with the literature, we impose the sign restrictions on the level of the responses, despite that some variables are taken in first differences. In this case, we set the sign restriction on the cumulative impulse responses.

¹⁹Estimating the SVAR for all variables in levels rather than first differences does not change our results concerning the importance of supply shocks. The same holds for a specification with a minimum of $k = 2$ lags, as suggested by Ljung-Box tests. The results are available from the authors upon request.

The forecast error variance decomposition of the generic identification is summarized in Table 4. As discussed above, we contrast the results based on the mode measure with the conventional median measure. The results are remarkably robust across these two summary statistics. Note however that only the variance decomposition using the mode measure sums to 100%.²⁰

[Insert Table 4 about here.]

We find that 30% to 40% of real exchange rate variability is explained by nominal shocks (monetary policy shocks in this case), approximately 50% of volatility is attributable to real demand shocks and only up to 10% is due to supply shocks. These results are generally in line with the median measures reported by Farrant and Peersman (2006) for the US-UK and US-Canada pairs of bilateral dollar exchange rates. For the US-Euro and US-Japan pairs of bilateral dollar exchange rates, they find that nominal shocks play a larger role (approximately 50 - 70%).

Based on these estimates, they conclude that nominal shocks play a substantial role in driving real exchange rate fluctuations. Therefore, they consider the exchange rate as a source of shocks rather than a shock absorber. In light of our setting, however, two things should be noted. First, across the four bilateral-exchange-rate pairs estimated by Farrant and Peersman (2006), the explained variance shares are not unambiguously clear. Therefore, the result stresses that nominal shocks may be due to country pair specific effects. By contrast, our approach using a “rest of world” aggregate and the corresponding effective exchange rate circumvents this problem and provides a clearer measure of the average behavior of the US international position. Second, the sample period in Farrant and Peersman (2006) covers only data up to 2002Q4, while our sample lasts until 2010Q4. This later period is characterized by a relatively calm monetary environment compared to the 1980s. Therefore, our estimates potentially assign a larger role to real shocks than to nominal shocks.

Next, we show the empirical results based on our “sharper” identification scheme for a larger set of variables. In our baseline estimation, we consider differentials of GDP, inflation, hours worked, and the nominal interest rate, jointly with the REER.

²⁰This underlines the problem of the median measure that combines different structural models. Thus, it is difficult to interpret the FEVD as a share of the total variance using the median measure. This is not the case when using the posterior mode.

3.4 Results based on a more specific identification scheme

3.4.1 Identification via sign restrictions

This section discusses the results of our detailed identification scheme. Thus, we show the effects of a cost-push shock in addition to the conventional productivity shock. We impose a minimum set of sign restrictions that allows us to identify all five structural shocks (cp. Table 2).²¹

Our sign restriction scheme is in accordance with a wide range of open economy macroeconomic models. For example, all of our restrictions are in accordance with those applied in [Farrant and Peersman \(2006\)](#), who derive their signs from the model in [Clarida and Galí \(1994\)](#). We leave the responses of the real exchange rate largely unrestricted, to ensure that our results for the REER are as data driven as possible. The restricted horizons are selected in accordance with our model impulse responses. The response of the REER to the real demand shock is not entirely clear-cut in our model. Thus, we restrict it with a negative sign only from quarter 3 onwards. We consider this restriction justified as approximately 90% of the theoretical impulse responses show a negative sign for these horizons.

3.4.2 Empirical impulse response functions

Figure 3 depicts the impulse responses of hours worked to the two structural supply shocks as obtained from our sign restriction identification. Solid black lines indicate the mode impulse responses, and gray lines represent the 68% region of highest posterior density as in [Inoue and Kilian \(2013\)](#).²² Dotted lines represent the median impulse responses. As Figure 3 (and Figure 4) shows, both, the median and mode measures generally yield qualitatively consistent impulse responses. However, as discussed above, the median measure is not necessarily consistent with a single structural model, but most likely mixes different identification schemes. Thus, we consider the mode measure more consistent for summarizing all accepted draws.

[Insert Figure 3 here.]

Figure 3 highlights the core of our identification strategy as we disentangle the productivity and cost-push shocks using the responses in hours worked. The figure shows that the identification works and the opposite signs are valid even after the restricted horizon.

²¹Note that this is not the unique set of sign restrictions that identifies all shocks. In the robustness analysis, we report results obtained from an alternative set.

²²Note that interpreting these regions incorporates two different things: parameter uncertainty from the estimation and model uncertainty from the sign restriction identification.

Next, Figure 4 depicts impulse responses of our variable of interest, the REER, to each relative structural shock. A positive relative productivity shock has only moderate effects on the REER. According to the mode measure, the REER exhibits a mild appreciation with a hump. As it is unrestricted, the mode impulse response is not necessarily in line with the prediction of our NOEM model. However, as the median impulse response lies slightly above the zero line, the median of accepted draws is still consistent with our theoretical model. **comparison to literature?**

[Insert Figure 4 here.]

In response to a favorable cost-push shock, even though unrestricted, the impulse response of the REER exhibits a hump-shaped depreciation, as predicted by our model. In response to a real demand shock, we observe an appreciation in the real effective exchange rate. From the third quarter to the sixth quarter, the negative impulse response is due to the sign restriction. However, as the appreciation is robust well beyond the restricted horizons according to both mode and median measures, this confirms the prediction of our model and the sign restriction we imposed in the SVAR. Similarly, although we restrict the sign restriction of REER impulse response to the risk premium shock to be positive from the first quarter to the third quarter, the empirical impulse response exhibits a significant depreciation over the whole horizon. Lastly, following an expansionary relative monetary policy shock, the REER exhibits depreciation according to the mode measure, which is in accordance with our theoretical model and other empirical studies (e.g., [Eichenbaum and Evans, 1995](#)). By contrast, the median measure presents an appreciation of the REER in response to the asymmetric monetary policy shock.

3.4.3 Variance decomposition

Next, we discuss our main result. In Table 4, the forecast error variance decomposition of the REER is reported for our five structural shocks at the 1st, 5th and 20th quarter horizons. In this table, we also contrast our results with those obtained from the generic identification scheme. In addition, as a robustness check, we also compare the results based on the median and mode measure. Again, quantitative results based on these two measures do not fundamentally differ; however, due to the problem discussed above, the decomposition based on the median measure does not sum to one. As a result, in the following discussion, we focus on the results based on the mode measure.²³

²³Note that the reported regions of the highest posterior density are rather large compared to what other studies find using quantiles across models. [Inoue and Kilian \(2013\)](#) make the same observation in their setting. Again, the regions cover model and parameter uncertainty jointly.

According to our baseline setup, the most important contributor to the REER forecast errors is the real demand shock. It accounts for 33 – 36% of real effective exchange rate fluctuations. This estimate is in line with the finding by Juvenal (2011). The second important shock is the cost-push shock, which explains approximately 30% of the REER variability. This result is novel in the literature, as all previous studies treat productivity shocks as the sole source of supply shocks and conclude that supply shocks play a minor role in driving real exchange rate fluctuations.²⁴ In our analysis, we also find that productivity shocks account for a modest fraction of REER volatility. However, together with the effects of cost-push shocks, the total effect of supply shocks is as important as that of the real demand shock. Overall, real shocks drive up to 66% of the volatility in REER movements, while the remaining fraction of REER variability is split between risk premium shocks (24%) and monetary policy shocks (10%).

In general, our variance decomposition results are consistent with the findings in the empirical literature. We find a large role for the real demand and risk premium shocks, but a small role for productivity and monetary policy shocks.²⁵ In addition, we identify a new and important source of REER fluctuations, namely factors that affect a firm’s marginal cost of production. We show that they play as significant a role as real demand shocks in driving the volatility of the real exchange rate and therefore the adjustment of exchange rates serves as a powerful mechanism for absorbing asymmetric real shocks.

Table 6 in the Appendix reports the results of the variance decomposition for the remaining variables. In line with our theory and common intuition, the variance in the output and hours differentials is primarily driven by productivity shocks and real demand shocks, whereas inflation volatility results from cost-push shocks and monetary policy shocks. The risk premium shocks account for the majority of the variance in the interest rate differential.

3.5 Discussion of identified cost-push shocks

As we find that the identified cost-push shock plays a crucial role in the volatility of the REER, this subsection examines the identified shock series in greater detail. We compare the cost-push shock series with a data series that is closely related to the costs of production in an economy. In particular, we use total labor costs as provided by the OECD.²⁶ We again construct a ROW

²⁴Juvenal (2011) identifies three structural shocks in a six-variable VAR model, and her three shocks jointly account for less than half of total volatility of the real exchange rate.

²⁵See: e.g., Clarida and Galí (1994), Farrant and Peersman (2006), Scholl and Uhlig (2008), Fratzscher et al. (2010) and Juvenal (2011).

²⁶Quarterly labor costs for the G7 are taken from the OECD data base (<http://stats.oecd.org/Index.aspx?queryname=340&querytype=view>).

aggregate and calculate the differential of total labor costs between the US and ROW exactly as in our SVAR model. To approximate the shocks to these series, we estimate the residuals from a simple ARIMA process for the total labor cost differential (the series is non-stationary in levels). In Figure 5, we contrast the identified cost-push shock series (black solid line) with the labor cost differential (grey dashed line). Note that a negative cost-push shock in this figure implies that US production became less expensive compared to the ROW aggregate (we multiplied the original shock series by negative one for a more intuitive interpretation). Moreover, we present a moving average of the original series to improve the readability of the plot.

[Insert Figure 5 here.]

One interesting observation stands out from this figure. We find that cost-push shocks are accompanied by movements of the same sign in relative labor cost (of the US vis-à-vis ROW). The correlation of the two series is 0.46 and significant. This finding demonstrates that our identified shock series indeed captures production cost factors. For example, we correctly identify the upward trend in labor cost (of the US versus ROW) which is the most obvious in the positive shocks beginning in 1996.

4 Robustness checks

4.1 Alternative sign restriction patterns

To examine the robustness of our results, we provide two alternative identification schemes. First, we explore a further set of sign restrictions that also identifies our five structural shocks. In this case, we relax the restriction on the interest rate response, allowing it to be agnostic with respect to a cost-push shock. Table 5 summarizes this alternative set of sign restrictions. Second, we take our model predictions even more serious and restrict all responses in the VAR according to our NOEM model (cp. Table 2).

[Insert Table 5 here.]

Table 4 also reports the forecast error variance decomposition of the real effective exchange rate that we obtain from the alternative set of sign restrictions. Even though the composition of the shocks slightly alters, supply shocks and in particular the cost-push shock remain important contributors to real exchange rate dynamics. In fact, according to the mode measure, the cost-push shock is even more important than in the baseline identification.

Restricting all signs renders the risk premium shock the most important contributor to REER dynamics as measured by the mode (cp. Table 4). The real demand shock is the second most important contributor. Our cost-push shock is of particular importance in the long-run and explains up to one fifth of REER fluctuations. Again, productivity and monetary policy shocks are of little importance.

4.2 Controlling for trade balance movements

To check for robustness and gain further insights into the driving forces of the international business cycle, we include the US trade balance in our SVAR. US trade balance data is obtained from the International Financial Statistics of the IMF. We express the trade balance in percent of US GDP. As our five structural shocks are clearly separated given the baseline identification scheme above, we leave the responses of the trade balance unrestricted. Thus, we use the same restrictions as summarized in Table 2.

The bottom panel of Table 4 reports these results. The cost-push shock remains very important for REER fluctuations; indeed, using the mode measure we explain approximately 45% of REER variability with cost-push shocks. Thus, our results are robust concerning this modification. Notably, the cost-push shock is of little relevance in driving movements in the trade balance. These are mainly driven by productivity shocks. [Barnett and Straub \(2008\)](#) also find that about 15% of trade balance fluctuations are driven by sole productivity shocks.

5 Conclusion

We show that supply shocks play an important role in driving real exchange rate fluctuations. This result is novel in the literature, which has thus far concluded that supply shocks are negligible for exchange rate movements. We arrive at this different conclusion, identifying a second source of supply shocks other than the productivity shock. The second source of supply shocks that we emphasize in this paper is the cost-push shock. We show that insights from a NOEM model can be used to distinguish between productivity and cost-push shocks in a structural VAR using sign restrictions. Furthermore, we draw our main conclusions based on the posterior mode as a summary statistic ([Inoue and Kilian, 2013](#)). This most recent approach in the sign restriction VAR literature circumvents several problems in applying sign restrictions in VARs.

In summary, our results imply that real shocks, i.e., productivity, cost-push and real demand shocks, account for more than half of real exchange rate fluctuations. This result has both positive

and normative implications. First, as discussed by Steinsson (2008), various sources of cost-push shocks can account for the pronounced hump-shaped response of real exchange rates in a NOEM. We show that these shocks are also important in driving the volatility of the data. This result entails that cost-push shocks are a good candidate for solving the “purchasing power parity puzzle,” as highlighted by Rogoff (1996).

Second, our results provide new empirical evidence for the debate on the optimal exchange rate regime. As stressed by Devereux and Engel (2007), there is a trade off between the desire to smooth fluctuations in real exchange rates and the need to keep the nominal exchange rate flexible. On the one hand, a flexible exchange rate serves as a real shock absorber by facilitating expenditure switching. On the other hand, nominal disturbances in financial markets distort real exchange rates and hence the real allocation. Thus, it is an empirical question as to which side of the trade off is more important in reality. As we show that real shocks explain a substantial share of real exchange rate fluctuations in the data, we provide support for a flexible exchange rate regime. That is, if policy makers decide to fix nominal exchange rates, one should bear in mind that this mutes an important shock absorbing mechanism.

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A Data sources

Country	Series	Source	Remarks
US	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator
	population	OECD	linearly interpolated from annual terms
	GDP deflator	IFS	2005 = 100
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, % per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
Canada	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator
	population	OECD	linearly interpolated from annual terms
	GDP deflator	IFS	2005 = 100
	exchange rate to US\$	IFS	market rate
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, % per annum
France [†]	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator
	population	OECD	linearly interpolated from annual terms
	GDP deflator	IFS	2005 = 100
	exchange rate to US\$	IFS	official rate
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
Germany [†]	short-term interest	OECD	3-month rates and yields, % per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator
	population	OECD	linearly interpolated from annual terms
	GDP deflator	IFS	2005 = 100
	exchange rate to US\$	IFS	market rate
Italy [†]	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, % per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator
	population	OECD	linearly interpolated from annual terms
	GDP deflator	IFS	2005 = 100 [‡]
Japan	exchange rate to US\$	IFS	market rate
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, % per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator
	population	OECD	linearly interpolated from annual terms
UK	GDP deflator	IFS	2005 = 100
	exchange rate to US\$	IFS	market rate
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, % per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
	GDP	IFS	per capita scaled by population, transformed to real terms using GDP deflator

Notes: All series cover 1978Q4-2010Q4. GDP is reported in quarterly levels. All GDP series are converted to US-\$ terms using the respective average exchange rate of the year 2005 as in Juvenal (2011). Short term rates are usually either the three month interbank offer rate attaching to loans given and taken amongst banks for any excess or shortage of liquidity over several months or the rate associated with Treasury bills, Certificates of Deposit or comparable instruments, each of three month maturity. [†] For Euro area countries the 3-month European Interbank Offered Rate and the Euro-US\$ exchange rate is used from date the country joined the Euro. [‡] Series only starts in 1981Q1, thus we fix the value of 1981Q1 for the missing values.

B Figures

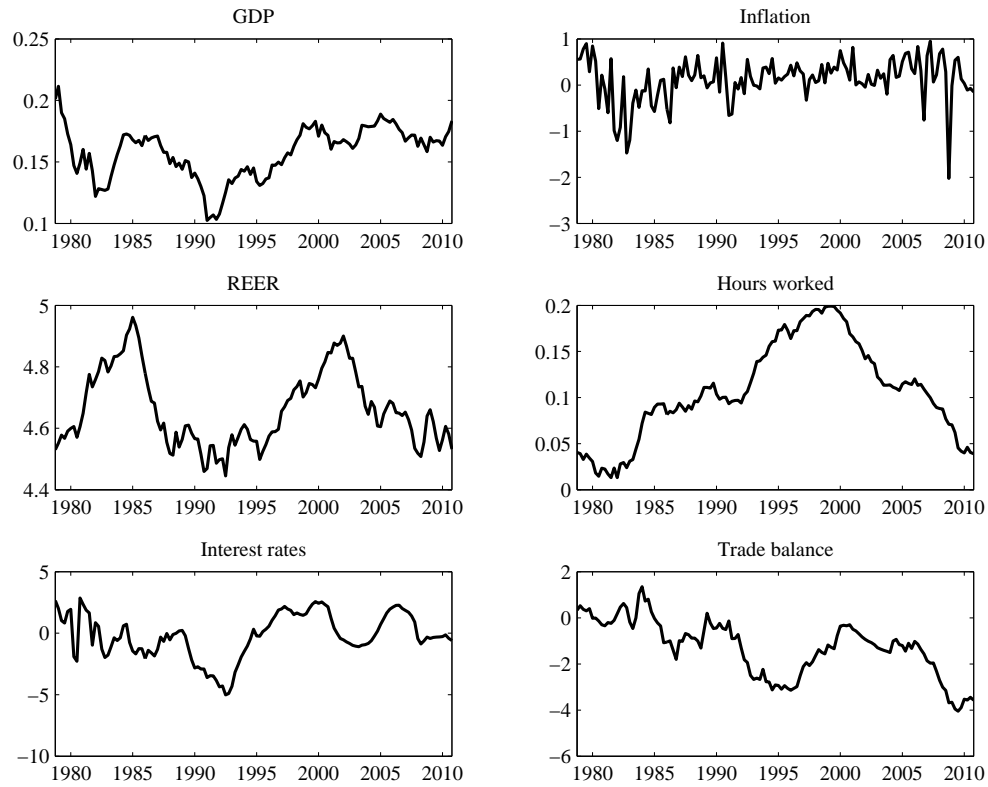


Figure 1: Data series used in the VAR estimation. All series are expressed in terms of differentials (US vis-à-vis ROW).

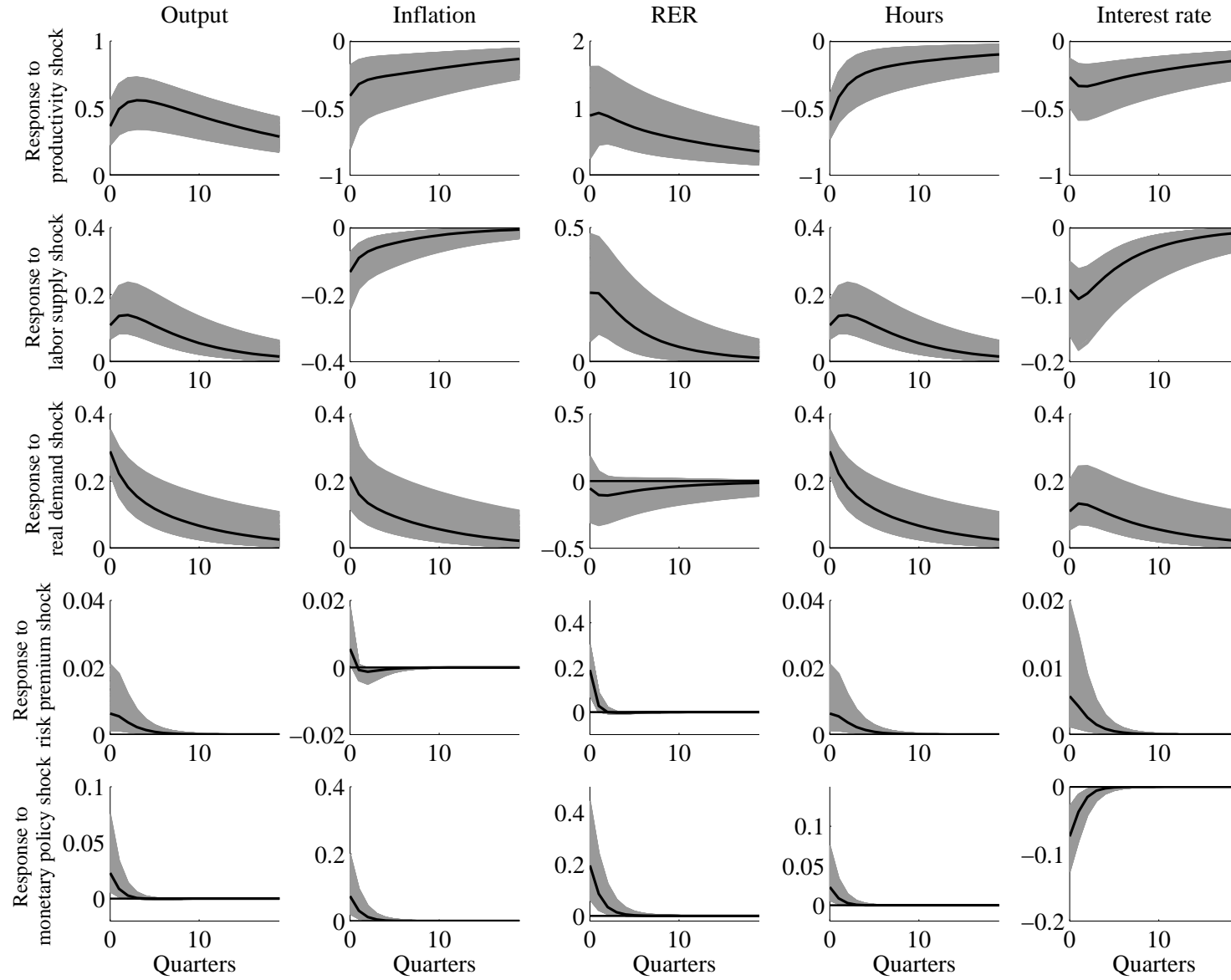


Figure 2: Robust theoretical impulse response functions. This figure shows the impulse responses of key variables to the five structural shocks in the NOEM model (note that shocks and variables are defined in terms of differentials between the two countries). The solid lines show the median impulse responses, while the grey area represents all impulse responses between the 5th and the 95th quantiles across responses.

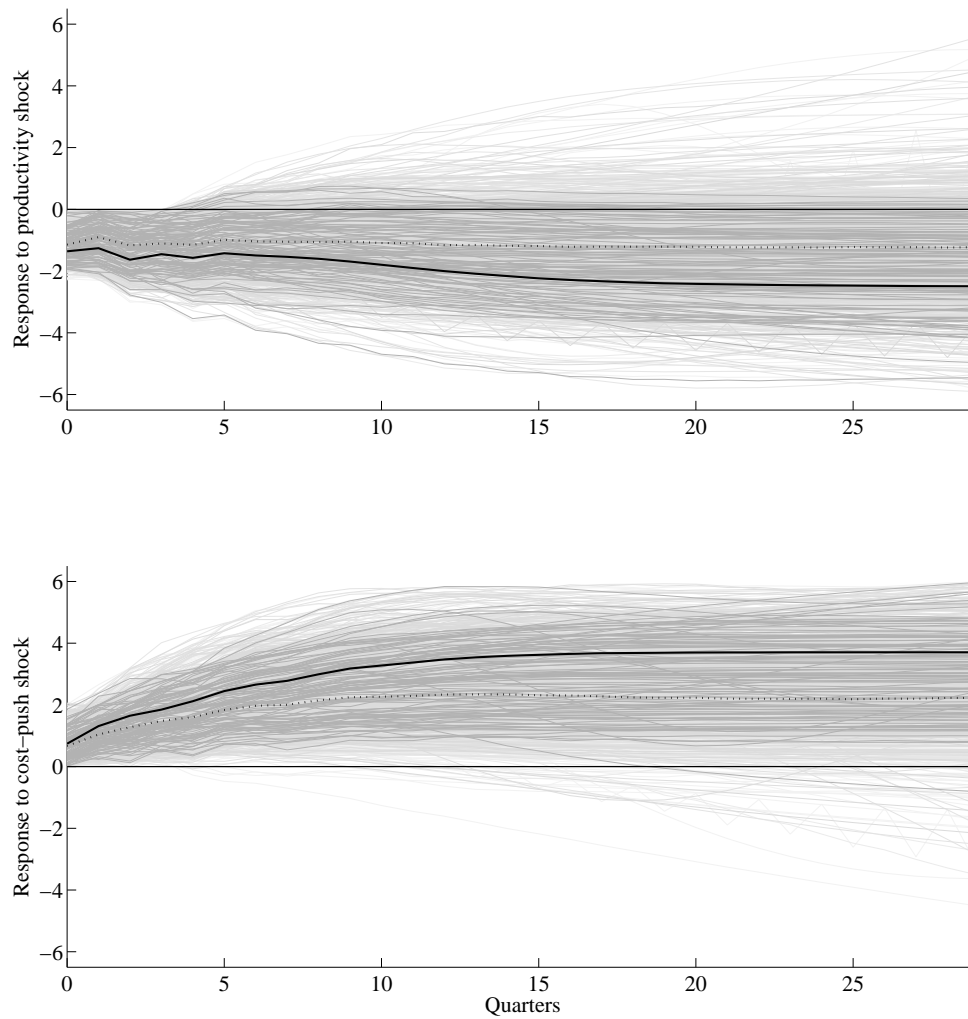


Figure 3: Baseline impulse responses of hours worked. The figure shows the impulse response functions of the REER to one-standard deviation relative shocks. Solid black lines show the mode impulse responses, and grey lines represent the 68% joint regions of highest posterior density (the darker, the higher the posterior density). The dotted line represents the median impulse response. These results are based on 1,698 accepted draws.

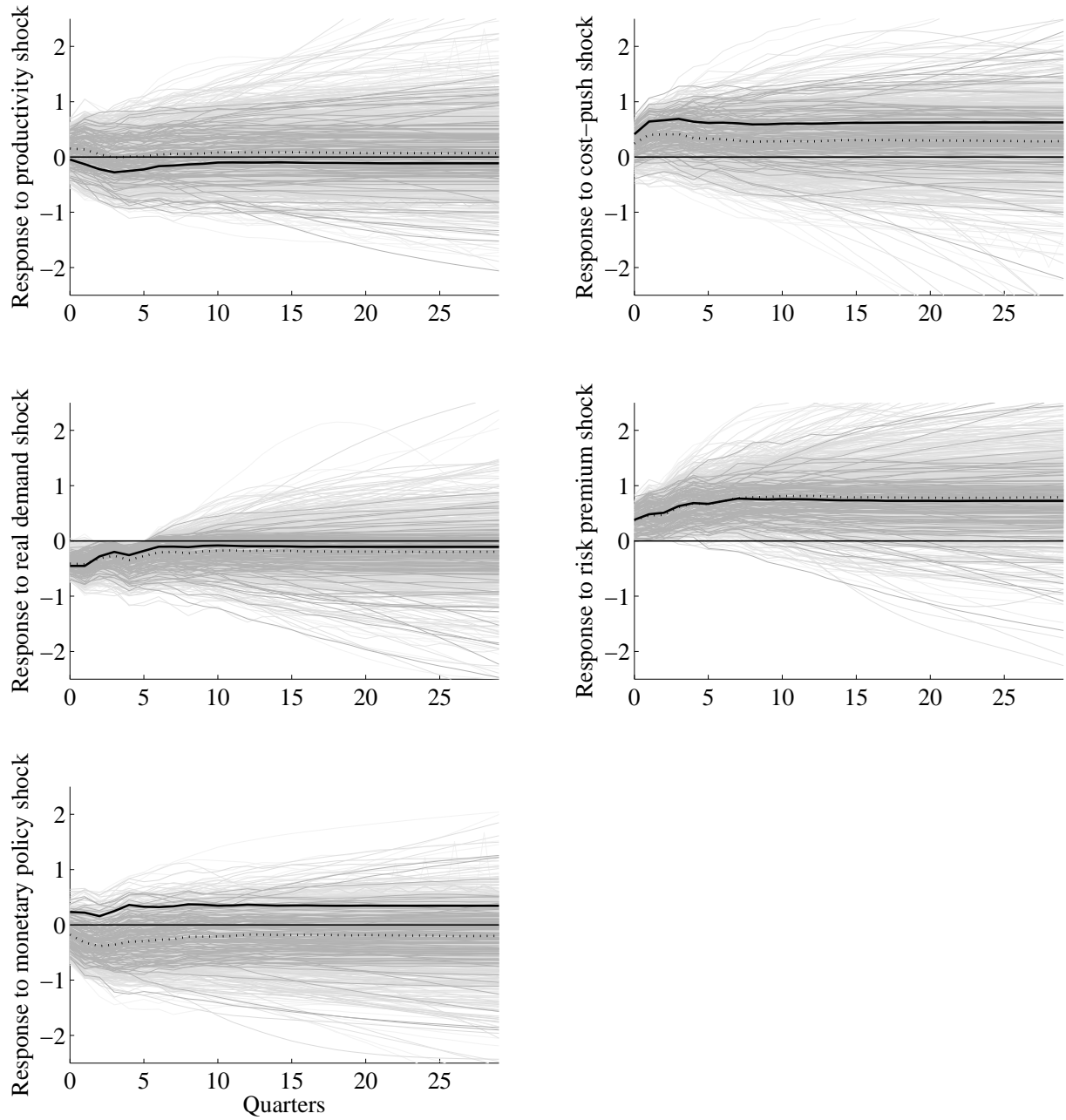


Figure 4: Baseline impulse responses of the REER. The figure shows the impulse response functions of the REER to one-standard deviation relative shocks. Solid black lines show the mode impulse responses, and grey lines represent the 68% joint regions of highest posterior density (the darker, the higher the posterior density). The dotted line represents the median impulse response. These results are based on 1,698 accepted draws.

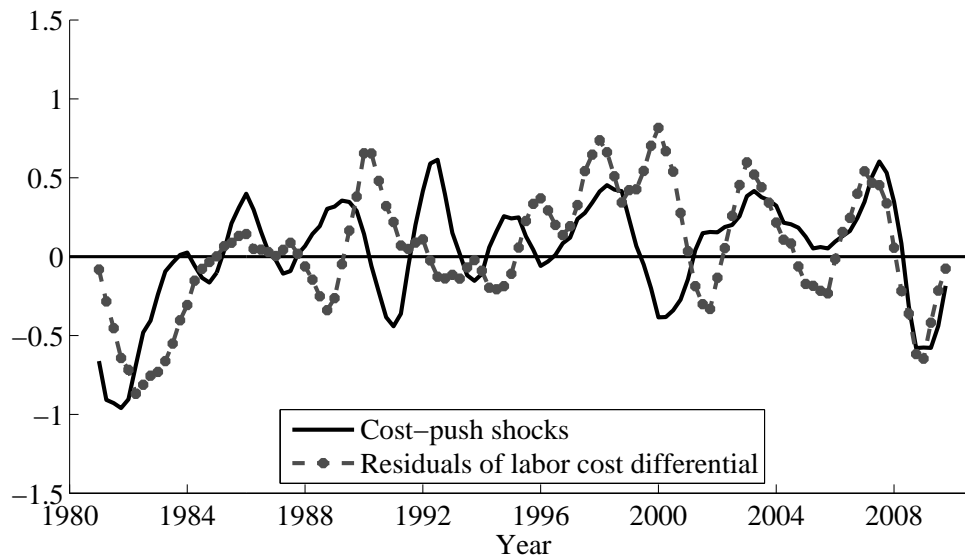


Figure 5: Structural cost-push shocks and residuals of the labor cost differential (moving average of quarterly series). We present the mode cost-push shock (the shock series is multiplied by negative one for easier interpretation; here a negative shock renders US production less expensive relative to the ROW). The labor cost differential is estimated from an ARIMA process and rescaled to unit variance.

C Tables

Parameter	Value	Description
C/Y	0.56 - 0.66	Consumption to GDP ratio in steady state
β	0.982 - 0.99	Discount factor
η	1 - 2	Elasticity of substitution between home and foreign goods
σ	1 - 6	Inverse of intertemporal elasticity of substitution
ϕ	0.5 - 3	Inverse of the Frisch elasticity of labor supply
α	0.025 - 0.25	Degree of consumption home bias
θ	0.55 - 0.75	Calvo sticky price parameter
η_π	1.5 - 2.15	Inflation coefficient in the Taylor rule
η_y	0.5 - 0.93	Output gap coefficient in the Taylor rule
ω	0.4 - 0.8	Interest smoothing in the Taylor rule
ρ_z	0.94 - 0.97	AR(1) coefficient of productivity shocks
ρ_d	0.83 - 0.97	AR(1) coefficient of real demand shocks
ρ_f	0.07 - 0.36	AR(1) coefficient of nominal exchange rate shocks
ρ_e	0.04 - 0.24	AR(1) coefficient of monetary shocks
ρ_ξ	0.797 - 0.933	AR(1) coefficient of labor supply shocks

Table 1: Range of calibrated values of each model parameter.

Shock/Variables	GDP	Inflation	REER	Hours	Interest rates
Productivity shock	+ (1-8)	− (1)	+ (*)	− (1-4)	− (*)
Cost-push shock	+ (1-6)	− (1)	+ (*)	+ (1-4)	− (1-4)
Real demand shock	+ (1-6)	+ (*)	− (3-6)	+ (1-4)	+ (1-2)
Risk premium shock	+ (1-3)	+ (1)	+ (1-3)	+ (*)	+ (1-4)
Monetary policy shock	+ (1-2)	+ (1)	+ (*)	+ (*)	− (1-2)

Table 2: Summary of the signs of theoretical impulse responses of our NOEM model. In case of ambiguous responses across parameterizations, we report the median. Restricted horizons (in quarters) as used in baseline SVAR in parentheses. An asterisk (*) denotes unrestricted impulse responses.

Shock/Variables	GDP	Inflation	REER
Productivity	+	-	*
Demand	+	+	-
Nominal	+	+	+

Table 3: Summary of sign-restrictions in 3-variable SVAR. Responses in inflation and the real exchange rate are imposed for one quarter. All other responses are imposed for four quarters. An asterisk (*) denotes unrestricted impulse responses.

		Productivity shock			Cost-push shock			Real demand shock			Risk premium shock			Monetary policy shock		
Horizon	Method	Median	Mode	68% Int.	Median	Mode	68% Int.	Median	Mode	68% Int.	Median	Mode	68% Int.	Median	Mode	68% Int.
Variance decomposition of REER																
1	Generic - 3 variables	0.05	0.00	[0.00; 0.96]				0.53	0.51	[0.00; 1.00]				0.34	0.48	[0.00; 1.00]
	Specific - 5 variables	0.07	0.00	[0.00; 0.76]	0.11	0.29	[0.00; 0.92]	0.28	0.36	[0.00; 0.91]	0.23	0.25	[0.00; 0.95]	0.07	0.09	[0.00; 0.86]
	Specific - 5 var., alt. sign	0.04	0.01	[0.00; 0.74]	0.11	0.56	[0.00; 0.82]	0.35	0.32	[0.00; 0.96]	0.26	0.09	[0.00; 0.95]	0.04	0.02	[0.00; 0.83]
	Specific - 5 var., all restricted	0.03	0.05	[0.00; 0.19]	0.08	0.08	[0.02; 0.40]	0.42	0.29	[0.10; 0.72]	0.27	0.52	[0.17; 0.52]	0.05	0.06	[0.00; 0.20]
	Specific - 6 variables.	0.05	0.04	[0.00; 0.61]	0.10	0.47	[0.00; 0.77]	0.18	0.30	[0.00; 0.66]	0.20	0.07	[0.00; 0.73]	0.06	0.06	[0.00; 0.69]
5	Generic - 3 variables	0.11	0.03	[0.00; 0.88]				0.51	0.51	[0.02; 0.96]				0.32	0.45	[0.01; 0.95]
	Specific - 5 variables	0.11	0.03	[0.00; 0.61]	0.16	0.30	[0.01; 0.74]	0.24	0.33	[0.01; 0.77]	0.24	0.23	[0.01; 0.73]	0.13	0.11	[0.01; 0.68]
	Specific - 5 var., alt. sign	0.09	0.01	[0.00; 0.59]	0.18	0.53	[0.00; 0.74]	0.29	0.32	[0.01; 0.75]	0.25	0.10	[0.00; 0.74]	0.10	0.04	[0.00; 0.63]
	Specific - 5 var., all restricted	0.08	0.08	[0.01; 0.19]	0.15	0.18	[0.05; 0.40]	0.32	0.25	[0.11; 0.52]	0.29	0.43	[0.21; 0.43]	0.07	0.06	[0.03; 0.16]
	Specific - 6 variables.	0.09	0.05	[0.01; 0.46]	0.13	0.41	[0.02; 0.54]	0.18	0.27	[0.02; 0.54]	0.19	0.07	[0.02; 0.46]	0.12	0.07	[0.03; 0.55]
20	Generic - 3 variables	0.13	0.04	[0.00; 0.86]				0.49	0.51	[0.02; 0.94]				0.32	0.45	[0.01; 0.94]
	Specific - 5 variables	0.12	0.03	[0.01; 0.54]	0.16	0.29	[0.01; 0.65]	0.24	0.33	[0.02; 0.72]	0.25	0.23	[0.03; 0.71]	0.13	0.11	[0.01; 0.58]
	Specific - 5 var., alt. sign	0.10	0.02	[0.01; 0.57]	0.18	0.52	[0.01; 0.69]	0.29	0.31	[0.03; 0.75]	0.26	0.11	[0.02; 0.69]	0.11	0.04	[0.00; 0.59]
	Specific - 5 var., all restricted	0.08	0.08	[0.03; 0.19]	0.16	0.19	[0.06; 0.36]	0.27	0.25	[0.20; 0.52]	0.26	0.39	[0.24; 0.39]	0.08	0.08	[0.04; 0.17]
	Specific - 6 variables	0.11	0.06	[0.02; 0.43]	0.14	0.40	[0.02; 0.50]	0.17	0.28	[0.03; 0.53]	0.20	0.08	[0.06; 0.44]	0.13	0.07	[0.03; 0.41]
Variance decomposition of trade balance																
1	Specific - 6 variables	0.10	0.24	[0.00; 0.80]	0.06	0.01	[0.00; 0.66]	0.10	0.13	[0.00; 0.61]	0.07	0.15	[0.00; 0.58]	0.09	0.00	[0.00; 0.86]
5	Specific - 6 variables	0.10	0.15	[0.01; 0.77]	0.06	0.02	[0.00; 0.50]	0.09	0.05	[0.01; 0.61]	0.12	0.05	[0.01; 0.66]	0.15	0.03	[0.01; 0.81]
20	Specific - 6 variables	0.10	0.17	[0.00; 0.58]	0.10	0.01	[0.01; 0.78]	0.10	0.02	[0.01; 0.62]	0.13	0.02	[0.01; 0.63]	0.16	0.08	[0.00; 0.71]

Table 4: Forecast error variance decomposition. Results are based on 1,698 accepted draws. The 68% interval denotes the 68% joint region of highest posterior density (note that this interval summarizes parameter and model uncertainty). The forecast horizon is denoted in quarters. Generic identification refers to the sign identification scheme of [Farrant and Peersman \(2006\)](#), specific identification refers to the scheme developed in this paper which allows a more sharp interpretation of the structural shocks. The table also reports the robustness checks with an alternative sign identification scheme (“alt. sign”), restrictions on all impulse responses (“all restricted”) and the trade balance as an additional variable (“6 variables”).

Shock/Variables	GDP	Inflation	REER	Hours	Interest rates
Productivity shock	+ (1-8)	− (1)	+ (*)	− (1-4)	− (*)
Cost-push shock	+ (1-6)	− (1)	+ (*)	+ (1-4)	− (*)
Real demand shock	+ (1-6)	+ (1)	− (3-6)	+ (1-4)	+ (1-2)
Risk premium shock	+ (1-3)	+ (1)	+ (1-3)	+ (*)	+ (1-4)
Monetary policy shock	+ (1-2)	+ (1)	+ (*)	+ (*)	− (1-2)

Table 5: Alternative set of sign restrictions. Restricted horizons (in quarters) in parentheses. An asterisk (*) denotes unrestricted impulse responses.

Horizon	Productivity shock			Cost-push shock			Real demand shock			Risk premium shock			Monetary policy shock		
	Median	Mode	68% Int.	Median	Mode	68% Int.	Median	Mode	68% Int.	Median	Mode	68% Int.	Median	Mode	68% Int.
<i>Variance decomposition of GDP</i>															
1	0.11	0.37	[0.00; 0.77]	0.08	0.05	[0.00; 0.79]	0.21	0.31	[0.00; 0.93]	0.24	0.11	[0.00; 0.93]	0.15	0.16	[0.00; 0.91]
5	0.13	0.33	[0.01; 0.60]	0.13	0.09	[0.01; 0.70]	0.19	0.26	[0.01; 0.76]	0.24	0.17	[0.02; 0.73]	0.16	0.15	[0.00; 0.72]
20	0.13	0.32	[0.01; 0.58]	0.15	0.10	[0.02; 0.63]	0.19	0.25	[0.01; 0.72]	0.24	0.18	[0.03; 0.68]	0.16	0.15	[0.02; 0.63]
<i>Variance decomposition of inflation</i>															
1	0.11	0.02	[0.00; 0.90]	0.19	0.51	[0.00; 0.97]	0.06	0.02	[0.00; 0.81]	0.09	0.04	[0.00; 0.95]	0.29	0.42	[0.00; 0.96]
5	0.13	0.06	[0.01; 0.64]	0.20	0.46	[0.00; 0.79]	0.14	0.07	[0.01; 0.57]	0.15	0.09	[0.01; 0.71]	0.25	0.31	[0.01; 0.77]
20	0.14	0.08	[0.01; 0.58]	0.20	0.45	[0.01; 0.68]	0.15	0.07	[0.01; 0.56]	0.18	0.09	[0.01; 0.67]	0.23	0.31	[0.01; 0.69]
<i>Variance decomposition of hours worked</i>															
1	0.28	0.40	[0.00; 0.93]	0.10	0.12	[0.00; 0.85]	0.16	0.43	[0.00; 0.88]	0.08	0.05	[0.00; 0.93]	0.11	0.00	[0.00; 0.84]
5	0.25	0.35	[0.01; 0.77]	0.15	0.19	[0.01; 0.69]	0.16	0.37	[0.01; 0.74]	0.14	0.06	[0.00; 0.81]	0.15	0.04	[0.01; 0.71]
20	0.23	0.31	[0.01; 0.72]	0.17	0.20	[0.02; 0.61]	0.17	0.32	[0.02; 0.71]	0.17	0.12	[0.01; 0.73]	0.15	0.04	[0.01; 0.65]
<i>Variance decomposition of interest rates</i>															
1	0.08	0.01	[0.00; 0.77]	0.13	0.03	[0.00; 0.79]	0.12	0.03	[0.00; 0.89]	0.34	0.80	[0.00; 0.95]	0.11	0.13	[0.00; 0.75]
5	0.08	0.03	[0.00; 0.80]	0.12	0.03	[0.00; 0.70]	0.20	0.10	[0.00; 0.90]	0.33	0.73	[0.00; 0.91]	0.09	0.12	[0.00; 0.70]
20	0.10	0.07	[0.00; 0.81]	0.13	0.02	[0.00; 0.83]	0.21	0.12	[0.00; 0.88]	0.31	0.69	[0.00; 0.89]	0.09	0.09	[0.00; 0.61]

Table 6: Forecast error variance decomposition of baseline SVAR. The 68% interval denotes the 68% joint region of highest posterior density. The forecast horizon is denoted in quarters. Results are based on 1, 698 accepted draws.