Abstract

I analyze the role of nominal and real shocks on the exchange rate behavior using a structural vector autoregressive model (sVAR) for the US vis-à-vis the rest of the world. I apply an identification strategy based on sign restrictions proposed by Fry and Pagan (2007). This method avoids the problems resulting from the multiplicity of impulse vectors and impulse responses are uniquely identified. I estimate the contribution of various shocks to explaining the movement of the real dollar exchange rate imposing short-run restrictions derived from an open economy macro model. The results show that although monetary policy shocks are not the main drivers of exchange rate fluctuations, they are important. Different VAR specifications provide a range for their short-horizon contribution: from 23% to 47%. I compare this to conventional identification methods. Both zero long-run and short-run restrictions find a much less relevant role for monetary policy. These identification strategies lead to significant "puzzles", thus casting doubt on their validity.

Keywords: Exchange Rates, Nominal Shocks, Vector Autoregression, Sign-restrictions.

JEL Classification: F31; F41; C30.
1 Introduction

The explanation of the sources of real exchange rate fluctuations is one of the most challenging issues in international economics. From a theoretical standpoint, the literature has focused on the leading role of monetary policy shocks in accounting for real exchange rate movements. The empirical evidence, however, has not shown much support that monetary policy shocks are important for real exchange rate determination. This paper combines a conventional open economy macro model with recent econometric developments to examine the impact of nominal and real shocks on the real exchange rate behavior.

A natural starting point for the link between monetary policy and exchange rates is Dornbusch (1976) model. Dornbusch prediction is that in response to a monetary policy shock the exchange rate would immediately overshoot its long run level and then adjust gradually. This conclusion follows from uncovered interest parity (UIP) and purchasing power parity (PPP). Since Dornbusch’s seminal work, the theoretical literature has mainly concentrated on the effects of monetary policy shocks (see Obstfeld and Rogoff, 1995; Beaudry and Devereux, 1995; Chari et al, 2002). Thus, the belief that monetary policy plays a dominant role in explaining real exchange rate fluctuations has long been an accepted fact in economics. Such is the case that Rogoff (1996, p. 647) highlights:

“Most explanations of short-term exchange rate volatility point to financial factors such as changes in portfolio preferences, short-term asset price bubbles, and monetary shocks.”

Although this quote reflects the “consensus” that nominal shocks are the main drivers of exchange rate fluctuations, the empirical evidence has not provided much support to this. Clarida and Gali (1994) estimate the relative contribution of various shocks to real dollar bilateral exchange rates. They find that the contribution of monetary shocks to the variance of the real exchange rate is less than 3% for the UK and Canadian cases. Eichenbaum and Evans (1995) study the effects of monetary policy shocks using three different models. Their results show that the mean contribution of monetary policy shocks is less than 25%.

Motivated by the previous literature, I concentrate on three issues. Firstly, I analyze the effects of nominal and real shocks on the real dollar exchange rate. Secondly, I quantify the importance of nominal vs real shocks for the variance of the real exchange rate. Thirdly, I evaluate the contribution of each of the shocks to the real exchange rate behavior. The first issue will allow us to study the impact of various shocks on the real exchange rate and to determine if the effects of monetary policy are consistent with Dornbusch’s overshooting. The second one addresses the question of whether monetary policy explains a large share of exchange rate fluctuations, as would be expected from
theory. The last one will allow us to link the sources of exchange rate movements with economic factors and thus will shed some light on the nature of real exchange rate fluctuations.

The first two questions of my analysis have been extensively analyzed in the literature. For example, Clarida and Gali (1994) and Eichenbaum and Evans (1995) find that the exchange rate overshoots its long-run value after a monetary policy shock but that the peak occurs from one to three years and not on impact as predicted by Dornbusch (1976). This result, known as delayed overshooting, became a consensus result in international economics. In a related study, Faust and Rogers (2003) find that the delayed overshooting result is sensitive to dubious assumptions of conventional estimation methods. In particular, when simultaneity is allowed between financial market variables (interest rates and exchange rates), they find that overshooting is nearly immediate. In line with Faust and Rogers (2003), Scholl and Uhlig (2005) show that the exchange rate overshooting takes place much quicker than the three years horizon found in Eichenbaum and Evans (1995).

Overall, it is generally found that monetary policy shocks generate deviations from UIP (Eichenbaum and Evans, 1995; Kim and Roubini, 2000; Faust and Rogers, 2003; Scholl and Uhlig, 2005).

The literature has not given a clear cut answer about the proportion of exchange rate variability explained by monetary policy shocks. In fact, results vary considerably depending on the countries under consideration and the identification strategy.

The empirical work cited above builds on the use of a structural VAR method to identify monetary policy shocks. The identification strategy employed varies from study to study and the ones relying on conventional estimation techniques are subject to some criticism. Those using zero short-run restrictions (Eichenbaum and Evans, 1995) identify shocks of interest based on some arbitrary assumptions which may be difficult to reconcile with a broad range of theoretical models. For example, the assumption of zero contemporaneous impact of a monetary policy shock on output is in contrast with some general equilibrium models (see Canova and Pina, 1999). Although long-run restrictions are often better justified by economic theory, there seem to be cases in which substantial distortions can arise due to small sample biases and measurement errors (Faust and Leeper, 1997).

The empirical work based around the use of sign restrictions such as Faust and Rogers (2003) and Scholl and Uhlig (2005) are not subject to the criticism of relying on arbitrary assumptions given that the identifying assumptions are derived from a theoretical model. In these studies the identification of the shock of interest - a monetary policy shock - is achieved by imposing sign restrictions on impulse responses while being agnostic about the response of the key variable of interest - in this case the exchange rate. However, as shown by Paustian (2007) this procedure
does not guarantee that the identification of structural shocks is exact because there are multiple matrices defining the linear mapping from orthogonal structural shocks to VAR residuals.

As a way to obtain more precise estimates of impulse responses, the sign restrictions method can be generalized to identify more than one shock. In this case the estimation is more precise because the range of reasonable impulse responses is narrowed down. To see this, note that when only one shock is identified, for example, a monetary policy shock, impulse responses that satisfy the sign restrictions of the monetary policy shock are accepted even if the responses to other shocks are unreasonable. This issue is avoided when more than one shock is identified because only the set of impulse responses that jointly satisfy all sign restrictions for all shocks are accepted. An example of this method is illustrated in Farrant and Peersman (2006), who analyze whether the real exchange rate is a shock absorber or a source of shocks for a series of dollar bilateral exchange rates using a sign restrictions method that identifies various shocks of interest. They find an important role of the real exchange rate as a shock absorber, mainly of demand shocks. In a related study, Fry and Pagan (2007) highlight some conceptual problems of this method, which result from the multiplicity of impulse vectors and suggest a rule to pin down unique impulse responses using sign restrictions.

In an attempt to overcome the limitations previously mentioned, this paper applies the approach developed by Fry and Pagan (2007) to study the sources of exchange rate fluctuations. The methodology requires imposing a number of short-run sign restrictions on impulse responses which are derived from the theoretical model of Clarida-Gali and are also consistent with a broader set of open economy macro models.

In the benchmark specification, I estimate the standard 3 variable VAR of Clarida and Gali (1994) composed of relative output, relative prices and the real exchange rate and identify supply, demand and nominal shocks. In the baseline case, I will refer interchangeably to nominal shocks and monetary shocks. The main findings are:

1. Nominal shocks lead to a depreciation of the exchange rate and the maximum overshooting occurs in the third quarter. Although this is in line with delayed overshooting, the delay takes place quicker than in previous literature.

2. At a 4 quarters horizon, the contribution of monetary policy shocks is 47%. Their relative importance is reduced at longer horizons. Indeed, at a horizon of 20 quarters only 20% of the variation of the real exchange rate is explained by monetary policy shocks.

3. Real shocks have been the main drivers of exchange rate fluctuations, accounting for up to 70% of the movements of the dollar real exchange rate at a horizon of 20 quarters.

4. The long-run predictions of the Clarida and Gali (1994) model are generally satisfied.
I then extend the model in order to break down the nominal shock into monetary and pure exchange rate shocks. The reason for doing this is that there are fluctuations in the real exchange rate which can hardly be attributed to fundamentals (see Truman, 2006; Farrant and Peersman, 2006; Fratzscher, Juvenal and Sarno, 2007). Thus, I estimate an augmented 4 variable VAR which adds the interest rate differential to the 3 variable VAR and I find the following. The responses to a demand and supply shocks are very similar to the ones of the 4 variable VAR. By contrast, monetary shocks explain 23% of the fluctuations of the real exchange rate at a horizon of 4 quarters. At a horizon of 8 and 20 quarters, 22% and 14% of the variation of the real exchange rate is explained by monetary policy shocks, respectively. Pure exchange rate shocks appear to be a less relevant driver of exchange rate movements, accounting for 11% of its variability at a horizon of 20 quarters.

Although the results reveal that real shocks explain most of the exchange rate movements, I highlight that the contribution of monetary policy shocks on the real exchange rate is significant. My findings are consistent with the results reported by Faust and Rogers (2003) that monetary policy shocks are not the main source of exchange rate volatility.

I then examine the sensitivity of my results to an alternative sub-sample analysis, to the use of another exchange rate measure and to alternative identification strategies. The results are robust to an alternative sub-sample analysis and to the use of another exchange rate measure. However, other identification strategies give strikingly contradictory results. Using long-run restrictions in the same fashion as Clarida and Gali (1994) I find that nominal shocks are unimportant to explain real exchange rate fluctuations. The identification of shocks with zero-short run restrictions leads to the conclusion that exchange rate fluctuations are mainly driven by pure exchange rate shocks. By contrast, monetary policy shocks only explain 10% of the movement of the real exchange rate at all horizons. Interestingly, these identification strategies yield significant “puzzles”, thus casting doubt on their validity.

The remainder of the paper is organized as follows. Section 2 outlines the Clarida and Gali (1994) model. Section 3 presents the empirical methodology based on a structural VAR framework with sign restrictions. Section 4 describes the data and also presents unit root and cointegration tests. The results of the baseline model are presented in Section 5. Section 6 contains the results of the extended model while I report a battery of robustness tests in Section 7. Section 8 concludes.
2 Theoretical Model and Sign restrictions

I estimate a structural VAR using theoretical restrictions derived from the Clarida-Gali model. This model is a stochastic version of the two-country rational expectations model by Obstfeld (1985). The model captures the short-run dynamics of the Mundell-Fleming-Dornbusch approach when prices adjust sluggishly to demand, supply and monetary shocks as well as the long-run dynamics, when the economy is in equilibrium and prices fully adjust to all shocks. The following set of equations describe the model. All variables are in logs except interest rates and represent home relative to foreign levels.

\[ y_t^d = d_t + \eta(s_t - p_t) - \sigma [i_t - E_t(p_{t+1} - p_t)] \]  
\[ p_t = (1 - \varphi)E_{t-1}p^e_t + \varphi p^e_t \]  
\[ m_t^s - p_t = y_t - \lambda i_t \]  
\[ i_t = E_t(s_{t+1} - s_t) \]

Equation (1) is an open-economy IS equation, in which relative output demand \( y_t^d \) depends positively on a relative demand shock \( d_t \) and on the real exchange rate \( q_t = s_t - p_t \), and is decreasing in the real interest rate differential. Equation (2) is a price setting equation in which the relative price level in period \( t \) \( p_t \) is an average of the market-clearing price in \( t - 1 \), \( E_{t-1}p^e_t \) and the price that would actually clear the market in time \( t \), \( p^e_t \). The parameter \( \varphi \) is a measure of price sluggishness. When \( \varphi = 1 \) prices are fully flexible and output is supply determined and when \( \varphi = 0 \) prices are fixed and predetermined one period in advance. Equation (3) is an LM equation in which real money balances are increasing in relative output \( y_t \) and decreasing in the relative interest rate \( i_t \). Equation (4) is an interest parity condition in which \( s_t \) denotes the nominal exchange rate.

In the Clarida and Gali (1994) model, relative output, relative prices and the real exchange rate are driven by three shocks: a relative supply shock, a relative demand shock and a relative monetary shock. Both \( y_t^s \) and \( m_t \) are assumed to follow a random walk process and \( d_t \) is characterized by a transitory and permanent component:

\[ y_t^s = y_{t-1}^s + \epsilon_t^s \]  
\[ d_t = d_{t-1} + \epsilon_t^d - \gamma \epsilon_{t-1}^d \]  
\[ m_t = m_{t-1} + \epsilon_t^m \]
The model can be solved for the long-run flexible-price equilibrium, described by the following equations:

\[ y^e_t = y^s_t \] (8)

\[ q^e_t = \left( y^s_t - d_t \right) / \eta + \left[ \eta (\eta + \sigma) \right]^{-1} \sigma \gamma \varepsilon^d_t \] (9)

\[ p^e_t = m_t - y^s_t + \lambda (1 + \lambda)^{-1} (\eta + \sigma)^{-1} \gamma \varepsilon^d_t \] (10)

Thus, in the long run, only supply shocks lead to increases in the level of relative output; supply and demand shocks have an impact in the long-run level of the real exchange rate; and the three shocks have an impact on relative prices in the long run. These restrictions are used by Clarida and Gali (1994) to identify supply, demand and nominal shocks. Interestingly, it is also possible to estimate the impact of these shocks concentrating on the short-run dynamics of the model instead of imposing long-run restrictions.

Solving the system for the case of a short-run open economy equilibrium with sluggish price adjustment, we obtain:

\[ p_t = p^e_t - (1 - \varphi) \left( \varepsilon^m_t - \varepsilon^s_t + \alpha \gamma \varepsilon^d_t \right) \] (11)

\[ q_t = q^e_t + v (1 - \varphi) \left( \varepsilon^m_t - \varepsilon^s_t + \alpha \gamma \varepsilon^d_t \right) \] (12)

\[ y_t = y^s_t + (\eta + \sigma) v (1 - \varphi) \left( \varepsilon^m_t - \varepsilon^s_t + \gamma \varepsilon^d_t \right) \] (13)

where \( \alpha \equiv \lambda (1 + \lambda)^{-1} (\eta + \sigma)^{-1}, v \equiv (1 + \lambda) (\lambda + \sigma + \eta)^{-1} \).

Equations (11), (12) and (13) describe the evolution of relative price levels, the real exchange rate and relative output in the short run, when the economy is characterized by a certain degree of price sluggishness, such that \( 1 < \varphi < 0 \). The predictions of the model are the following.

In response to a positive monetary shock, relative output and relative prices increase and the exchange rate depreciates. A demand shock leads to an increase in output and relative prices and an appreciation of the real exchange rate. In response to a supply shock relative output increases, relative prices decrease and the real exchange rate depreciates. These restrictions, summarized in Table 1 below, refer to the short-run impact of the three shocks on the main variables of interest.\(^2\)

\(^1\)For details on the derivation of the model see Clarida and Gali (1994).

\(^2\)In the data the real effective exchange rate is expressed as the number of foreign currency per unit of domestic currency. Thus, an appreciation (depreciation) of the dollar implies an increase (reduction) of the real exchange rate.
Table 1. Identification of shocks through short-run sign restrictions

<table>
<thead>
<tr>
<th>Shock</th>
<th>( y - y^* )</th>
<th>( p - p^* )</th>
<th>( q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Demand</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Nominal</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

These restrictions are sufficient to identify the three shocks of interest and are also consistent with a broad class of theoretical models. In the next section I will incorporate the sign restrictions into an empirical model in order to shed light on the sources of real exchange rate fluctuations.

3 VAR model and Identification

I am interested in analyzing the impact of nominal shocks on the real exchange rate avoiding the problems arising from imposing arbitrary restrictions. As noted by Paustian (2007), VARs are completely atheoretical. Thus, if an atheoretical reduced form is combined with weak identifying restrictions, one can not expect to uniquely pin down the impulse responses of interest. In order to obtain clear cut answers a large number restrictions should be imposed. Thus, even if I am interested in identifying the impact of nominal shocks on the real exchange rate, I estimate a broader set of shocks, both nominal and real, using the theoretical restrictions derived from a conventional open economy model outlined in the previous section. The identification of more than one shock will help to obtain a more precise estimate of the impact of the shock of interest. When only one shock is identified, for example a monetary policy shock, impulse responses that satisfy the restrictions of the monetary policy shock are accepted even if the responses to other shocks are unreasonable. This issue is avoided when more than one shock is identified because only the set of impulse responses that jointly satisfy all the restrictions for all shocks are accepted.

I follow the approach based on sign restrictions developed by Faust (1998), Canova and de Nicoló (2002) and Uhlig (2005). These papers are based on the identification of one shock, a monetary policy shock. Since I am interested in identifying a full set of shocks, I employ a methodology that extends the sign restriction approach to identify more than one shock. In particular, I apply the method described in Fry and Pagan (2007), who highlight some conceptual problems arising from the multiplicity of impulse vectors. Their approach builds on Mountord and Uhlig (2005) and Peersman (2005).
3.1 VAR Model

Consider the reduced form VAR

\[ Y_t = c + B(L)Y_{t-1} + A\epsilon_t \]

where \( c \) is an \( N \times 2 \) matrix of constants and linear trends, \( Y_t \) is an \( N \times 1 \) vector of endogenous variables; \( B(L) \) is a matrix polynomial in the lag operator \( L \); \( \epsilon_t \) is an \( N \times 1 \) vector of structural innovations. The endogenous variables \( Y_t \) that we include in the VAR are the first difference of relative output (\( \Delta y_t \)), the first difference of relative prices (\( \Delta p_t \)) and the first difference of the real exchange rate (\( \Delta q_t \)).

My aim is to identify three types of innovations: a supply, a demand and a monetary shock, \( \epsilon_t = [s \ d \ m] \). I identify these shocks using a sign restriction approach. In the next subsection I discuss the motivation for using this methodology and explain the estimation procedure.

3.1.1 Sign restriction approach

Conventional estimation techniques used to identify VAR models have a series of shortcomings. Methods involving zero-short run restrictions, such as the Choleski decomposition, have been questioned on various grounds. Firstly, they are usually derived from some arbitrary assumptions which may be difficult to reconcile with theoretical models. For example, the assumption of zero contemporaneous impact of a monetary policy shock on output is in contrast with some general equilibrium models (see Canova and Pina, 1999). Secondly, they sometimes yield counter-intuitive impulse response functions of key endogenous variables which are not easy to rationalize on the basis of conventional economic theory. An example is the so called price puzzle, which refers to the increase in prices after a monetary tightening (see Sims and Zha, 2006; Christiano, Eichenbaum and Evans, 1999; Kim and Roubini, 2000). Thirdly, as noted by Sarno and Thornton (2004), the results are often sensitive to the ordering of the variables.

Although long-run restrictions are often better justified by economic theory, there seem to be cases in which the block diagonality involved in the Blanchard-Quah decomposition is based on subtle assumptions regarding which variables affect others in the long run. In the same way as in the case of the Choleski decomposition, sometimes the impulse responses contradict predictions of the theoretical model. In addition, Faust and Leeper (1997) show that substantial distortions can arise due to small sample biases and measurement errors when using long-run restrictions.

In order to overcome the potential problems of the previous methods, I use an alternative identification procedure based on sign restrictions. Faust (1998), Canova and de Nicoló (2002) and

Since the shocks are assumed to be orthogonal, so that $E[\epsilon_t \epsilon_t'] = I$, the variance-covariance matrix of equation (14) is equal to: $\Sigma = AA'$. For any orthogonal decomposition of $A$, we can find an infinite number of possible orthogonal decomposition of $\Sigma$, such that $\Sigma = AQQ'A'$, where $Q$ is any orthonormal matrix ($QQ' = I$). A Choleski decomposition, for example, would assume a recursive structure on $A$ so that $A$ is lower triangular. Another candidate for $A$ is the eigenvalue-eigenvector decomposition, $\Sigma = PDP' = AA'$, where $P$ is a matrix of eigenvectors, $D$ is a diagonal matrix of eigenvalues and $A = PD^{1/2}$. This decomposition generates orthonormal shocks, making the value of $P$ unique for each variance-covariance matrix decomposition without imposing zero restrictions. Following Canova and de Nicoló (2002), I consider $P = \prod_{m=1}^{N-1} \prod_{n=m+1}^{N} Q_{m,n}(\theta)$, where $Q_{m,n}(\theta)$ is an orthonormal rotational matrix of the form:

$$Q_{m,n} = \begin{bmatrix}
1 & 0 & \cdots & 0 & 0 \\
\cos(\theta) & -\sin(\theta) & \cdots & 0 & 0 \\
\cdots & \cdots & \cdots & \cdots & \cdots \\
0 & \sin(\theta) & \cdots & \cos(\theta) & 0 \\
0 & 0 & \cdots & 0 & 1
\end{bmatrix}$$

(15)

where $(m,n)$ indicate that the rows $m$ and $n$ are being rotated by the angle $\theta$.

In a 3 variable model we have a 3x3 rotational matrix $Q$ and 3 bivariate rotations. The angles $\theta = \theta_1, \ldots, \theta_3$, and the rows $m$ and $n$ are rotated such that

$$P = \begin{bmatrix}
\cos(\theta_1) & -\sin(\theta_1) & 0 \\
\sin(\theta_1) & \cos(\theta_1) & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos(\theta_2) & -\sin(\theta_2) \\
0 & \sin(\theta_2) & \cos(\theta_2)
\end{bmatrix} \begin{bmatrix}
\cos(\theta_3) & 0 & -\sin(\theta_3) \\
0 & 1 & 0 \\
\sin(\theta_3) & 0 & \cos(\theta_3)
\end{bmatrix}$$

My estimation strategy follows Fry and Pagan (2007) and Peersman (2005) and is carried out as follows. Firstly, all possible rotations are produced by varying the rotation angles $\theta_1, \theta_2, \theta_3$ in the range $[0, \pi]$. For practical purposes, I grid the interval $[0, \pi]$ into $M$ points. After estimating the coefficients of the $B(L)$ matrix using ordinary least squares (OLS), the impulse responses of $N$ variables up to $K$ horizons can be calculated for the contemporaneous impact matrix, $A_j (j = 1, \ldots, M^3)$ as follows:

$$R_{j,t+k} = [I - B(L)]^{-1} A_j \epsilon_t$$

(16)

In general terms, we have a total of $N(N-1)/2$, where $N$ is the number of variables.
where $R_{j,t+k}$ is the matrix of impulse responses at horizon $k$. In order to identify the shock $v$ of
interest, sign restrictions can be imposed on $p$ variables over the horizon $0, ..., K$ in the form:

$$R_{j,t+k}^p v \leq 0$$  \hspace{1cm} (17)

I am interested in identifying three shocks: a supply shock, a demand shock and a monetary
shock. The sign restrictions are imposed based on the Clarida-Gali open economy model as sum-
marized in table 1 over the time horizon $k = 0, ..., K$. Details about the number of periods for
which the restrictions hold are given below.

To identify a supply shock, $s$, I impose that relative output does not decrease, relative prices
do not increase for four quarters ($k = 4$) and that the real exchange rate does not appreciate for
one quarter ($k = 1$):

$$R_{1s}^{j,t+k} \geq 0, \ k = 0, ..., 4$$
$$R_{2s}^{j,t+k} \leq 0, \ k = 0, ..., 4$$
$$R_{3s}^{j,t+k} \leq 0, \ k = 0, 1$$

The restrictions to identify a demand shock, $d$, are that relative output and relative prices do
not decrease for four quarters and that the real exchange rate does not depreciate for one quarter:

$$R_{1d}^{j,t+k} \geq 0, \ k = 0, ..., 4$$
$$R_{2d}^{j,t+k} \geq 0, \ k = 0, ..., 4$$
$$R_{3d}^{j,t+k} \geq 0, \ k = 0, 1$$

A monetary policy shock, $m$, is identified by restricting relative output and relative prices not
to decrease for four quarters and the real exchange rate not to appreciate for one quarter:

$$R_{1m}^{j,t+k} \geq 0, \ k = 0, ..., 4$$
$$R_{2m}^{j,t+k} \geq 0, \ k = 0, ..., 4$$
$$R_{3m}^{j,t+k} \leq 0, \ k = 0, 1$$

\footnote{Changing the values of the number of quarters for which the restrictions are binding has no effect on the conclusions of the results.}
Out of all possible rotations I select those that satisfy the sign restrictions of the impulse responses of the three shocks. Impulse responses are constructed using a Monte Carlo experiment. For each Monte Carlo draw, I draw one rotation out of all possible rotations and check if the imposed restrictions are satisfied for all shocks. Solutions that satisfy all the restrictions are kept and the others are discarded. In practice I repeat this procedure until 1000 draws satisfying the restrictions are found.

3.1.2 Summarizing the information

A common way to present the information is by reporting the median of the impulse responses based on a certain number of solutions. As noted by Fry and Pagan (2007), this may not provide a useful measure. Let us consider as an example the responses of two variables to one shock. Say that $\tau_1(i)$ represents the impulse responses of variable 1 and $\tau_2(i)$ represents the impulse responses of variable 2, where $i$ indexes the values of $\theta$. What is usually presented is $med((\tau_1(i)))$ and $med((\tau_2(i)))$. If $\tau_q(i)$ was monotonic in $\theta$, this would be $\tau_q(med(\theta(i)))$. Thus, the median of the impulse responses would be generated by the same model, represented by $med(\theta(i))$. Given that there is no guarantee of monotonicity, the median of the impulse responses will generally be associated with different values of $\theta$. Thus, the median of the impulse responses will not come from a single model. This will happen for the impulse responses for all variables and for all shocks. As a consequence, the shocks identified are no longer orthogonal to each other. Apart from the fact that the assumption of uncorrelated shocks is essential to estimate a VAR model, if correlations are non-zero, the variance decomposition does not exist.\footnote{This problem remains even if there is only a single shock, as in Uhlig (2005), since there is nothing that ensures it is uncorrelated with the remaining shocks in the model whenever we take the impulse responses from different models.}

Fry and Pagan (2007) suggest locating a unique vector of $\theta$’s such that the impulses are closest to its median while maintaining the orthogonality condition. Firstly, impulse responses are calculated based on those that satisfy the sign restrictions. Given that the impulse responses are not unit free, they are standarized by subtracting their median and dividing by their standard deviation. These standarized impulse responses are included in a vector $\phi_i$ for each value of $\theta_i$ (in the 2 variable case below $\phi$ is a $4 \times 1$ vector as there are 4 impulse responses. The choice of $\theta$ is the one that minimizes the following quantity.

$$\Psi(\theta_i) = \phi_i' \phi_i$$  \hspace{1cm} (18)
Substituting $\theta_{\text{min}}$ into $Q(\theta)$ will produce a set of orthogonal shocks and the descriptive statistics are computed based on this rotation.

4 Data

I use quarterly data over the period 1976-2006. The “rest of the world” (hereafter ROW) series include an aggregate of the other G7 countries (except the US) and another OECD economy (Australia) and are identified by an asterisk in our notation.\footnote{These 8 countries add up to roughly half of world GDP at PPP values, so they represent a substantial sample of the global economy. Moreover, trade flows among them also amount to over a half of their respective total trade, on average.}

All the series are taken from the International Financial Statistics (IFS) of the International Monetary Fund (IMF). The data on real GDPs are seasonally adjusted in local currencies at 2000 price levels. I convert the GDP series in local currencies to US dollars using the average market exchange rate of 2000 (I do this to preserve consistency with the prices base year and to avoid mixing changes in real GDP with changes in the value of the dollar). As explained in the previous section, the US real GDP ($y$) is measured in deviation from GDP in the ROW ($y^*$), which is the sum of output in the other G7 plus Australia. Price series correspond to the consumer price index (CPI) and interest rates are federal funds rates for the US and 3-month money market rates for the other countries.\footnote{I prefer to use the federal funds rates for the US given that it is the one commonly used in previous studies (see Uhlig, 2006). The results do not vary when I consider the 3-month treasury bill rate for the US.}

The series $p^*$ and $i^*$ are calculated respectively, as an aggregate of prices and interest rates in the ROW weighted according to their respective (time-varying) GDP shares at PPP values. The GDPs used for calculating the weights are at price levels and PPP values of 2000 and obtained from the OECD. The real effective exchange rate corresponds to the REU series of the IFS. All the series are plotted in Figure 1.

Table A1 in the appendix reports the results of the Augmented Dickey-Fuller (ADF) and Kwiatkowski et al. (1992; KPSS) unit root tests. The ADF test fails to reject the unit root null hypothesis and the KPSS test rejects the trend-stationary null for the levels of relative output, relative prices and real effective exchange rate. Inference is mixed for the level of relative interest rates given that there is evidence of trend-stationarity from one of the ADF tests and the KPSS test. By contrast, all variables are trend-stationary in first differences.

The Clarida-Gali model implies that there are no cointegration relationships among the levels of the variables. Table A2 in the appendix attends to this. It shows the results of the Johansen (1991) test for the number of cointegrating vectors. According to the trace test, the null of no
cointegration vectors cannot be rejected both for the baseline and the extended model. Overall, these results suggest estimating the VARs in first differences.

5 Results Baseline Model

5.1 Impulse Response Analysis

I now turn to the empirical findings, by presenting the benchmark results from implementing the VAR described in Section 3.

Figure 2 shows the impulse responses of relative output, relative inflation and the exchange rate with respect to the three shocks of interest. The impulse responses suggest that a supply shock leads to a persistent depreciation of the real exchange rate. More precisely, the US dollar depreciates 0.5% on impact and it continues to decline until it reaches a depreciation of 1.3% after 9 quarters. In addition, a supply shock generates a persistent increase in relative output and a persistent decrease in relative prices.

After a demand shock, there is a persistent rise of around 0.8% in relative output. By contrast, there is a temporary effect on relative prices, which increase 0.07% on impact. The real exchange rate appreciates 2% on impact and it continues to rise up to 3.7% after 9 quarters.

Finally, a monetary policy (or nominal) shock leads to a temporary depreciation of the US dollar. After an initial depreciation of 2%, the real exchange rate reaches its minimum value after 3 quarters and then reverts to equilibrium (consistent with PPP), showing no statistically significant reaction after 10 quarters. This result supports the delayed overshooting conclusion given that the peak is not immediate as predicted in Dornbusch (1976). A monetary shock also leads to a temporary positive effect on relative output (it increases 0.5% on impact and shows no significant reaction after 6 quarters) and a persistent rise in relative prices, which increase by 1% after 9 quarters.

The long-run predictions of the Clarida-Gali model are satisfied empirically except for the impact of a demand shock on relative output. According to the theoretical model, only supply shocks influence the long run level of output. However, the empirical results show that demand shocks also have a persistent effect on output.

5.2 Variance Decomposition

The variance decomposition can be used to assess how much of the variance of the real exchange rate is given by supply, demand and monetary shocks over different forecast horizons. The results,
given in Table 2, show that a substantial share of the variation in the real exchange rate is explained by monetary shocks over short horizons but at long horizons their relative importance is reduced. Indeed, at a 4 quarters horizon the contribution of monetary policy shocks to real exchange rate fluctuations is 47%. At a horizon of 20 quarters only 20% of the variation of the real exchange rate is explained by monetary policy shocks. By contrast, demand shocks explain a substantial proportion of the variance of the real exchange rate both at short and long horizons (50% and 70% at a horizon of 4 quarters and 20 quarters respectively). The results also show that supply shocks play a minimal role in explaining real exchange rate fluctuations. In particular, I find that supply shocks explain 0.03%, 0.07% and 0.10% of the movement in the real exchange rate at a 4 quarters, 12 quarters and 20 quarters respectively.

### Table 2. Variance Decomposition of the Real Effective Exchange Rate

<table>
<thead>
<tr>
<th>Steps</th>
<th>Supply</th>
<th>Demand</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 quarters</td>
<td>0.03</td>
<td>0.50</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>[0.00 ; 0.11]</td>
<td>[0.24 ; 0.71]</td>
<td>[0.23 ; 0.71]</td>
</tr>
<tr>
<td>8 quarters</td>
<td>0.05</td>
<td>0.58</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>[0.01 ; 0.14]</td>
<td>[0.31 ; 0.80]</td>
<td>[0.14 ; 0.61]</td>
</tr>
<tr>
<td>12 quarters</td>
<td>0.07</td>
<td>0.65</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>[0.01 ; 0.17]</td>
<td>[0.35 ; 0.84]</td>
<td>[0.09 ; 0.54]</td>
</tr>
<tr>
<td>16 quarters</td>
<td>0.08</td>
<td>0.68</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>[0.01 ; 0.19]</td>
<td>[0.39 ; 0.86]</td>
<td>[0.07 ; 0.48]</td>
</tr>
<tr>
<td>20 quarters</td>
<td>0.10</td>
<td>0.70</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>[0.01 ; 0.20]</td>
<td>[0.42 ; 0.87]</td>
<td>[0.06 ; 0.44]</td>
</tr>
</tbody>
</table>

**Notes:** The table shows the percentage of the error variance of the real effective exchange rate due to each shock at 4, 8, 12, 16 and 20 quarter horizons. Lag length is 4. In brackets are the 16th and 84th quantiles.

In summary, the findings of the analysis of the variance decomposition indicate that demand shocks have been the main determinant of real exchange rate fluctuations both at short and long horizons. By contrast, monetary policy shocks have been an important driver of the real exchange rate over short horizons but at longer horizons they become less relevant. This result is consistent with the theoretical model in that monetary policy shocks have transitory effects on the exchange rate. Thus, most if its impact should be materialized in the short run.

### 5.3 Interpreting Real Exchange Rate Fluctuations

Variance decompositions reveal which shocks are important in explaining the variance of the real exchange rate across different horizons. However, this measure does not provide a complete picture of the nature of real exchange rate fluctuations. In order to relate the sources of exchange rate
movements with economic factors it is useful to analyze the contribution of each of the shocks to the real exchange rate.

The time series of the shocks is presented in Figure 3 and Figure 4 shows the historical decomposition of the real exchange rate for the period 1976:1 to 2006:4.

From the graph of the real effective exchange rate in Figure 1, it is possible to distinguish a first episode of dollar depreciation between 1978 and 1980. The historical decomposition shows that monetary policy shocks were the main drivers of exchange rate fluctuations during this episode.

Between 1980 to 1985 the dollar appreciates significantly. As described in Obstfeld (1995), observers differ as to whether important shifts in fundamental factors such as the Volcker disinflation, the Reagan fiscal expansion and the fiscal contraction outside the US can explain this rise. The historical decomposition allows us to distinguish the contribution of monetary policy and demand shocks to the real exchange rate increase. The Volcker disinflation is clearly linked with a monetary policy shock and the fiscal expansion in the US and fiscal contraction abroad is associated with a demand shock. Figure 4 shows that monetary policy shocks play a dominant role in the dollar appreciation at the beginning of this period and demand shocks become the main contributor to exchange rate movements between 1983 and 1985. The relative importance of monetary policy shocks may be attenuated due to the fact that as a result of the dollar appreciation, other industrialized countries faced depreciating currencies and inflationary pressures. The policy response to this was a contractive monetary policy and consequent interest rate increases, which lowers the magnitude of the interest rate differential.

In the period from 1986 until 1988 the dollar declined significantly. This period is usually not identified as one of dollar weakness if one considers its value with respect to the 1976-2006 average. However, there is a decline with respect to the previous episode of appreciation. Figure 4 shows that both monetary and demand shocks played an important role in explaining the real exchange rate movement during this episode. This pattern squares very well with some events that took place during this period. In October 1987 there was a US and global stock market collapse which should have lead to a decrease in demand. In response to the crash the Fed decreased interest rates.

Between 1989 and 1995 the dollar was more stable than in the previous ten years. The decline from 1990 to 1991 is mainly due to demand shocks given that the US economy moved into a mild recession during this period in the context of the Gulf War. A further decline of the dollar took place within the ERM crisis of 1992-1993.

Starting in 1995, there is a continuous increase in the value of the dollar until 2002. The historical decomposition reveals that this was mainly due to positive demand shocks and that the
contribution of monetary policy shocks was much less important between 1995 and 2000. Many observers in fact highlighted that initially the dollar strength during this period was associated with a healthy US economy and strong demand (see Truman, 2006).

6 Extended Model

In this section I include the interest rate differential into the VAR of section 3 to check for the robustness of my results. In the baseline specification the nominal shock is the monetary shock. By extending the model I can now break down the nominal shock into monetary and pure exchange rate shocks. The motivation for doing this is the following. It is clear that part of the exchange rate fluctuations can be due to a reaction of exchange rates to monetary policy shocks. However, as highlighted by Artis and Ehrmann (2000), Peersman and Farrant (2006) and Fratzscher, Juvenal and Sarno (2007), exchange rates can also be driven by pure exchange rate shocks. These shocks can be interpreted as steaming from a time varying risk premium or by fluctuations that can not be explained by fundamentals. Related to the latter, Truman (2006, p.203-204) notes:

“The G-7 finance ministers and the central bank governors on April 25, 1995, ‘agreed that recent movements [in real exchange rates] have gone beyond the levels justified by underlying economic conditions in the major countries.’[...] If this reading is accepted, it might be said that the US authorities in cooperation with their counterparts successfully dealt with a bubble.”

In order to be able to identify monetary policy and exchange rate shocks I now include an additional variable, the interest rate differential ($i_t$). Thus, $Y_t = \left[ \Delta y_t \Delta p_t \Delta q_t \right]$. My aim is to identify four types of innovations: a supply, a demand, a monetary and a pure exchange rate shock, $\epsilon'_t = \left[ r^s \Delta r^d \Delta m^e \Delta v^e \right]$. These four shocks can be identified including some additional restrictions. These restrictions, shown in table 3, are in line with the aggregate supply-demand diagram and also confirm the conventional undergraduate textbook intuition.

<table>
<thead>
<tr>
<th>Shock</th>
<th>$y - y^*$</th>
<th>$p - p^*$</th>
<th>$i - i^*$</th>
<th>$q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Demand</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Monetary</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Exchange Rate</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
</tbody>
</table>

The restrictions imposed for relative output, relative prices and real exchange rate are the same as in table 1. In order to identify the four shocks of interest I added the following additional restrictions. Firstly, I impose that the interest rate differential does not increase after a supply and
monetary shock. Secondly, I restrict the interest rate differential not to decrease after a demand shock. Finally, the restrictions imposed to identify a depreciation shock are that the real exchange rate does not increase (i.e. does not appreciate) and that relative output, relative prices and relative interest rate differential do not decrease. The rationale for these restrictions stems from the perspective of a monetary policy reaction function: an exogenous depreciation should raise import prices and domestic inflation, thus requiring an increase in domestic short-term interest rates. The restriction on output is based on the conventional Mundell-Fleming model that predicts an expansionary effect of a depreciation on output through expenditure switching effects. I assume that the restrictions for relative output and relative prices are binding for four quarters (\(k = 4\)) and that the restrictions for relative interest rate and real exchange rate are binding for 1 quarter (\(k = 1\)).

I estimate the model applying the same methodology as the one described in Section 3 for the case of a 4 variables VAR and 4 shocks. In a 4 variables model we have 4x4 rotational matrix \(Q\) and 6 bivariate rotations. The angles \(\theta = \theta_1, \ldots, \theta_6\), and the rows \(m\) and \(n\) are rotated by the angle \(\theta_i\) as shown in (3).\(^8\) The rest of the estimation is carried out as before. I present the results based on the minimization of the distance with respect to the median and the 16th and 84th quantiles.

Figure 5 shows the impulse responses of relative output, relative inflation, relative interest rates and the exchange rate with respect to the four shocks of interest. The responses to a supply and demand shocks are very similar to the ones of the three variable VAR. The only point to highlight is that supply and demand shocks have a temporary impact on the relative interest rate (a supply shock decreases the relative interest rate and a demand shock increases it).

In line with the baseline estimation, after an expansionary monetary policy shock the real exchange rate depreciates, reaching a minimum after 3 quarters and then reverts to equilibrium (consistent with PPP). The effects of a monetary policy shock are insignificant after eight quarters. By and large, the behavior of the real exchange rate is consistent with the delayed overshooting hypothesis. I also find that a monetary policy shock has a temporary effect on relative output and relative interest rate differential. By contrast, relative prices show a persistent response to

\[^8\text{In this case, } P = \begin{bmatrix}
\cos(\theta_1) & -\sin(\theta_1) & 0 & 0 \\
\sin(\theta_1) & \cos(\theta_1) & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos(\theta_2) & -\sin(\theta_2) & 0 \\
0 & \sin(\theta_2) & \cos(\theta_2) & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
\cos(\theta_3) & 0 & -\sin(\theta_3) & 0 \\
0 & 1 & 0 & 0 \\
0 & \sin(\theta_4) & \cos(\theta_4) & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
\cos(\theta_4) & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
\sin(\theta_4) & 0 & \cos(\theta_4) & 0 \\
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos(\theta_5) & -\sin(\theta_5) & 0 \\
0 & \sin(\theta_5) & \cos(\theta_5) & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & \cos(\theta_6) & -\sin(\theta_6) \\
0 & 0 & \sin(\theta_6) & \cos(\theta_6) \\
\end{bmatrix}\]
\]
monetary policy shocks.

The impulse responses suggest that an exchange rate shock (a depreciation of the US dollar) temporary increases relative output, the relative interest rate and relative prices. After the initial depreciation, the real exchange rate gradually reverts back to its mean, consistent with PPP. In fact, the reaction of the real exchange rate becomes insignificant after eight quarters. One important point to highlight is that the interaction between interest rates and exchange rates resembles the dynamics implied by the forward discount bias, extensively documented in empirical work on exchange rates (Fama, 1984; Engel, 1996). To see this, note that the negative real exchange rate shock induces an upward movement in interest rates, which according to uncovered interest rate parity (UIP) should imply expectations of a subsequent currency depreciation. However, the US dollar appreciates after the initial depreciation, consistent with the presence of a forward discount bias. One interpretation of the interest rate response is that it is in line with a monetary policy reaction function – in particular as the interest rates are short-term rates, controlled by the central bank. Hence, domestic interest rates are raised by the monetary authority after a currency depreciation due to higher inflationary pressures and are then subsequently lowered as prices decrease.

Note that the relationship between interest rates and exchange rates is different when we consider a monetary policy and exchange rate shock. In the case of a monetary policy shock, it is the reduction in interest rates that triggers a depreciation. By contrast, in the case of exchange rates shocks, the depreciation of the exchange rate generates inflationary pressures that lead to interest rate increases.

Table 4 shows the results of the variance decomposition of the real exchange rate. The contributions of supply and demand shocks are very similar to those of the three variable VAR. Interestingly, exchange rate shocks play an important role in explaining real exchange rate fluctuations in the short run. In particular, at a 4 quarters horizons, 27% of the variability of the real exchange rate is explained by real exchange rates shocks. At a 20 quarters horizons the role of pure exchange rate shocks is very limited, explaining only 11% of exchange rate fluctuations (the same a supply shocks). The results also show that the relative importance of monetary policy shocks is higher in the short run and attenuated at longer horizons. Indeed, 23% of the fluctuations of the real exchange rate is explained by monetary shocks at a horizon of 4 quarters. At a horizon of 8 and 20 quarters, 22% and 14% of the variation of the real exchange rate is explained by monetary policy shocks, respectively.
Table 4. Variance Decomposition of the Real Effective Exchange Rate

<table>
<thead>
<tr>
<th>Steps</th>
<th>Supply</th>
<th>Demand</th>
<th>Monetary</th>
<th>Exchange Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 quarters</td>
<td>0.02</td>
<td>0.48</td>
<td>0.23</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>[0.00; 0.08]</td>
<td>[0.28; 0.70]</td>
<td>[0.03; 0.45]</td>
<td>[0.07; 0.51]</td>
</tr>
<tr>
<td>8 quarters</td>
<td>0.05</td>
<td>0.55</td>
<td>0.22</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>[0.02; 0.14]</td>
<td>[0.35; 0.77]</td>
<td>[0.02; 0.44]</td>
<td>[0.04; 0.39]</td>
</tr>
<tr>
<td>12 quarters</td>
<td>0.07</td>
<td>0.60</td>
<td>0.20</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>[0.02; 0.18]</td>
<td>[0.40; 0.80]</td>
<td>[0.02; 0.39]</td>
<td>[0.04; 0.31]</td>
</tr>
<tr>
<td>16 quarters</td>
<td>0.09</td>
<td>0.63</td>
<td>0.16</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>[0.02; 0.21]</td>
<td>[0.42; 0.81]</td>
<td>[0.02; 0.32]</td>
<td>[0.04; 0.26]</td>
</tr>
<tr>
<td>20 quarters</td>
<td>0.10</td>
<td>0.65</td>
<td>0.14</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>[0.02; 0.22]</td>
<td>[0.43; 0.81]</td>
<td>[0.02; 0.31]</td>
<td>[0.04; 0.26]</td>
</tr>
</tbody>
</table>

Notes: See table 2.

Overall, I find that demand shocks have been the main determinant of real exchange rate fluctuations both at short and long horizons. Although the importance of monetary shocks is reduced in the four variables model, their contribution is significant and they explain a higher proportion of exchange rate fluctuations than pure exchange rate shocks. Given that the contribution of real shocks remains similar between both specifications, it is possible to argue that pure exchange rate shocks have a nominal nature. Thus, the results highlight the relevance of separating the nominal shock into monetary and pure exchange rate shocks.

The time series of the shocks, presented in Figure 6, shows that the volatility of monetary policy shocks was pronounced between 1976-1991 and decreased significantly afterwards. This shock displays a significant negative movement in 1979, around one of the so-called Romer and Romer dates. The exchange rate shock shows two episodes of significant negative disturbances: in correspondence with the Plaza Agreement (1985) and during the ERM crisis in 1992-1993. Given this pattern, it seems relevant to carry out a sub-sample analysis, which is presented in the next section.

7 Robustness: estimating alternative models

Empirical results often depend on modelling assumptions and variables definitions. Thus, in this section I estimate different VAR specifications and I also use alternative variables definitions to assess the robustness of my results.

7.1 Sub-Sample analysis

Financial markets in the G7 countries have witnessed substantial changes over the sample period. For example, capital controls have been gradually eliminated during the 1980s. These changes may
have affected the way monetary policy shocks are transmitted into the economy. Thus, I divide the
period in two sub-samples (1976:1-1989:4 and 1990:1-2006:4) and estimate the impulse responses for
each of them in order to check whether regime shifts change the results. The advantage of breaking
the sample is that I avoid mixing periods with different structural characteristics. However, this
comes with a cost. The estimation of the impulse responses is more likely to be imprecise and the
shocks more difficult to detect. I choose 1990 as the split between the two samples given that it
could be defined as the starting point for the recent wave of financial globalization.

Impulse responses are shown in figures 7.A. and 7.B. For the first sub-sample, impulse responses
mirror those obtained for the full sample. The only difference that emerges is that the short-run
contribution of nominal shocks increases with respect to the baseline case (the variance decompo-
sition is not shown here to preserve space but is available upon request).

In the second sub-sample, nominal shocks appear to have a weaker effect on the real exchange
rate. In fact, the real exchange rate shows no statistically significant reaction to nominal shocks
after 5 quarters. The relative contribution of nominal shocks to real exchange rate fluctuations
declines for this period.

When estimating the 4 variable VAR for the two sub-samples, I find consistent results with
respect to the 3 variable VAR.

7.2 Alternative exchange rate measure

I test for the sensitivity of the results by using the real effective exchange rate taken from the US
Federal Board Reserve Statistics instead of the one sourced from the IFS. As shown in Figure 8
the results are not sensitive to using different measures of the real effective real exchange rate.
The impact of each of the shocks to the variables of the system is only marginally affected. The
variance decomposition of the nominal effective exchange rate (not presented here to preserve space
but available upon request) is very similar to that of the real effective exchange rate.

7.3 Other Methods

In order to gain a further understanding of the sources of real exchange rates fluctuations, it is
informative to identify the shocks using other methods. In particular, I use the structural VAR
framework of Blanchard and Quah as in Clarida and Gali (1994) and also examine the impact of
monetary shocks using zero short-run restrictions in the same fashion as Eichenbaum and Evans
(1995). The latter identification strategy is based on zero short-run restrictions, which is different
from Clarida-Gali or even the sign restriction approach, but it is illustrative to analyze it and
compare the results with the other techniques. I highlight that these identification strategies lead to significant “puzzles”, thus casting doubt on their validity.

### 7.3.1 Clarida and Gali (1994) approach

The open economy macro model described in section 2 is triangular in the long-run. Thus, it is possible to impose zero-long run restrictions to identify supply, demand and nominal shocks. The restrictions originate in the fact that supply shocks are expected to influence output in the long run, while both supply and demand shocks have an impact on the real exchange rate in the long run.

Demand shocks are identified by assuming that such shocks do not have an impact on relative output in the long run. Nominal shocks are restricted not to have an impact on relative output and the real exchange rate in the long run.

Figure 9 shows the impulse responses to a supply, demand and nominal shock using long-run restrictions in the same fashion as Clarida and Gali (1994). The results differ with respect to the sign restriction approach in the following. Firstly, using long-run restrictions, the real exchange rate exhibits a temporary appreciation after a supply shock. This result is in contrast with the predictions of the Clarida and Gali (1994) theoretical model. This puzzle is avoided in the sign restriction approach by imposing that the real exchange rate does not appreciate after a supply shock. Secondly, consistent with the theoretical model, demand shocks lead to a temporary increase in relative output when using long-run restrictions. This result is obtained by construction, because demand shocks are restricted not to affect relative output in the long run. Finally, the responses to a monetary policy shock are similar using the two identification schemes. However, when the monetary policy shock is identified using long-run restrictions, the exchange rate overshoots its long-run value almost immediately (in one quarter) in contrast to the three quarters delayed overshooting found with the sign restriction approach.

Table 5 compares the variance decomposition of the real exchange rate using the Clarida and Gali (CG) methodology and the sign restrictions (SR) presented before.
From table 5 it is clear that there is a stark difference in the results from both identification procedures. Using long-run restrictions in the same fashion as Clarida and Gali (1994) leads to the conclusion that nominal shocks are unimportant to explain real exchange rates fluctuations. Indeed the contribution of nominal shocks to real exchange rate fluctuations ranges between 7% and 1% at a 4 quarter and 20 quarter horizon, respectively. By contrast, according to the sign restriction approach, nominal shocks explain 47% of real exchange rate fluctuations at a 4 quarters horizon and 20% at a 20 quarters horizon. In the Clarida and Gali identification scheme, demand shocks are the main driver of the real exchange rate. At a horizon of 4 and 20 quarters, 86% and 93% of the variation of the real exchange rate is explained by demand shocks, respectively.

### 7.3.2 Zero short-run restrictions approach

Figure 10 shows the impulse responses using the Choleski decomposition. I identify the monetary policy and exchange rate shocks with innovations in the interest rate differential and the real exchange rate, respectively. The VAR model is estimated with the interest rate differential ordered third and the real exchange rate fourth.

The results show that a monetary contraction leads to a temporary appreciation of the real exchange rate. In contrast to the sign restriction method, overshooting occurs on impact. Interestingly, prices go up for two quarters and decrease afterwards. This response of prices to a monetary tightening resembles the so-called “price puzzle” pointed out by Sims (1992). The response of relative output is insignificant over all horizons.

Table 6 compares the variance decomposition of the real exchange rate due to monetary policy...
and exchange rate shocks using the Choleski Decomposition (CD) and the sign restrictions (SR) presented before.\(^9\)

<table>
<thead>
<tr>
<th>Steps</th>
<th>Monetay</th>
<th>Exchange Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 quarters</td>
<td>CD 0.10</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>SR 0.23</td>
<td>0.27</td>
</tr>
<tr>
<td>8 quarters</td>
<td>CD 0.10</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>SR 0.22</td>
<td>0.18</td>
</tr>
<tr>
<td>12 quarters</td>
<td>CD 0.10</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>SR 0.20</td>
<td>0.13</td>
</tr>
<tr>
<td>16 quarters</td>
<td>CD 0.10</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>SR 0.16</td>
<td>0.12</td>
</tr>
<tr>
<td>20 quarters</td>
<td>CD 0.10</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>SR 0.14</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Notes: See table 2.

The results from both identification methods differ substantially. According to the recursive approach real exchange rate fluctuations are mainly driven by pure exchange rate shocks. By contrast, monetary policy shocks only explain 10% of the movement of the real exchange rate at all horizons. Using the sign restriction approach, monetary policy shocks explain around 20% of the variability of the real exchange rate and pure exchange rate shocks are not the main driver of real exchange rate fluctuations.

8 Conclusion

The explanation of the sources of real exchange rate fluctuations is still an open area. There has been a widespread belief that monetary policy is the main driver of exchange rate movements. A great deal of theoretical literature has focused on confirming this belief. However, the empirical evidence on the role of monetary policy shocks has not given clear cut answers on the link between monetary policy and exchange rate movements. In addition, this work has often been criticized due to the lack of credible identifying assumptions.

This paper has focused on one specific question: How important are nominal and real shocks as drivers of the US real exchange rate? In order to address this question, this paper employs a

\(^9\)We only report these two shocks because it is hard to compare innovations in relative output and relative inflation with the shocks studied before.
VAR model with sign restrictions which identifies supply, demand and nominal shocks. The sign restrictions used to identify the shocks of interest are derived from a conventional open economy macro model. The main advantage of this method is that it avoids imposing arbitrary assumptions.

I find that demand shocks have been the main driver of exchange rate fluctuations. In fact, in the baseline VAR, 70% of the movements of the real dollar exchange rate can be accounted by demand shocks at a 20 quarters horizon. In the extended VAR model, demand shocks explain 65% of the real exchange rate movements at a 20 quarters horizon. The relative contribution of monetary shocks is higher in the short-run. In the baseline and extended model respectively they explain 47% and 23% of the fluctuations in the real exchange rate at a 4 quarters horizon. I also find that the response of monetary shocks is in line with UIP. In the extended model pure exchange rate shocks explain 27% of the movements in the real exchange rate at 4 quarters horizon. I highlight that these shocks lead to deviations from UIP.

These results have important implications. Firstly, even though monetary policy shocks are a significant driver of exchange rate fluctuations, they are not the most important one. In fact, demand shocks seem to play a leading role in explaining real exchange rate movements both in the short and long run. Thus, the high persistence of the real exchange rate should not be surprising. Secondly, nominal shocks have different implications depending on their nature. Monetary policy shocks lead to delayed overshooting. By contrast, pure exchange rate shocks imply an interaction between interest rates and exchange rates that is characterized by the forward discount bias. The literature has generally not separated between these two shocks but only analyzed the comovement between exchange rates and interest rate differentials. The lack of distinction between these two shocks could be one of the reasons why large UIP deviations are often found.

My paper also shows that conventional estimation techniques find that monetary shocks are unimportant. These results demonstrate how different models may give rise to different results. However, I highlight that conventional estimation strategies lead to significant “puzzles”, thus casting doubt on their validity. I take these findings as being part of the general criticism on the use of arbitrary assumptions when estimating VAR models.

An interesting extension would be the development of a theoretical model that allows for exchange rate shocks arising from, for example, information problems, and a disaggregation of real shocks into fiscal, trade and technology shocks. This framework may offer a promising set up to gain a further understanding on the sources of exchange rate fluctuations.
References


Figure 1. Data

Figure 2. Impulse Responses to Supply, Demand and Nominal Shocks based on Sign Restrictions (3-variable VAR)

Notes: The figure shows the Impulse Responses to a demand, supply and nominal shocks using sign restrictions. The solid lines are calculated based on the minimization of the distance with respect to the median as explained in section 3. The dashed lines represent the 16% and 84% quantiles.
Figure 3. Structural Shocks based on Sign Restrictions: 1976:01-2006:04 (3-variable VAR)

Figure 4. Contribution of Demand, Supply and Nominal Shocks to the Real Effective Exchange Rate based on Sign Restrictions
Figure 5. Impulse Responses to Supply, Demand, Monetary and Pure Exchange Rate Shocks based on Sign Restrictions
(4-variable VAR)

Notes: The figure shows the Impulse Responses to a demand, supply, monetary and exchange rate shocks using sign restrictions. The solid line is calculated based on the minimization of the distance with respect to the median as explained in section 3. The dashed lines represent the 16% and 84% quantiles.

Figure 6. Structural Shocks based on Sign Restrictions: 1976:01-2006:04
(4-variable VAR)
Figure 7.A. Impulse Responses to Supply, Demand and Nominal Shocks based on Sign Restrictions. Sub-sample: 1976:01-1989:04
(3-variable VAR)

Notes: The figure shows the Impulse Responses to a demand, supply and nominal shocks using sign restrictions. The solid lines are calculated based on the minimization of the distance with respect to the median as explained in section 3. The dashed lines represent the 16% and 84% quantiles.

Figure 7.B. Impulse Responses to Supply, Demand and Nominal Shocks based on Sign Restrictions. Sub-sample: 1990:01-2006:04
(3-variable VAR)

Notes: The figure shows the Impulse Responses to a demand, supply and nominal shocks using sign restrictions. The solid lines are calculated based on the minimization of the distance with respect to the median as explained in section 3. The dashed lines represent the 16% and 84% quantiles.
Figure 8. Impulse Responses to Supply, Demand and Nominal Shocks based on sign restrictions. Alternative REER (3-variable VAR)

Notes: The figure shows the Impulse Responses to a demand, supply and nominal shocks using sign restrictions when the model is specified using the nominal effective exchange rate. The solid lines are calculated based on the minimization of the distance with respect to the median as explained in section 3. The dashed lines represent the 16% and 84% quantiles.

Figure 9. Impulse Responses to Supply, Demand and Nominal Shocks based on Clarida-Gali identification (3-variable VAR)

Notes: The figure shows the Impulse Responses to a demand, supply and nominal shocks using the Clarida-Gali identification approach. The solid lines represent the point estimates and the dashed lines represent the 16% and 84% quantiles.
Notes: The figure shows the Impulse Responses to a demand, supply and nominal shocks using the Choleski decomposition. The solid lines represent the point estimates and the dashed lines represent the 16% and 84% quantiles.