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Phillips Curve Shocks and Real Exchange Rate Fluctuations: SVAR Evidence☆

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Abstract

Steinsson (2008) shows that real shocks that affect the New Keynesian Phillips curve explain the behavior of the real exchange rate in a sticky-price business cycle model. This paper reveals that these shocks are important for the volatility of the real exchange rate in the data. In a structural VAR analysis, we identify productivity, labor supply, cost-push, government spending, risk premium, and monetary policy shocks using sign restrictions derived from Steinsson's model. We study different methods of variance decomposition. According to the forecast error variance decomposition, the real demand shocks are the most important source of real exchange rate volatility. At business cycle frequencies, however, three supply shocks account for up to 40 percent of real exchange rate fluctuations.

Keywords: real exchange rate, supply shock, structural vector autoregression, sign restriction, business cycle variance decomposition

JEL Classification: C32, F31, F32, F41

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1 Introduction

Does the real exchange rate move in response to real or to nominal disturbances? This question is of major interest in international economics. The majority of the theoretical and empirical literature has focused on the role of conventional business cycle shocks, such as real demand, productivity and monetary policy shocks. More recently, Steinsson (2008) argues that real shocks affecting the New Keynesian Phillips curve are important for explaining the persistence and the hump-shaped impulse response of the real exchange rate in a sticky-price business cycle model. He also shows that these "Phillips curve shocks" generate more volatile real exchange rate movements than the monetary policy shock. In the light of his findings, this paper investigates whether Phillips curve shocks are important drivers of real exchange rate fluctuations in a formal structural vector autoregression (SVAR) analysis.

We implement sign restriction as advanced by Faust (1998), Uhlig (2005), and Canova and De Nicoló (2002) to identify structural shocks of interest. Using a sticky-price model similar to that in Steinsson (2008), we derive sign restrictions that identify productivity, labor supply, cost-push, government spending, risk premium and monetary policy shocks. The first four shocks are the Phillips curve shocks highlighted by Steinsson (2008), and the latter two are nominal shocks that are commonly deemed to be important drivers of the real exchange rate in the SVAR literature. We report decomposition results based on both the forecast error variance decomposition and the business cycle variance decomposition, as proposed by Altig, Christiano, Eichenbaum, and Linde (2011). The latter approach filters out dynamics at high and low frequencies leaving only business cycle frequencies, which are most consistent with the dynamic behavior described by business cycle models.

In the existing SVAR literature, the debate on the sources of real exchange rate fluctuations has not been settled. In a seminal paper, Clarida and Galí (1994) use triangular long run restrictions to identify supply, demand and monetary shocks. They find that real shocks are more important than nominal shocks, and the role of supply shocks is negligible compared to real demand shocks. This view is confirmed by other studies using long run restrictions.[1] On the other hand, Rogers (1999) estimates SVAR models

[1]For example, Chadha and Prasad (1997) find a similar result using the Japanese yen-US dollar exchange rate.

with historical data for the US and the UK and concludes that monetary shocks are more important than real shocks for real exchange rate movements. Artis and Ehrmann (2006) estimate small open economy VAR models and identify monetary and exchange rate shocks as the main sources of real exchange rate fluctuations. More recently, Farrant and Peersman (2006) argue that identification schemes based on long-run zero restrictions represent limiting cases in the tails of the range of models that are consistent with theoretical sign restrictions. Using sign restrictions derived from the structural models as in Clarida and Galí (1994), they find that nominal shocks account for about the half of the forecast error variance in bilateral real exchange rates between the UK, Euro zone, Japan and Canada vis-à-vis the US. Juvenal (2011) derives sign restrictions from an open-economy dynamic stochastic general equilibrium (DSGE) model to identify productivity, preference, and monetary policy disturbances. Her forecast error variance decomposition result shows that real demand shocks are more important than productivity and monetary policy shocks, but its role is not as large as that found in previous studies based long-run restrictions.

The contribution of this paper is two-fold to the existing literature. First, we explicitly identify non-productivity supply shocks that have not been considered by previous sign-restriction SVAR studies. As in Steinsson (2008), our theoretical model has labor supply and cost-push shocks as additional sources of supply shocks other than productivity shocks.[2] To the best of our knowledge, we are the first in the sign restriction SVAR literature to explicitly identify these additional supply shocks together with productivity shocks. Second, we evaluate the sensitivity of the variance decomposition on the frequency domain. As virtually all previous studies draw their conclusions based on the variance decomposition of forecast errors, our second contribution is to present results based on a business cycle variance decomposition.[3] In contrast to the forecast error variance decomposition, this approach allows us to focus on the dynamic behavior of time series data at business cycle frequencies. We document that the variance decomposition of the real exchange rate is sensitive to the frequencies one looks at.

[2]The relevance of labor supply disturbances for real exchange rates has recently been noted in the empirical literature. Berka, Devereux, and Engel (2013) find that unit labor costs are of empirical importance for real exchange rate dynamics in a cross-country study.

[3]The business cycle decomposition has been used in a number of recent empirical studies. For example, Justiniano, Primiceri, and Tambalotti (2010) show that focusing on business cycle frequencies emphasizes the relative importance of investment shocks for output and hours.

Using time series data of the US vis-à-vis an aggregate of industrialized countries, our empirical results show that, under the forecast error variance decomposition (FEVD), the government spending shock and the risk premium shock are the most important contributors to the volatility of the real exchange rate. Each of them accounts for approximately 30 percent of the forecast error variance. Supply shocks (productivity and labor-supply/cost-push shocks combined) explain about 26 percent, while monetary policy shocks only contribute 6 percent to real exchange rate fluctuations. A novel finding in these FEVD results is that labor-supply/cost-push shocks are at least as important as productivity shocks in driving the real exchange rate. When we focus on business cycle frequencies, however, the relative importance of shocks changes significantly.[4] At business cycle frequencies, supply shocks become the most important driving force, explaining about 40 percent of the volatility of the real exchange rate. The government spending shock's role reduces to 20 percent. Overall, real shocks account for about two third of the volatility of the real exchange rate, while nominal shocks' role is mainly due to risk premium shocks, instead of monetary policy shocks. When focusing on business cycle frequencies, supply shocks are more important than real demand shocks in driving real exchange rate fluctuations. The robustness of these findings is verified under various sign restriction schemes and across different summary statistics for accepted sign-identified models.

The remainder of the paper is organized as follows. Section 2 describes the theoretical model and derives sign restrictions by applying a robust calibration strategy. In Section 3, we present the SVAR model and describe our data set. Section 4 reports our baseline results and provides validity and robustness checks. Section 5 concludes.

2 The open-economy DSGE model

The model we use to derive the sign restrictions for identifying structural shocks is the same as in Steinsson (2008).[5] The world economy consists of two symmetric countries

[4] We define business cycle frequencies as the components of a time series with periods of 8 to 32 quarters.

[5] Steinsson (2008) presents two versions of the model. These models are different in treading capital as a fixed or an adjustable input in the production function. We adopt the former version for simplicity with the note that two versions of the model do not have different implications for the sign restrictions used in our empirical analysis.

of equal size. In each country, the representative household supplies labor to firms, invests in a complete set of state-contingent bonds and consumes a non-traded final good. The final good is produced by competitive firms that aggregate varieties of intermediate goods produced in both countries. Intermediate good producers are assumed to be monopolistic competitors and set prices in the unit of the buyer's currency following a staggered fashion à la Calvo (1983).

To limit the number of variables in the empirical model, we derive log-linearized equilibrium conditions in terms of differential variables (home versus foreign). The core of the model consists of 5 equations.[6]

The aggregate consumption differential $\hat{c}_t$ evolves according to the consumption Euler equation:

$$\sigma E_t \left[\hat{c}_{t+1} - \hat{c}_t\right] = \hat{\imath}_t - E_t \left[\hat{\pi}_{t+1}\right], \tag{1}$$

where $\hat{\imath}_t$ is the nominal interest rate differential and $\hat{\pi}_t$ denotes the differential rate of inflation between the home and the foreign country. $\sigma^{-1} > 0$ is the intertemporal elasticity of substitution that is the same across both countries.

The uncovered interest rate parity (UIP) implies that

$$q_t = \sigma \hat{c}_t - f_t, \tag{2}$$

where q_t is the real exchange rate and f_t captures a time-varing risk premium shock to the nominal exchange rate.[7] We introduce this shock, because empirical studies find that the exchange rate is not only an absorber of relative shocks, but also a source of nominal disturbance as well (Farrant and Peersman, 2006).

The dynamics of the inflation differential are governed by the New Keynesian Phillips curve (NKPC)

$$\hat{\pi}_t = \beta E_t[\hat{\pi}_{t+1}] + 2\kappa\alpha(1-\alpha)q_t + \kappa(1-2\alpha)\hat{mc}_t, \tag{3}$$

[6]A detailed exposition of the model and the complete set of log-linearized equations is available on request as supplementary technical notes.

[7]This shock can also be interpreted as a systematic failure of exchange rate expectations (Kollmann, 2002) or it may arise from noise trading in the foreign exchange market (Mark and Wu, 1998 and Jeanne and Rose, 2002).

where β is the discount factor, and $\alpha \in [0, 1]$ measures the degree of home bias for home goods versus foreign goods. The parameter $\kappa = \frac{(1-\theta)(1-\theta\beta)}{\theta}$ represents the slope of the NKPC in a closed economy setting, where θ is the non-adjustment rate in the Calvo staggered price-setting.

The real marginal cost differential ($\hat{mc}_t$) is determined by

$$\hat{mc}_t = \frac{(1-2\alpha)(\phi+\sigma)}{1+\phi\eta}\hat{c}_t + \frac{(1-2\alpha)\phi}{1+\phi\eta}\hat{g}_t - \frac{(1+\phi)}{1+\phi\eta}\hat{a}_t + \frac{1}{1+\phi\eta}(\hat{\xi}_t - \hat{\theta}_t), \tag{4}$$

where $\eta > 0$ is the elasticity of substitution between home and foreign goods and $\phi \geq 0$ is the inverse of the Frisch elasticity of labor supply.

Similar to Steinsson (2008), the real marginal cost in this model is influenced by four structural shocks: relative government spending shocks ($\hat{g}_t$), relative productivity shocks ($\hat{a}_t$), relative labor supply shocks ($\hat{\xi}_t$) and relative cost-push shocks ($\hat{\theta}_t$). Note that the last two shocks cannot be separately identified using the sign restriction approach, because they generate the same sign of the impulse response functions for all variables we use in the SVAR model.

Each central bank implements monetary policy according to an interest rate feedback rule following Taylor (1993). The interest rate differential follows

$$\hat{\imath}_t = \rho_i \hat{\imath}_{t-1} + (1-\rho_i)\left[\eta_\pi \hat{\pi}_t + \eta_c \hat{c}_t\right] + \hat{e}_t, \tag{5}$$

where $\rho_i \in [0, 1]$ is the interest rate smoothing parameter. η_π and η_c are the response parameters to inflation and output. $\hat{e}_t$ is the relative monetary policy shock that captures transitory deviations from the Taylor rule.

2.1 Robust sign restrictions

To obtain robust sign restrictions, we consider a broad range of plausible values for our model's parameters.[8] Following Peersman and Straub (2009), we proceed in three steps. First, we specify a plausible range of values for each parameter. 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

[8]Our parameter range covers those values used in Steinsson (2008).

response functions (IRF) for each set of parameter values.

We choose ranges of parameter values following closely the sign restriction literature using DSGE models.[9] The calibration is summarized in Table 1. The consumption to GDP ratio in steady state is set to the range $[0.56; 0.66]$, which is consistent with the long-run great ratios considered in the real business cycle literature. We choose the discount factor β over the range $[0.982; 0.99]$, which implies a steady state risk-free real return on financial assets of 4.2 to 7.5 percent per annum. The Frisch elasticity of labor supply ϕ is set between 0.5 and 3. The upper bound is motivated by the value chosen by Steinsson (2008). For the relative risk aversion parameter, we consider $[1; 6]$ as a plausible range of values. The upper bound is used in Chari, Kehoe, and McGrattan (2002), who choose this value to match the relative volatility of the real exchange rate compared to consumption in US data. In steady state, the consumption home bias α is equal to the ratio of imports to GDP. We follow the literature to use values over the range $[0.025; 0.25]$. Next, 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 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 simple Taylor rules. We set 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 and 0.5. We consider values of the interest rate smoothing parameter ρ_i between 0.4 (Rudebusch, 2006) and 0.8, which corresponds to estimates commonly found for the Volcker-Greenspan period.

We choose values for the persistence parameters of the shock processes according to Bayesian estimates of 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

[9]See, e.g., Enders, Müller, and Scholl (2011) for a detailed discussion of the range of values chosen based on microeconomic and macroeconomic evidence.

[10]Here, 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.

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; 0.5]	Output gap coefficient in the Taylor rule
ρ_i	[0.4; 0.8]	Interest rate 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 government spending shocks
ρ_f	[0.07; 0.36]	AR(1) coefficient of nominal exchange rate shocks
ρ_ε	[0.04; 0.24]	AR(1) coefficient of monetary shocks
ρ_ξ	[0.797; 0.933]	AR(1) coefficient of labor supply/cost-push shocks

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

according to the posterior distribution of interest rate premium disturbances estimated by Smets and Wouters (2007). The 90 percent interval of this parameter lies between 0.07 and 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 of 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 government 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.

Given the parameter ranges, we compute the theoretical impulse response functions (IRFs) of the five structural shocks across $50,000$ parameter realizations. Figure 1 shows the median and the 5th and the 95th percentiles of the IRFs. Figure 1 only shows the variables that are used in the SVAR later on. In order to impose sign restrictions, we are only interested in the qualitative signs of the responses at this point. The quantitative properties of the responses are determined by the data in the SVAR estimation. Given the parameter ranges, the impulse responses, in all cases except two, have an unambiguous sign in the whole parameter region. The two cases with ambiguous signs occur in the real exchange rate response to the real demand shock and the inflation response to the risk premium shock. The responses of the real exchange rate to the real demand shock show mainly a negative sign, but a few of the responses in the 90 percent interval cover the positive region in the first two periods after the shock. As a result, we impose a negative sign for this response from the third to the 6th quarter. Likewise, the responses of inflation to the risk premium shock change sign (from positive to negative) in the second quarter. In this case, we impose a positive sign only on the impact response. The sign restrictions derived from the theoretical IRFs are summarized in Table 2.

Shock/Variables	GDP	Inflation	REER	Hours	Interest rates
Productivity	+ (1-8)	− (1)	+ (1)	− (1-4)	− (1-2)
Labor supply/cost-push	+ (1-6)	− (1)	+ (1-2)	+ (1-4)	− (1-4)
Government spending	+ (1-6)	+ (1)	− (3-6)	+ (1-4)	+ (1-2)
Risk premium	+ (1-3)	+ (1)	+ (1-3)	+ (1-4)	+ (1-4)
Monetary policy	+ (1-2)	+ (1)	+ (1)	+ (1-2)	− (1-2)

Table 2: Summary of the signs of theoretical impulse responses of our DSGE model. In case of ambiguous responses across parameterizations, we report the median. Restricted horizons (in quarters) as used in baseline SVAR in parentheses. Shocks and variables are relative and expressed as differentials, except for risk premium shocks and the REER.

2.2 Discussion

The qualitative predictions of the DSGE model are consistent with conventional economic intuition. After a positive relative supply shock, the output differential rises and the inflation differential falls. After a positive relative demand shock, both output and inflation differential rise. In addition, our theoretical model 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 the same as in Farrant and Peersman (2006) (based on a different model setup).

The DSGE model sheds light on the impulse responses of a large set of macro variables, which allows us to identify further structural shocks compared to earlier SVAR

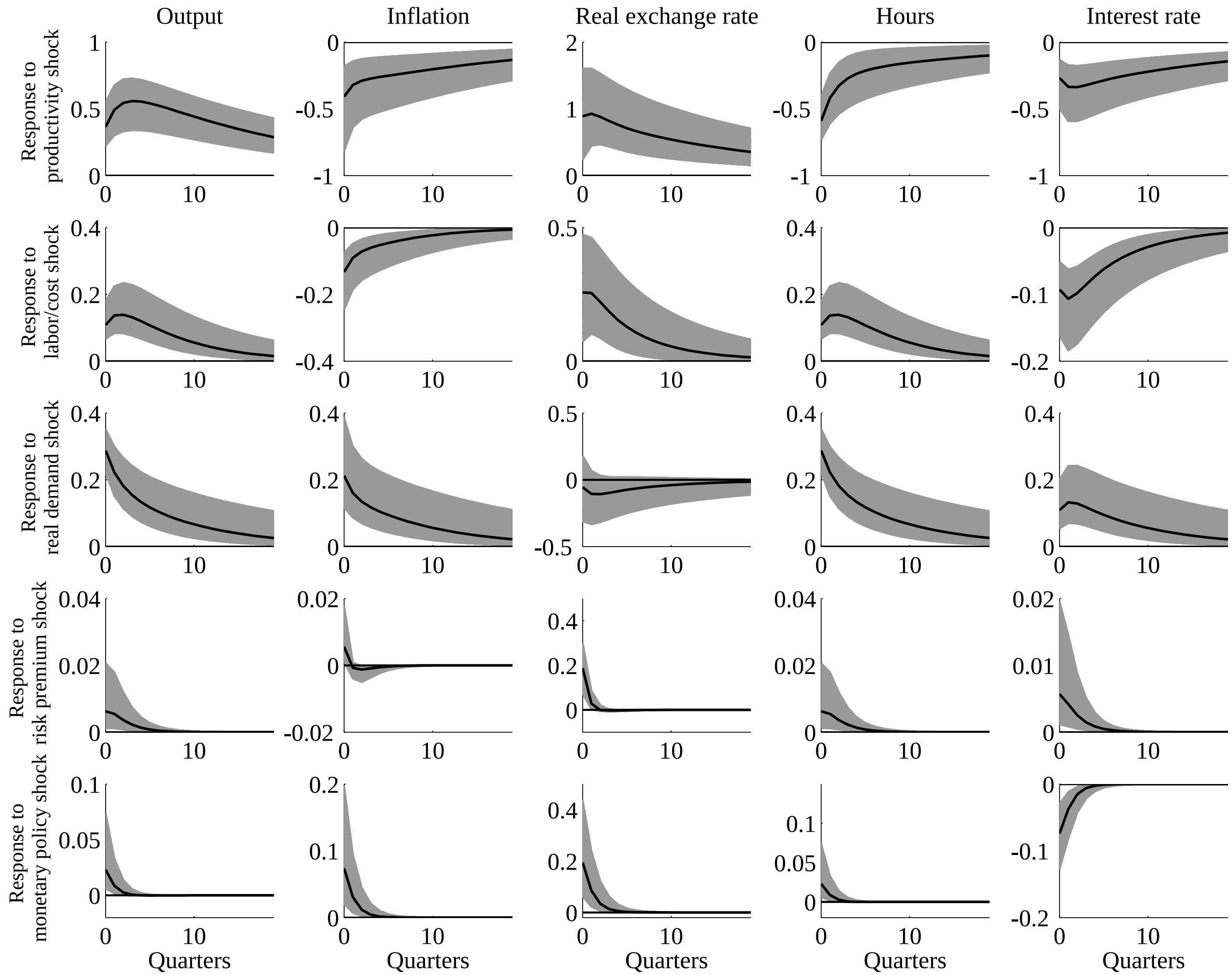

Figure 1: Robust theoretical impulse response functions. This figure shows the impulse responses of key variables to the five structural shocks in the DSGE model. The solid lines show the median impulse responses, while the gray area represents all impulse responses between the 5th and the 95th quantiles across responses. Note that shocks and variables are defined in terms of differentials between countries, except for the exchange rate and the risk premium shock.

studies. We make three observations. First, as seen in the first two rows of Table 2, we distinguish productivity shocks and labor-supply/cost-push shocks, using the impulse responses of hours worked. The model predicts that the hours differential rises after a favorable labor-supply/cost-push shocks, but falls in response to a positive relative productivity shocks over the whole range of parameter values.[11] Given that this is a robust feature of New Keynesian models, we use this pair of signs to distinguish the labor-supply/cost-push shocks from the productivity shock in our benchmark identification. However, being fully aware of the empirical controversy on the issue,[12] we conduct robustness checks on these sign restrictions in the empirical analysis. Second, the DSGE model distinguishes government spending shocks from risk premium shocks through the responses of the real exchange rate. As the response of the real exchange rate to the government spending shock is not entirely clear-cut in the model, we impose a negative sign only from quarter 3 onwards, which is justified based on the 90 percentiles of all theoretical impulse responses. Third, we include the nominal interest rate differential in our SVAR model, because the theoretical IRFs of the nominal interest rate are informative for disentangling monetary policy shocks and risk premium shocks. As seen in the last two rows of Table 2, these two disturbances generate impulse responses with the same signs for all variables except for the nominal interest rate. The relative nominal interest rate falls after an expansionary monetary policy shock because of the Taylor rule, while it rises after a positive risk premium shock due to uncovered interest parity. A positive risk premium shock causes a depreciation of the nominal exchange rate, and, in order to reestablish interest rate parity, the home nominal interest rate needs to rise faster than the foreign rate.

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

[12] While Galí (1999), Basu, Fernald, and Kimball (2006) and Francis and Ramey (2005) argue that hours worked should fall after a productivity shock, Christiano, Eichenbaum, and Vigfusson (2004), Dedola and Neri (2007) and Peersman and Straub (2009) among others find the opposite.

3 Empirical methodology and data

3.1 Methodology

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

$$Y_t = B(L)Y_{t-1} + u_t, \qquad t = 1, ..., T, \tag{6}$$

where Y_t is an $N \times 1$ vector of endogenous variables and the lag polynomial $B(L)$ represents $N \times N$ coefficient matrices up to the maximum lag length k. The reduced form innovations, denoted by the $N \times 1$ vector u_t, are independent and identically distributed with mean zero and variance-covariance matrix Σ_u.

We obtain the underlying structural shocks e_t by transforming the reduced form innovations u_t with matrix A such that $A^{-1}u_t = e_t$. The structural innovations e_t are orthogonal and economically interpretable. The variance of each structural innovation is normalized to one, then $\Sigma_e = E[e_t e_t'] = I_n$. The transformation matrix A 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 other identification schemes commonly applied in the SVAR literature, the sign restriction approach does not set a single transformation matrix A, but it accepts all transformations that satisfy the imposed sign restrictions. We construct random candidate draws for matrix A based on a QR decomposition (Rubio-Ramirez, Waggoner, and Zha, 2010).[13] For each candidate draw, we compute the impulse response functions and retain the draws that satisfy the sign restrictions.

We estimate the VAR with Bayesian methods to account for parameter uncertainty in the decision to accept or reject the identification scheme. As emphasized by Uhlig (2005), one leaves parameter uncertainty unaddressed if determining acceptance or rejection solely upon point estimates. Instead, we consider $300,000$ draws from the posterior distribution of the reduced form VAR parameters and, for each draw, check the signs of the SVAR impulse responses derived from $300,000$ candidate transformation matrices A. In our baseline specification, we obtain approximately $1,000$ accepted

[13]Orthogonal matrices from a QR decomposition ensure 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). The two methods yield equivalent results, but the former is computationally superior (Fry and Pagan, 2011).

draws.[14] We follow Uhlig (2005) and set a weak Normal-Wishart prior that generates posterior means of the reduced form VAR equal to the OLS estimates of $B(L)$ and Σ_u.

Compared to strict short or long run restrictions, sign restrictions entail the costs that the interpretation of the SVAR results is less straightforward. The reason is the multitude of accepted models that all satisfy the sign restrictions (here approximately $1,000$ draws). Generally, the accepted models have conflicting implications for the question at hand. The literature frequently reports the pointwise median and percentiles across accepted draws as a measure of the central tendency of the accepted models. However, this practice mixes structural models.[15] As a result, the pointwise median does not necessarily arise from a rotation of the reduced form VAR and lacks structural interpretability. The problem of structural interpretability of pointwise summary statistics is even more severe in the context of a variance decomposition. The pointwise variance decomposition does not necessarily sum to one.[16] Therefore, the interpretation of pointwise variance shares is difficult.

To address these concerns, we report results based on the single model that is closest to the pointwise median as proposed by Fry and Pagan (2011) in addition to the pointwise median. Following Fry and Pagan (2011), we refer to this model as the optimal median. The single model is structurally interpretable as it represents one single rotation of the reduced form VAR.[17]

3.2 Data and specification

We use data for the US vis-à-vis an aggregate of industrialized countries (rest of the world, ROW). Aggregated time series data from the G7 countries excluding the US (Japan, Germany, the UK, Italy, Canada, and France) composes the ROW data for real GDP, inflation, hours worked, and interest rates. While aggregating, we weight each country according to trade shares as reported in the narrow weighting matrix of the Bank for International Settlements for the period 2008 to 2010. Nominal seasonally

[14] This number is large enough so that additional draws do not change the results.

[15] See Fry and Pagan (2011) and Inoue and Kilian (2013) for a discussion.

[16] The intuition for this finding is that the shocks constructed from the non-structural pointwise median impulse response are not necessarily uncorrelated.

[17] In an earlier version of this paper, we considered the model at the mode of the posterior of the impulse responses as proposed by Inoue and Kilian (2013) as a summary statistic. However, Boysen-Hogrefe, Gehrke, and Plödt (2014) show that this posterior mode is not unique.

adjusted GDP is converted to real terms using the GDP deflator 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 by Juvenal (2011), this strategy distinguishes movements in real GDP from exchange rate fluctuations.

For hours worked, we resort to the data set of Ohanian and Raffo (2012). This data set provides internationally comparable data on hours worked.[18] This data allows us to account for both the intensive and extensive margin of labor adjustment. Detailed data sources for all series and for each country are summarized in Appendix A. As in our theoretical model, we define each data series as the differential between the home and the foreign country, i.e., the ROW aggregate is subtracted from the US data. For GDP and hours worked, we consider the log differential; inflation and interest rate differentials are expressed in absolute terms. To calculate 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. Our quarterly data covers the period from 1978Q4 to 2010Q4.

We estimate the VAR using first differences in the GDP and hours differential and the real exchange rate. This follows Farrant and Peersman (2006) and makes our results comparable to the existing literature. In accordance with the literature, we impose the sign restrictions on the level of the responses. We fit a VAR with $k = 4$ lags for the quarterly data.[19]

4 Empirical results

This section discusses our baseline results. We impose the full set of robust sign restrictions as derived from the DSGE model (Table 2) since we are primarily interested in the volatility of the REER. In a robustness check, we relax sign restrictions sequentially.[20]

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

[19]Estimating 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 fewer lags. The results are available upon request.

[20]For easier readability, we speak simply of shocks in the following. In the two economies setting, this term refers to relative or asymmetric shocks between the two countries.

4.1 Empirical impulse response functions

Figure 2 depicts the impulse responses of our baseline SVAR. Solid black lines show the pointwise median, gray lines represent all accepted draws in the 16th and 84th pointwise percentiles across accepted draws.[21] Dashed black lines represent the optimal median of Fry and Pagan (2011), i.e., the single structural model closest to the pointwise median. In general, the optimal impulse responses are similar to the pointwise median.

Not surprisingly, the empirical impulse responses reflect the sign restrictions imposed. For most of the shocks and variables, impulse responses exhibit the imposed sign well beyond the restricted horizons. However, the empirical response of the real exchange rate to a productivity shock changes sign immediately after the restricted horizon. From quarter two onwards, the REER shows a persistent appreciation instead of a depreciation (as predicted by our model). The appreciation of the REER after a productivity shock is well in line with the results of other SVAR studies (Farrant and Peersman, 2006 and Corsetti, Dedola, and Leduc, 2014). Within open economy DSGE models, a combination of wealth effects and strong home bias explains this result. Given that this sign restriction is not decisive to identify our set of structural shocks, we relax this restriction in a robustness check. Interestingly, the REER exhibits hump-shaped responses to the joint labor supply/cost-push shock. This result neatly corresponds to the theoretical argument of Steinsson (2008) that the hump-shaped response in reaction to shocks to the Phillips curve generates the necessary persistence in the real exchange rate. We document that this pattern indeed arises in the data in response to labor supply and cost-push shocks that are identified in a SVAR.

4.2 Forecast error variance decomposition

We deploy two distinct decomposition techniques to explore the contribution of the different structural shocks to the volatility of the REER. We begin by inspecting the most commonly applied method of variance decomposition, the forecast error variance decomposition (FEVD). Recently, an alternative decomposition technique that focuses

[21]Note that these regions reflect two different concepts: parameter uncertainty from the estimation and model uncertainty from the sign restriction identification. The broad range of impulses does not necessarily mean that the impulses are not significant in a statistical sense.

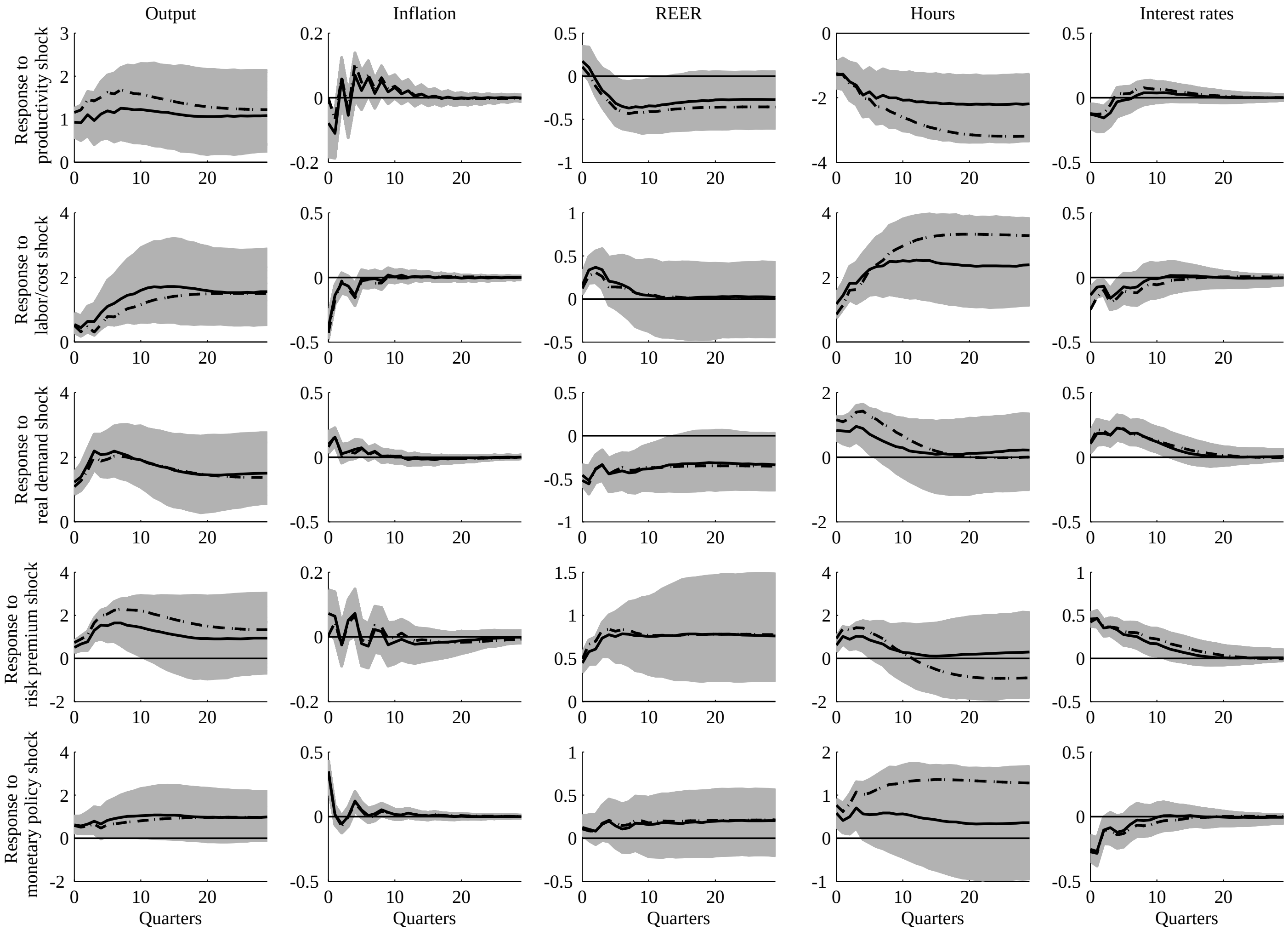

Figure 2: Baseline impulse responses (all signs restricted). The figure shows the impulse response functions to one-standard deviation relative shocks. Solid black lines show the pointwise median impulse responses, and gray lines represent all responses between the 16th and 84th pointwise percentiles of all accepted draws. Dashed black lines represent the optimal median. Results are based on $1,047$ accepted draws. Note that shocks and variables are defined in terms of differentials between countries, except for the exchange rate and the risk premium shock.

on decomposing variances at business cycle frequencies has been promoted in the literature. We contrast the results of both decomposition techniques in the next section.

We present the FEVD at the pointwise median and at the corresponding percentiles across all accepted draws. These results are directly comparable to earlier studies (e.g., Farrant and Peersman, 2006). To address the concerns about pointwise summary statistics, we additionally report the FEVD based on the optimal median. Table 3 reports the FEVD of our baseline SVAR at the 1, 5 and 20 quarter forecast horizon for each summary statistic.

The first rows of Table 3 report the FEVD of the REER. The most important structural sources of REER fluctuations are government spending and risk premium shocks. Each of these two shock explains approximately 40 percent of REER fluctuations as measured by the optimal median (slightly less if one considers the pointwise median). The risk premium and the government spending shock are the most relevant at the one quarter forecast horizon, whereas their importance declines at longer horizons. The strong role of government spending shocks corresponds to the substantial role of real demand shocks found in earlier empirical studies (Clarida and Galí, 1994 and Juvenal, 2011). The strong role of risk premium shocks is consistent with the findings of Farrant and Peersman (2006). They document that generic nominal shocks and exchange rate shocks, in particular, are main driving forces of REER fluctuations.

One of the core results of this paper is the role of asymmetric supply shocks. Once, we account for different sources of supply shocks, these explain a substantial share of the medium to long run forecast errors of the REER. At the five quarter horizon, supply shocks contribute 15 to 25 percent to real exchange rate fluctuations. The optimal median predicts a smaller role for supply shocks than the pointwise median. By contrast, supply shocks play a secondary role for short run REER fluctuations. At the one quarter horizon, all three supply shocks combined contribute approximately 10 percent to REER forecast error fluctuations. The variance decomposition is split equally between productivity and labor supply/cost-push shocks. This finding is new to the literature, which largely ignores the role of labor supply and cost-push shocks for REER fluctuations, thus far. Consistent with earlier findings in the literature, monetary policy has hardly any effect on REER dynamics. Monetary policy shocks contribute approximately 5 percent to the forecast error variance of the US-ROW real exchange rate.

The remainder of Table 3 reports the FEVD of the remaining variables in the SVAR.

Horizon	Productivity			Labor supply/cost-push			Government spending			Risk premium			Monetary policy		
Variable	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.
Variance decomposition of the REER															
1	0.05	0.02	[0.00; 0.22]	0.05	0.03	[0.00; 0.15]	0.37	0.49	[0.20; 0.58]	0.35	0.44	[0.20; 0.55]	0.03	0.02	[0.00; 0.12]
5	0.13	0.07	[0.07; 0.23]	0.13	0.08	[0.07; 0.22]	0.31	0.43	[0.18; 0.45]	0.30	0.39	[0.19; 0.44]	0.06	0.03	[0.03; 0.13]
20	0.14	0.08	[0.08; 0.23]	0.14	0.08	[0.08; 0.22]	0.29	0.42	[0.18; 0.41]	0.29	0.38	[0.20; 0.41]	0.08	0.04	[0.05; 0.14]
Variance decomposition of the GDP differential															
1	0.23	0.36	[0.09; 0.40]	0.08	0.07	[0.02; 0.21]	0.41	0.32	[0.18; 0.62]	0.07	0.15	[0.02; 0.17]	0.11	0.09	[0.02; 0.27]
5	0.20	0.30	[0.09; 0.34]	0.11	0.08	[0.05; 0.20]	0.37	0.32	[0.20; 0.53]	0.14	0.22	[0.07; 0.24]	0.10	0.08	[0.04; 0.22]
20	0.18	0.28	[0.09; 0.31]	0.14	0.10	[0.08; 0.23]	0.34	0.31	[0.19; 0.48]	0.16	0.22	[0.10; 0.26]	0.11	0.08	[0.05; 0.22]
Variance decomposition of the inflation differential															
1	0.02	0.00	[0.00; 0.10]	0.47	0.59	[0.26; 0.72]	0.03	0.02	[0.00; 0.12]	0.02	0.00	[0.00; 0.07]	0.38	0.39	[0.17; 0.59]
5	0.09	0.05	[0.05; 0.16]	0.39	0.54	[0.24; 0.55]	0.11	0.08	[0.06; 0.19]	0.06	0.02	[0.03; 0.12]	0.29	0.31	[0.15; 0.43]
20	0.11	0.07	[0.06; 0.17]	0.33	0.51	[0.21; 0.48]	0.13	0.09	[0.08; 0.22]	0.11	0.03	[0.06; 0.21]	0.25	0.30	[0.15; 0.37]
Variance decomposition of the hours worked differential															
1	0.33	0.31	[0.15; 0.55]	0.26	0.14	[0.10; 0.44]	0.14	0.26	[0.05; 0.30]	0.07	0.17	[0.02; 0.20]	0.06	0.11	[0.01; 0.16]
5	0.30	0.30	[0.16; 0.47]	0.27	0.18	[0.14; 0.41]	0.14	0.23	[0.07; 0.27]	0.11	0.18	[0.06; 0.20]	0.09	0.12	[0.04; 0.17]
20	0.28	0.28	[0.15; 0.43]	0.26	0.19	[0.15; 0.38]	0.16	0.22	[0.09; 0.27]	0.14	0.21	[0.08; 0.23]	0.09	0.10	[0.05; 0.16]
Variance decomposition of the interest rate differential															
1	0.05	0.04	[0.01; 0.16]	0.05	0.18	[0.01; 0.14]	0.03	0.04	[0.00; 0.11]	0.59	0.52	[0.42; 0.77]	0.18	0.22	[0.06; 0.33]
5	0.06	0.04	[0.02; 0.17]	0.06	0.12	[0.02; 0.12]	0.12	0.13	[0.05; 0.24]	0.55	0.57	[0.37; 0.71]	0.13	0.14	[0.05; 0.26]
20	0.07	0.04	[0.03; 0.15]	0.08	0.09	[0.03; 0.18]	0.17	0.17	[0.07; 0.30]	0.48	0.60	[0.31; 0.64]	0.11	0.10	[0.05; 0.23]

Table 3: Forecast error variance decomposition of baseline SVAR. The 68 percent interval denotes the pointwise 16th and 84th percentile error bands across accepted draws. The forecast horizon is denoted in quarters. Results are based on $1,047$ accepted draws. Shocks are relative shocks, except for risk premium shocks.

In line with common intuition, the variance of the output differential is mainly driven by relative productivity and government spending shocks. The majority of the inflation differential variability is explained by relative labor supply and cost-push shocks, and monetary policy disturbances. Relative supply shocks are the most important contributors to the volatility of the hours worked differential. Risk premium shocks account for the majority of the variance of the interest rate differential, followed by asymmetric monetary policy shocks.

The main lesson from the FEVD is that we find convincing evidence in US data that real Phillips curve shocks, i.e., productivity, labor supply, cost-push, and real demand shocks as emphasized by Steinsson (2008) indeed contribute to real exchange rate volatility. The major contribution originates from real demand rather than supply shocks. Supply shocks are of relevance in the medium to long run. However, nominal disturbances also contribute a substantial share to real exchange rate fluctuations. Nominal shocks arise from UIP disturbances rather than monetary policy. Next, we show that a focus on business cycle frequencies enhances the relative role of supply shocks.

4.3 Variance decomposition at business cycle frequencies

In the following, we decompose the variance of the REER with the business cycle variance decomposition (BCVD) as proposed by Altig et al. (2011) instead of the conventional FEVD. In contrast to decomposing the variance of the forecast errors, the BCVD decomposes the variance of the time series while focusing on business cycle frequencies.[22] A number of recent empirical studies on variance decompositions uses the business cycle decomposition (Ravn and Simonelli, 2007, Justiniano et al., 2010, and Enders et al., 2011, among others). Justiniano et al. (2010) find that whether focusing on business cycle frequencies or not may alter the relative importance of investment shocks on output and hours. Given that time series data contains dynamics from high frequency trading noise to low frequency trend movements, the variance decomposi-

[22] Here, we do not analyze the fraction of forecast error variance that a shock in period t explains in period $t + h$ (conditional of period t), but analyze the fraction of variance that a specific shock explains on average over the whole sample (i.e., we perform an unconditional variance decomposition) at frequencies of interest. Note that the forecast error variance decomposition at the infinite forecast horizon corresponds to the times series decomposition over all frequencies as the conditional variance approaches the unconditional variance.

tion depends on the specific frequencies that researchers focus on. The variance shares derived from the BCVD are more consistent with our research question that focuses on sources of business cycle fluctuations in the real exchange rate.[23]

To highlight the relevance of the frequency domain, we examine the variance decomposition of the REER across the entire spectrum. We compute the decomposition from the spectrum of the VAR as described by Altig et al. (2011).[24] As is common in the literature, we define business cycle frequencies as the components of a time series with periods of 8 to 32 quarters. Figure 3 reveals that the importance of each structural shock varies considerably across frequencies. Shaded areas mark business cycle frequencies. As before, we compare results at the pointwise median across variance shares and at the optimal median. Productivity shocks are the most relevant at business cycle and low frequencies. Labor supply and cost-push shocks contribute to REER fluctuations, in particular to the movements at medium business cycle frequencies. These findings reflect the observation from the FEVD that supply shocks are of relevance in the long run. Government spending shocks, the third source of Phillips curve shock that captures real demand side disturbances, are an important source of high and medium frequency exchange rate movements, but less so at business cycle frequencies. Monetary policy shocks contribute to REER dynamics at medium to high frequency movements. In general, the spectral decomposition in Figure 3 documents clearly that the relevance of the structural disturbances for REER fluctuations depends on the frequencies one focuses at. We explore the exact variance shares at business cycle frequencies in the following.

From now on, we report the business cycle variance decomposition based on filtered counterfactual time series from the estimated SVAR. This procedure closely fol-

[23]The business cycle variance decomposition is related to a large literature on time series filtering and detrending (Beveridge and Nelson, 1981, King, Plosser, Stock, and Watson, 1991 and Baxter and King, 1999).

[24]Using the spectrum of the VAR representation, we compute the spectral density at frequency ω of a variable when only shock j is active, $f^j(\omega)$, and when all shocks are active, $f(\omega)$. The spectrum of the VAR is given by $f(\omega) = (2\pi)^{-1}\sum_{h=-\infty}^{\infty} E(Y_t Y_{t-h}')e^{-i\omega h} = (2\pi)^{-1}\big(1 - B(e^{-i\omega})e^{-i\omega h}\big)^{-1}\Sigma_u\Big(\big(1 - B(e^{-i\omega})e^{-i\omega}\big)^{-1}\Big)'$, with $\Sigma_u = A\Sigma_e A'$. Set all shocks except shock j in $\Sigma_e = I_n$ to zero to obtain $f^j(\omega)$. As discussed by Altig et al. (2011), the contribution of one shock to each variable is given by the ratio of the spectra at the frequencies of interest (here, $\omega_1 = \frac{2\pi}{32}$ and $\omega_2 = \frac{2\pi}{8}$). Then, the variance share explained by shock j at frequencies ω_1 to ω_2 is given by $\frac{\int_{\omega_1}^{\omega_2} f^j(\omega)d\omega}{\int_{\omega_1}^{\omega_2} f(\omega)d\omega}$.

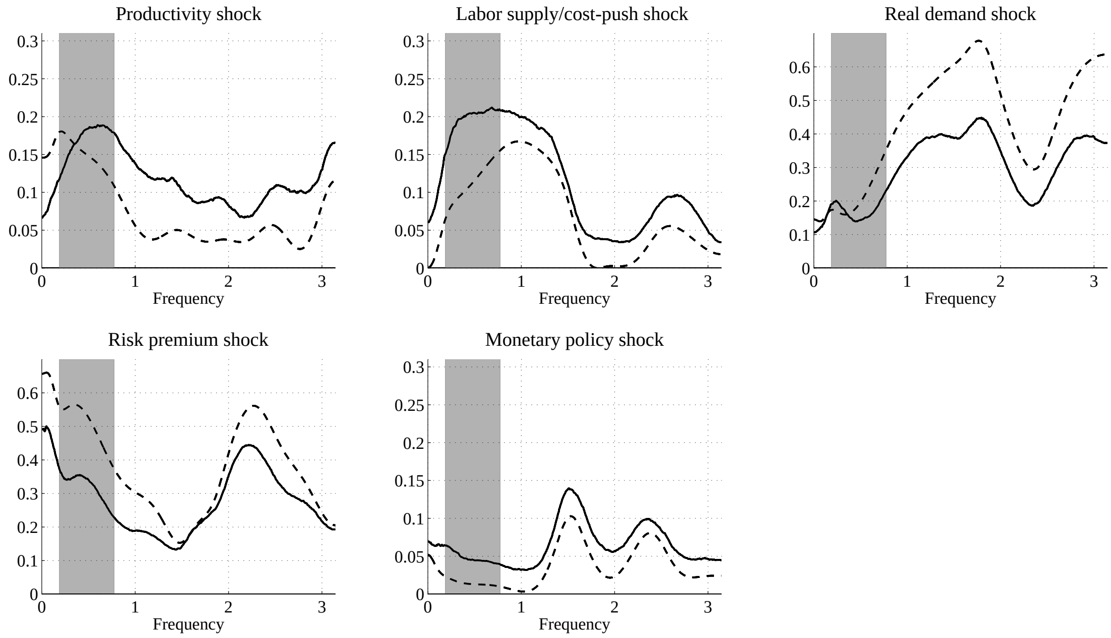

Figure 3: Variance decomposition of the REER across the entire spectrum in baseline SVAR. The spectral density is computed from the SVAR representation using $1,000$ frequency bins. Shaded areas mark business cycle frequencies capturing cycles between 8 and 32 quarters. Solid lines represent the pointwise median across accepted draws, dashed lines represent the spectral decomposition at the optimal median. Shocks are relative shocks, except for risk premium shocks.

lows Ravn and Simonelli (2007) and Enders et al. (2011).[25] In a Monte Carlo experiment, we simulate data from the SVAR that has the same length as the original data series. We filter out business cycle frequencies using the optimal bandpass filter of Christiano and Fitzgerald (2003). The counterfactual series are set up such that they are only triggered by one structural shock at the time. The ratio of the variance of each filtered counterfactual series to the variance of the filtered actual time series (i.e., the series that is driven by the full set of shocks) is a natural estimate of the explained variance share of each structural shock. The variance share measures the importance of one structural shock for the dynamics of the actual time series at business cycle frequencies. The artificial data depends on the initialization of the simulation. As a result, the projected and filtered series may exhibit small patterns of correlation and the decomposition from simulated data does not necessarily sum to one (but is, in general,

[25]Results from counterfactual time series are more straightforward to compare to real world data. Nevertheless, we further evaluated the BCVD based on estimated spectra (as in Figure 3). Results are very similar.

very close to one). Our results remain unchanged if we use the HP filter instead of the bandpass filter, or abstract from initial conditions by assuming zero as initial values for the endogenous variables.

Table 4 contrasts the variance decomposition of the real exchange rate based on forecast errors at the five quarter horizon with the BCVD that decomposes the times series at business cycle frequencies. All statistics are computed at the optimal median. Additionally, we report the pointwise median across a decomposition of each of the accepted sign-identified SVARs.

	Productivity shock		Labor supply/cost-push shock		Government spending shock		Risk premium shock		Monetary policy shock	
Decomposition	Median	Optimal Median	Median	Optimal Median	Median	Optimal Median	Median	Optimal Median	Median	Optimal Median
FEVD	0.13	0.07	0.13	0.08	0.31	0.43	0.30	0.39	0.06	0.03
BCVD	0.19	0.15	0.22	0.11	0.20	0.22	0.34	0.52	0.07	0.02

Table 4: Comparison of forecast error and business cycle variance decomposition of the real effective exchange rate in the baseline SVAR (all signs restricted) using the pointwise median and the optimal median as summary statistic. The BCVD measures the variance of counterfactual time series relative to the variance of the actual time series. Series are filtered with a bandpass filter. Numbers are means over 500 Monte Carlo simulations. Results are based on $1,047$ accepted draws. Shocks are relative shocks, except for risk premium shocks.

In line with the variance decomposition across all frequencies (Figure 3), focusing on business cycle frequencies enhances the role of supply side disturbances substantially. Productivity shocks explain between 15 and 20 percent of the fluctuations of the real exchange rate at business cycle frequencies. Labor supply and cost-push shocks contribute another 10 to 20 percent to REER fluctuations. In sum, supply side disturbances drive up to 40 percent of the movements of the real exchange rate. Real demand disturbances are slightly less relevant at business cycle frequencies compared to the FEVD, but still contribute approximately 20 percent to the variation of the REER. Consequently, the majority of business cycle movements in the US real exchange rate is attributed to real disturbances (or Phillips curve shocks). Nominal shocks explain between 40 and 50 percent of REER fluctuations. Again, the lion's share originates from risk premium shocks. Monetary policy shocks are of minor importance for real exchange rate movements at almost all frequencies.

Table 9 in the Appendix summarizes the business cycle variance decomposition for the additional variables of the SVAR. In general, the relative importance of the different shocks remains similar compared to the FEVD. The GDP differential moves due to productivity and real demand and risk premium shocks; the inflation differential is driven by monetary, labor supply, and cost-push shocks. Real shocks and risk premium shocks explain the business cycle movements of the hours worked differential. The interest rate differential depends mainly on UIP disturbances and monetary policy.

4.4 Robustness checks

4.4.1 Farrant and Peersman (2006) SVAR setup

In this section, we conduct several robustness checks. To begin with, we demonstrate that our main finding is not due to our sample period or peculiarities of our data set. To examine this issue, we apply the sign restriction scheme and the VAR setting of Farrant and Peersman (2006) to our data. We estimate a three variable VAR with the output differential, the inflation differential, and the real effective exchange rate. We set the same sign restrictions as in Farrant and Peersman (2006) to identify generic supply, demand and nominal shocks. Although these sign restrictions are derived from a different theoretical model, they are fully in accordance with the sign restrictions derived from our DSGE model. We obtain 972 accepted draws using $1,000$ posterior draws and 50 rotations each.

The variance decomposition is summarized in Table 5. As before, we contrast the FEVD and the BCVD based on the optimal median along with the conventional pointwise median. The results of our FEVD are generally in line with what is reported in Farrant and Peersman (2006) (repeated here for convenience in the lower part of the table). Note that Farrant and Peersman (2006) analyze the pointwise median only. We identify a strong role for demand and generic nominal shocks and a small to negligible role for supply shocks. This ranking holds in particular at the optimal median. Small differences are driven by two factors. First, Farrant and Peersman (2006) study four US bilateral exchange rate pairs to Canada, Japan, the UK and the Euro area, while we explore the REER of the US vis-à-vis an ROW aggregate. Second, the sample period in Farrant and Peersman (2006) covers only data up to 2002Q4, while our sample extends through to 2010Q4.

	Supply shock		Demand shock		Nominal shock	
	Median	Opt. Median	Median	Opt. Median	Median	Opt. Median
Results based on our data set*						
FEVD	0.11	0.07	0.41	0.50	0.39	0.43
BCVD	0.13	0.09	0.47	0.50	0.35	0.40
FEVD of Farrant and Peersman (2006); Table 1**						
United Kingdom	0.05		0.54		0.34	
Euro area	0.18		0.19		0.53	
Japan	0.03		0.24		0.67	
Canada	0.03		0.74		0.18	

Table 5: Comparison of forecast error and business cycle variance decomposition of the real effective exchange rate in the Farrant and Peersman (2006) SVAR using the pointwise median and the optimal median as summary statistic. * FEVD from our data is computed at the 5-quarter forecast horizon. Results are based on 972 accepted draws. ** Results from Farrant and Peersman (2006); Table 1 show the FEVD based on a 3-variable VAR at the one year forecast horizon. Shocks are relative shocks, except for risk premium shocks.

In contrast to Farrant and Peersman (2006), we further analyze the variance decomposition at business cycle frequencies in addition to the FEVD. Consistent with our results from the five variable baseline SVAR, focusing on the BCVD enhances the relative role of supply side disturbances also in the three variable SVAR. However, the effects are smaller in this setting. Given that we replicate the Farrant and Peersman (2006) findings with out data set, we conclude that our main findings are not driven by our data set or sample period. However, the Farrant and Peersman (2006) identification underestimates the role of supply side disturbances for REER dynamics in favor of demand and nominal shocks. In contrast, our five variable SVAR highlights the contribution of supply side disturbances to real exchange rate dynamics.

4.4.2 Alternative sign restriction patterns

In this section, we show the robustness of our main result towards alternative (less restrictive) sign restriction patterns. First, we estimate the SVAR with two alternative sets of sign restrictions that relax several restrictions, especially on the REER. Second, given that the response of hours worked to a productivity shock is controversial in the literature, we relax this restriction in two further SVAR settings.

		Productivity shock		Labor supply/cost-push shock		Government spending shock		Risk premium shock		Monetary policy shock	
		Median	Optimal Median	Median	Optimal Median	Median	Optimal Median	Median	Optimal Median	Median	Optimal Median
		Baseline									
FEVD	all restricted	0.13	0.07	0.13	0.08	0.31	0.43	0.30	0.39	0.06	0.03
BCVD	all restricted	0.19	0.15	0.22	0.11	0.20	0.22	0.34	0.52	0.07	0.02
		Less restrictions on the REER									
FEVD	alt. sign (1)	0.13	0.03	0.12	0.06	0.27	0.26	0.22	0.57	0.14	0.08
	alt. sign (2)	0.11	0.10	0.14	0.11	0.32	0.29	0.24	0.35	0.10	0.15
BCVD	alt. sign (1)	0.18	0.04	0.16	0.08	0.17	0.15	0.28	0.57	0.19	0.16
	alt. sign (2)	0.16	0.21	0.19	0.18	0.23	0.15	0.26	0.21	0.14	0.23
		Less restrictions on hours worked									
FEVD	alt. sign (3)	-		0.12	0.12	0.36	0.45	0.24	0.33	0.07	0.02
	alt. sign (4)	-		0.13	0.07	-		-		-	
BCVD	alt. sign (3)	-		0.19	0.11	0.23	0.39	0.31	0.37	0.09	0.04
	alt. sign (4)	-		0.22	0.23	-		-		-	

Table 6: Robustness checks under alternative sets of sign restrictions. The table reports the FEVD at the five quarter forecast horizon. Results are based on 799 accepted draws for alt. sign (1), 976 accepted draws for alt. sign (2), $1,016$ accepted draws for alt. sign (3), and on 949 accepted draws for alt. sign (4). Shocks are relative shocks, except for risk premium shocks.

The results of these robustness checks are summarized in Table 6. First, Table 6 compares the FEVD and the BCVD of the baseline SVAR and the SVARs with less restrictions on the variable of foremost interest, the REER. Table 7 and 8 summarize the less restrictive sets of sign restrictions and show that these sign restriction patterns still clearly disentangle the five different structural shocks in the data. In particular, the responses of the REER to productivity, labor supply, cost-push, and monetary policy shocks are now unrestricted.[26] Moreover, the REER responds freely to a risk premium and a monetary policy shock in hours. In alternative sign restriction (1), we further relax the restriction on inflation in response to the government spending shock. In alternative sign restriction (2), we additionally relax the restriction on the interest rate response

[26]These sign restriction patterns allow for an appreciation of the REER in response to productivity shocks as found frequently in empirical studies. Indeed, also the results here document a clear appreciation after a productivity shock.

with respect to labor supply and cost-push shocks.

Shock/Variables	GDP	Inflation	REER	Hours	Interest rates
Productivity	+ (1-8)	− (1)	?	− (1-4)	?
Labor supply/cost-push	+ (1-6)	− (1)	?	+ (1-4)	− (1-4)
Government spending	+ (1-6)	?	− (3-6)	+ (1-4)	+ (1-2)
Risk premium	+ (1-3)	+ (1)	+ (1-3)	?	+ (1-4)
Monetary policy	+ (1-2)	+ (1)	?	?	− (1-2)

Table 7: Alternative sign restrictions (1). Restricted horizons (in quarters) in parentheses. A question mark (?) denotes unrestricted impulse responses. Shocks and variables are relative and expressed as differentials, except for risk premium shocks and the REER.

Shock/Variables	GDP	Inflation	REER	Hours	Interest rates
Productivity	+ (1-8)	− (1)	?	− (1-4)	?
Labor supply/cost-push	+ (1-6)	− (1)	?	+ (1-4)	?
Government spending	+ (1-6)	+ (1)	− (3-6)	+ (1-4)	+ (1-2)
Risk premium	+ (1-3)	+ (1)	+ (1-3)	?	+ (1-4)
Monetary policy	+ (1-2)	+ (1)	?	?	− (1-2)

Table 8: Alternative sign restrictions (2). Restricted horizons (in quarters) in parentheses. A question mark (?) denotes unrestricted impulse responses. Shocks and variables are relative and expressed as differentials, except for risk premium shocks and the REER.

Table 6 illustrates several interesting results. First, real shocks continue to contribute the majority of fluctuations to real exchange rate dynamics also under alternative sets of sign restrictions. According to the FEVD, this finding is mainly due to a strong role of real demand shocks and secondarily due to supply side disturbances. Second, focusing on business cycle frequencies enhances the role of supply side disturbances consistently. Third, under alternative sign restriction patterns, the role attributed to monetary policy increases. However, this latter finding does not change the main results discussed before. In sum, our main findings of the baseline SVAR are robust towards sign restriction patterns that relax restrictions on the real exchange rate itself.

In the lower part of Table 6, we compare the FEVD and the BCVD of the real exchange rate under sign restrictions that relax the negative restriction on hours worked to productivity shocks. Without this restriction, the distinct sources of supply side disturbances are no longer separately identifiable within our framework. Given that the sign restriction of hours worked in response to labor supply and cost-push shocks is controversial in the literature, we use a subset of the sign restrictions in Table 2 to identify four structural disturbances. We refer to this identification scheme as alternative sign restrictions (3). This scheme does not identify productivity shocks explicitly. In alternative sign restrictions (4), we identify labor supply and cost-push shocks only, leaving all other shocks unidentified. Even though the latter identification scheme is very uninformative, it allows to assess whether the role of the non-productivity supply shocks depends on the identification of the other structural shocks.[27]

The results of the decomposition of the REER volatility based on identification schemes (3) and (4) are comparable to the results of the previous sign restriction patterns, even though they are less informative. While the FEVD suggests that real demand shocks and risk premium shocks contribute a substantial share to REER fluctuations, the BCVD emphasizes an additional role for supply side disturbances. Relaxing the sign on hours to productivity shocks does not change our baseline finding that labor supply and cost-push shocks explain approximately 10 to 20 percent of the volatility of the REER. In sum, these robustness checks demonstrate that our empirical findings are neither a result of the negative sign restriction on hours in response to a productivity shock, nor are they specific to our baseline SVAR setting. In our view, we provide compelling evidence that real Phillips curve shocks, including supply shocks, contribute a substantial share to real exchange rate dynamics. This conclusion holds, in particular, at business cycle frequencies as supply side disturbances become relatively more important.

5 Conclusions

This paper provides new SVAR evidence on the role of real shocks in driving US real exchange rate fluctuations. We find that real shocks account for about two thirds of the volatility of the real exchange rate. Of the nominal shocks, the risk premium shock plays a much larger role than the monetary policy shock. Contributing to these results

[27]This approach corresponds to the identification of a monetary policy shock only in Uhlig (2005).

are the facts that we explicitly identify non-productivity supply shocks and that we also explore variance decompositions at different frequencies. Supply shocks are particularly important when looking at business cycle frequencies. Our empirical results substantiate the theoretical argument of Steinsson (2008) that real shocks - Phillips curve shocks - are the most promising candidates for solving the purchasing power parity puzzle.

We further find that nominal shocks in the exchange rate itself continue to contribute a large fraction to real exchange rate volatility even when controlling for additional sources of real shocks in the SVAR. Our findings have normative implications. As stressed by, e.g., Obstfeld (1985) and Devereux and Engel (2007), the need to keep the nominal exchange rate flexible and the desire to smooth fluctuations in real exchange rates constitutes a trade off for policy makers. 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. It is an empirical question which side of the trade off prevails. Our results suggest that neither real nor nominal shocks dominate real exchange rate fluctuations. This finding delivers an important implication. When policy makers decide to fix exchange rates to isolate the economy from nominal disturbances, they should bear in mind that this mutes an important shock absorbing mechanism by exchange rate adjustments. Open economies may develop long lasting imbalances caused by asymmetric real shocks, if no alternative adjustment margins are developed. The imbalances in the Euro area between the northern and the southern member states preceding the government debt crises are one example.

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A Data sources and supplementary tables

Country	Series	Source	Remarks
US			
	GDP	IFS	transformed to real terms using GDP deflator
	GDP deflator	IFS	2005 = 100
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
Canada			
	GDP	IFS	transformed to real terms using GDP deflator
	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, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
France†			
	GDP	IFS	transformed to real terms using GDP deflator
	GDP deflator	IFS	2005 = 100
	exchange rate to US$	IFS	official rate
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	OECD	3-month rates and yields, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
Germany†			
	GDP	IFS	transformed to real terms using GDP deflator
	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, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
Italy†			
	GDP	IFS	transformed to real terms using GDP deflator
	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, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
Japan			
	GDP	IFS	transformed to real terms using GDP deflator
	GDP deflator	IFS	2005 = 100
	exchange rate to US$	IFS	market rate
	CPI inflation	OECD	all items, quarterly rates, 2005 = 100
	short-term interest	IFS	Libor on 3 Month Deposits, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)
UK			
	GDP	IFS	transformed to real terms using GDP deflator
	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, percent per annum
	hours worked	OH (2012)	total hours in potential hours (given population, 365 days per year, and 14hs per day)

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. Data sources are International Financial Statistics (IFS) of the IMF, OECD statistics (OECD), and Ohanian and Raffo, 2012 (OH (2012)).

Variable	Productivity shock			Labor supply/cost-push shock			Government spending shock			Risk premium shock			Monetary policy shock		
	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.	Median	Optimal Median	68% Int.
REER	0.19	0.15	[0.11; 0.28]	0.22	0.11	[0.10; 0.35]	0.20	0.22	[0.11; 0.35]	0.34	0.52	[0.21; 0.47]	0.07	0.02	[0.03; 0.15]
GDP	0.15	0.25	[0.07; 0.29]	0.10	0.02	[0.04; 0.20]	0.42	0.39	[0.24; 0.60]	0.24	0.31	[0.13; 0.40]	0.10	0.05	[0.05; 0.20]
Inflation	0.15	0.09	[0.08; 0.25]	0.44	0.65	[0.28; 0.58]	0.16	0.11	[0.08; 0.30]	0.12	0.02	[0.05; 0.24]	0.16	0.14	[0.09; 0.26]
Hours worked	0.23	0.19	[0.11; 0.41]	0.28	0.17	[0.15; 0.43]	0.19	0.26	[0.09; 0.33]	0.22	0.36	[0.11; 0.38]	0.09	0.08	[0.04; 0.17]
Interest rates	0.20	0.19	[0.13; 0.30]	0.17	0.20	[0.12; 0.26]	0.22	0.23	[0.13; 0.34]	0.49	0.55	[0.32; 0.63]	0.21	0.21	[0.13; 0.33]

Table 9: Business cycle variance decomposition of baseline SVAR. Numbers are means over 500 simulations. The 68 percent interval denotes the pointwise 16th and 84th percentile error bands across all accepted draws. Results are based on $1,047$ accepted draws. Shocks and variables are relative and expressed as differentials, except for risk premium shocks and the REER.

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