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Monetary policy and exchange rate overshooting: Dornbusch was right after all ☆

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ABSTRACT

Dornbusch's exchange rate overshooting hypothesis is a central building block in international macroeconomics. Yet, empirical studies of monetary policy have typically found exchange rate effects that are inconsistent with overshooting. This puzzling result has been viewed by some researchers as a "stylized fact" to be reckoned with in policy modelling. However, many of these studies, in particular those using vector autoregressive (VARs) approaches, have disregarded the strong contemporaneous interaction between monetary policy and exchange rate movements by placing zero restrictions on them. In contrast, we achieve identification by imposing a long-run neutrality restriction on the real exchange rate, thereby allowing for contemporaneous interaction between the interest rate and the exchange rate. In a study of four open economies, we find that the puzzles disappear. In particular, a contractionary monetary policy shock has a strong effect on the exchange rate, which appreciates on impact. The maximum effect occurs within 1–2 quarters, and the exchange rate thereafter gradually depreciates to baseline, consistent with the Dornbusch overshooting hypothesis and with few exceptions consistent with uncovered interest parity (UIP).

1. Introduction

Dornbusch's (1976) well-known exchange rate overshooting hypothesis is a central building block in international macroeconomics, stating that an increase in the interest rate should cause the nominal exchange rate to appreciate instantaneously, and then depreciate in line with uncovered interest parity (UIP). Its influence is evident in the rapidly growing "New Open Economy Macroeconomics" (NOEM) literature (see Obstfeld and Rogoff, 1995, 2000) as well as in practical policy discussions spanning far outside the academic sphere. With what seems like an ever-increasing number of citations, it has been described as one of the most important papers in international economics of the twentieth century (Rogoff, 2002).

When confronted with data, however, few empirical studies that analyse the effects of monetary policy have found support for Dornbusch overshooting; see e.g. Sims (1992), Eichenbaum and Evans (1995) and Kim and Roubini (2000) for G7 countries, Peersman and Smets (2003) and Favero and Marcellino (2004) for the aggregate Euro area, Mojon and Peersman (2003) for individual Euro area countries and Lindé (2003) for Sweden. Instead, they have found that following a contractionary monetary policy shock, the real exchange rate either depreciates, or, if it appreciates, it does so only gradually and for a prolonged period of up to 3 years, thereby giving a hump-shaped response that violates UIP. In the literature, the first phenomenon has been termed the *exchange rate puzzle*, whereas the second has been referred to as *delayed overshooting* or the *forward discount puzzle*, see Cushman and Zha (1997). In light of all this evidence that is inconsistent with Dornbusch overshooting and UIP, one might expect the theory to have been abandoned by economists. Yet, this is not the case. Both the hypothesis of Dornbusch overshooting and the UIP remain at the core of theories of international economics. The elegance and clarity of

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the Dornbusch model as well as its obvious policy relevance has put it in a separate class from other international macroeconomic papers (Rogoff, 2002).

The common approach for establishing the quantitative effects of monetary policy in the above mentioned studies has been the structural vector autoregressive (VAR) approach, first initiated by Sims (1980).[1] There is, however, a major challenge when analysing the open economy through structural VARs; namely how to properly address the simultaneity problem between monetary policy and the exchange rate. Most of the VAR studies of open economies (including those mentioned above), deal with a possible simultaneity problem by placing recursive, zero contemporaneous restrictions on the interaction between monetary policy and exchange rates.[2] However, by not allowing for potential simultaneity effects in the identification of monetary policy shock, they may have produced a numerically important bias in the estimate of the degree of interdependence.[3]

This point has recently been emphasized by Faust and Rogers (2003), exploring sign restrictions. By dropping what they call *dubious* (zero contemporaneous) restrictions one by one, they find that the responses in the exchange rate to (U.S.) monetary policy are sensitive to the restrictions imposed. Their results allow for an early peak in the exchange rate, which may allow for the conventional overshooting model. However, the effect is not uniquely identified, so no robust conclusions can be drawn with regard to the exact timing of the peak response, which could be immediate or delayed. Similar results are also found in Scholl and Uhlig (2008), using a procedure related to that of Faust and Rogers (2003).

Hence, the implied interest rate and exchange rate responses following a monetary policy shock continue to remain distinct from Dornbusch's prediction, with both the delayed overshooting feature and/or deviation from UIP emerging as consensus. In fact, some researchers now view the puzzles themselves as *stylized facts*, which recent "Dynamic Stochastic General Equilibrium" (DSGE) models should seek to replicate, see e.g. Smets and Wouters (2002), Lindé et al. (2004), Murchison et al. (2004) and Adolfson et al. (2008). However, as DSGE models have begun to dominate the field of applied macroeconomics and policymaking, it now seems more likely that the economic profession might eventually abandon the Dornbusch overshooting model, also in theory.

This paper strongly cautions against allowing for exchange rate puzzles to develop into consensus for the following reason: although relying on sign restrictions is a useful way of testing the implications of alternative short term restrictions, this approach implies a weak form of identification that may produce weak results (Fry and Pagan, 2007). The main objection to this approach is that the identification scheme will be non-unique. Due to the weakness of information contained in the sign restrictions, there are many impulse responses that can satisfy each sign restriction. Drawing an inference with regard to the precise timing of a peak response in the exchange rate instead requires a strong form of information. This suggests that one should seek to identify VAR models by applying restrictions that ensure a *unique* identification while keeping the contemporaneous interaction between monetary policy and the exchange rate intact. Doing so, we find that the Dornbusch overshooting results hold after all.

To be more precise, this paper suggests identification by restricting the long run multipliers of shocks. In particular, monetary policy shocks are assumed to have no long run effect on the level of the real exchange rate. In the short run, however, monetary policy is free to influence the exchange rate. Eventually though, the effect dies out and the real exchange rate returns to its initial level. This is a standard neutrality assumption that holds for a large class of models in the monetary policy literature (see Obstfeld, 1985; Clarida and Gali, 1994).

Once allowing for a contemporaneous relationship between the interest rate and the exchange rate, the remaining VAR can be identified using standard recursive zero restrictions on the impact matrix of shocks; assuming a lagged response in domestic variables (such as output and inflation) to monetary policy shocks. That monetary policy affects domestic variables with a lag, is consistent with the transmission mechanism of monetary policy emphasised in Svensson's (1997) theoretical set up. These restrictions are therefore less controversial, and studies identifying monetary policy without these restrictions have found qualitatively similar results, see for example Faust et al. (2004) and the references therein. Furthermore, the assumption of a delayed response in output and inflation *combined* with a long run neutrality restriction on the real exchange rate following a monetary policy surprise, are core assumptions underlying Dornbusch's overshooting model, which are consistent with NOEM implications (Lane, 2001) and empirically realistic (Rogoff, 2002).

We impose the alternative identification strategy on four small open economies with floating exchange rates: Australia, Canada, New Zealand and Sweden, and the results are striking.[4] Contrary to the findings of recent studies, we find that a contractionary monetary policy shock has a strong effect on the real exchange rate, which appreciates on impact. The maximum impact occurs within 1–2 quarters, and the exchange rate thereafter gradually depreciates back to baseline, consistent with the Dornbusch overshooting hypothesis and with few exceptions consistent with UIP.

The rest of this paper is organised as follows: Section 2 discusses the VAR methodology used to identify monetary policy shocks; Section 3 presents the empirical results; Section 4 provides extensive robustness checks (focusing both on model specification and identifying restrictions); and Section 5 concludes.

2. The structural VAR model

The variables in the VAR model are chosen to reflect the theoretical set up of a New-Keynesian small open economy model, such as that described in Clarida et al. (2001) and Svensson (2000). In particular, the VAR model comprises the annual change in the log of consumer prices (π_t)–referred to hereafter as inflation, the log of real gross domestic product, (y_t), the three-month domestic interest rate (i_t), the trade-weighted foreign interest rate (i_t*) and the first difference of the log of the trade-weighted real exchange rate (Δe_t).

We follow the traditional closed economy VAR literature (Christiano et al., 1999, 2005, among many others), in that a standard recursive structure is identified between macroeconomic variables and monetary policy, so that macroeconomic variables such as output and inflation do not react contemporaneously to monetary

[1] For the role of VAR models in policy analysis, see for instance Greenspan (2005).

[2] To be precise, Kim and Roubini (2000) allow for a contemporaneous interaction between monetary policy and the exchange rate, but assume instead that monetary policymakers do not respond contemporaneously to changes in the foreign interest rate. As a result they observe fewer puzzles in the exchange rates than other studies, although for some countries (notably Canada and Germany), a pronounced delay overshooting puzzle still remains.

[3] A related problem has also been pointed out when identifying the interdependence between monetary policy and the stock market in the U.S., see Bjørnland and Leitemo (2009).

[4] See also Bjørnland (2008) for an analysis of Norway that finds corroborate results. That analysis builds on the present model, but due to a much shorter sample (1993–2005), explores event studies using daily data.

shocks, whereas there may be a simultaneous feedback from the macro environment to monetary variables. With regard to the open economy applications, most studies have identified monetary policy shocks by using a Cholesky decomposition that either: i) restricts the (systematic) monetary policy from reacting contemporaneously to an exchange rate shock; or ii) restricts the exchange rate from reacting immediately to a monetary policy shock. The first restriction (see e.g. Sims, 1992; Eichenbaum and Evans, 1995 for initial applications) is equivalent to assuming that the monetary authority ignores any surprise movement in exchange rates that have occurred during the time in which decisions on the policy variables are made. For small open economies, this seems far from being a practical way to set monetary policy. The exchange rate is an important transmission channel for foreign shocks that the central bank may respond to within the month or quarter, which is the usual sampling frequency in these studies. Furthermore, the exchange rate, being an asset price, is inherently a forward-looking and expectations-determined variable that will reflect expected future return on the asset. This may in itself provide important information about the expected development of the determinants of the targeting variables that the central bank may want to react to, see Obstfeld and Rogoff (1995) and Taylor (2001) for arguments, and Clarida et al. (1998) for empirical evidence.

The second set of restrictions commonly used, namely that the exchange rate cannot react immediately to a monetary policy shock (i.e. Favero and Marcellino, 2004; Mojon and Peersman, 2003, among others), is also hard to square with basic economic theory. The exchange rate is an asset price that will reflect expected future return on the asset. As news on monetary policy will change the expected return on assets, the exchange rate should react instantaneously to monetary policy. This has been confirmed recently in a series of event studies; see Bonser-Neal et al. (1998), Zettelmeyer (2004) and Kearns and Manners (2006) among others. Finally, delayed reactions in the exchange rate seem inconsistent with the observed volatile behaviour of exchange rates in the post Bretton Woods era.

Hence, both of these restrictions are inconsistent with established theory and also in contrast to how practitioners view the relationship between the interest rate and the exchange rate in small open economies. It is, however, fair to say that several of the authors who use traditional VARs have been concerned about the validity of these restrictions and have investigated their implications by rearranging the direction of causation between the interest rate and the exchange rate to see if this makes a difference. However, it is not clear if this strategy will produce the correct impulse responses if there is a genuine simultaneous relationship between the two variables. This will effectively be demonstrated below.

The present approach differs from the more traditional methods in that we allow for full simultaneity between monetary policy and exchange rate responses. Instead monetary policy shocks are restricted from having long-run effects on real exchange rates. As already emphasised, this is a standard neutrality assumption that holds for a large class of models in the monetary policy literature. In particular, Clarida and Gali (1994) show that this kind of restriction on the real exchange rate is consistent with a stochastic version of the two-country, rational expectations open-macro model developed by Obstfeld (1985). The model exhibits the standard Mundell–Fleming–Dornbusch results in the short run when prices react sluggishly, but in the long run, prices adjust fully to all shocks. Note, however, that although monetary policy shocks are neutral with respect to the real exchange rate in the long run, the exchange rate may still be affected by other demand and supply shocks permanently; thereby allowing for long-run deviations from purchasing power parity (PPP). A feature of persistent deviation from PPP is consistent with the findings of many recent studies of exchange rate determination, see e.g. Rogoff's (1996) survey.

2.1. Identification

In the following we define Z_t as the (5×1) vector of the macroeconomic variables discussed above: $Z_t=[i^*_t,\ y_t,\ \pi_t,\ i_t,\ \Delta e_t]'$. Specified this way, the VAR is assumed to be stable[5] and can be inverted and written in terms of its moving average (ignoring any deterministic terms)

$$Z_t = B(L)v_t, \tag{1}$$

where ν_t is a (5×1) vector of reduced form residuals assumed to be identically and independently distributed, $v_t \sim iid(0,\Omega)$, with the positive definite covariance matrix Ω. $B(L)$ is the (5×5) convergent matrix polynomial in the lag operator L, $B(L)=\sum_{j=0}^{\infty}B_jL^j$. Following the literature, the underlying orthogonal structural disturbances (ε_t) are assumed to be written as linear combinations of the innovations (v_t), i.e., $v_t=S\varepsilon_t$. The VAR can then be written in terms of the structural shocks as

$$Z_t = C(L)\varepsilon_t, \tag{2}$$

where $B(L)S=C(L)$. Clearly, if S is identified, one can derive the MA representation in Eq. (2), since $B(L)$ can be calculated from a reduced form estimation. Hence, to go from the reduced form VAR to the structural interpretation, one needs to apply restrictions on the S matrix. Only then can one recover the relevant structural parameters from the covariance matrix of the reduced form residuals.

To identify S, the $_t$'s are first assumed to be normalized with unit variance. We order the vector of uncorrelated structural shocks as $\varepsilon_t=[\varepsilon^{i^*}_t,\ \varepsilon^{Y}_t,\ \varepsilon^{CP}_t\ \varepsilon^{MP}_t\ \varepsilon^{ER}_t]'$, where ε^{MP} is the monetary policy shock and e^{ER}_t the exchange rate shock. The remaining three shocks are loosely interpreted as inflation (or cost push) shocks (moving prices before output) (e^{CP}_t), output shocks (e^{Y}_t) and foreign interest rate shocks ($e^{i^*}_t$). The standard closed economy assumption that macroeconomic variables react with a lag to monetary policy shocks, while monetary policy can react immediately to disturbances in the macroeconomic environment, is taken care of by placing foreign interest rates, output and inflation above the interest rate in the ordering, and assuming three zero restrictions on the relevant coefficients in the S matrix, as shown in Eq. (3),

$$\begin{bmatrix} i^* \\ y \\ \pi \\ i \\ \Delta e \end{bmatrix}_t = B(L)\begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix}\begin{bmatrix} \varepsilon^{i^*} \\ \varepsilon^{Y} \\ \varepsilon^{CP} \\ \varepsilon^{MP} \\ \varepsilon^{ER} \end{bmatrix}_t. \tag{3}$$

Similar recursive restrictions are imposed on the relationship between the exchange rate and macroeconomic variables. The exchange rate can react immediately to all shocks, but due to nominal rigidities, there is a slow process of exchange rate pass through to macroeconomic variables. Regarding the ordering of the first three variables, the foreign interest rate is placed on the top of the ordering, assuming it will only be affected by exogenous foreign monetary policy contemporaneously, a plausible small country assumption. However, note that the responses to the monetary policy shock (or the exchange rate shock) will be invariant to the ordering of the three first

[5] This will be discussed further and verified in Section 3 below.

variables. This follows from a generalization of Christiano et al. (1999; Proposition 4.1), and is discussed further in the section on robustness below.

Turning to the interaction between monetary policy and the real exchange rate, the standard practice in the VAR literature is to place the exchange rate last in the ordering and assume $S_{45}=0$, so that the interest rate is restricted from reacting simultaneously to the exchange rate shock, while the exchange rate is allowed to react simultaneously to all shocks. This should provide enough restriction to identify the system, thereby allowing for the use of the standard Cholesky recursive decomposition.

However, if that restriction is not valid but is nonetheless imposed, the estimated responses to the structural shocks will be severely biased. Instead, the restriction that a monetary policy shock can have no long-run effect on the real exchange rate is imposed, which as discussed above, is a plausible neutrality assumption. This can be found by setting the values of the infinite number of relevant lag coefficients in Eq. (2), $\sum_{j=0}^{\infty} C_{54,j}$, equal to zero. Writing the long-run expression of $B(L)S=C(L)$ as

$$B(1)S = C(1), \tag{4}$$

where $B(1)=\sum_{j=0}^{\infty} B_j$ and $C(1)=\sum_{j=0}^{\infty} C_j$ indicate the (5×5) long-run matrix of $B(L)$ and $C(L)$ respectively, the long-run restriction that $C_{54}(1)=0$ implies

$$B_{51}(1)S_{14} + B_{52}(1)S_{24} + B_{53}(1)S_{34} + B_{54}(1)S_{44} + B_{55}(1)S_{54} = 0. \tag{5}$$

The model is now uniquely identified and the shocks orthogonalized. The restrictions allow for contemporaneous interaction between monetary policy and exchange rate dynamics, without having to resort to methods that deviate extensively from the established view of how one identifies monetary policy shocks in the closed economy literature. Furthermore, the long run neutrality assumption used is theoretically appealing, and consistent with the underlying assumptions in Dornbusch's overshooting model. Yet, introducing a new restriction does not come without costs. In particular, using an infinite (long run) restriction on finite dimension VAR may provide unreliable estimates, unless the economy satisfies some types of strong restrictions on the finite horizon (see Faust and Leeper, 1997). Although potentially a problem, the joint use of short run and long run constraints used in the present VAR model, should be sufficient to side-step some of this criticism. However, the robustness of the chosen restrictions will be examined in Section 4 below.

3. Empirical results

The model is estimated for Australia, Canada, New Zealand and Sweden. We choose to focus on small open countries, as the exchange rate is an important transmission channel for shocks in open economies. Quarterly data from Q1 1983 to Q4 2004 are used, except for New Zealand. Using an earlier starting period than 1983 would make it difficult to identify a stable monetary policy regime, as monetary policy prior to 1983 experienced important structural changes and unusual operating procedures that would introduce severe parameter instability (see for instance Bagliano and Favero, 1998; Clarida et al., 2000). For New Zealand, the start date is set to 1988 as the period 1983–1987 was characterised by a high degree of volatility since New Zealand changed from a closed and centrally controlled economy to one of the most open countries in the OECD (see Evans et al., 1996).

As noted in Section 2, the choice of data and transformation reflect the model set up in Svensson (1997) as data generating process, suggesting we include domestic and foreign interest rates, annual inflation rates, output and real exchange rates in the VAR (see Appendix A for a description of data and sources). Giordani (2004) argues that rather than including output in levels, one should either include the output gap in the VAR, or the output gap along with the trend level of output. However, a practical point that Giordani does not address is how to compute trend output (thereby the output gap). We therefore instead follow Lindé (2003) by including a linear trend in the VAR along with output in levels. In that way we try to address this problem by modelling the trend implicit in the VAR. In Section 4 below we will, however, carry out extensive robustness tests to the VAR specifications.

The real exchange rate is differenced so that when long-run restrictions are applied to the first-differenced real exchange rate, the effects of a monetary policy shock on the *level* of the exchange rate will eventually sum to zero (c.f. Blanchard and Quah 1989). By restricting the sum of the differenced exchange rate to zero, monetary policy shocks cannot have a permanent effect on the level of the real exchange rate. We confirm, however, that the estimated VAR satisfies the stability condition: No eigenvalues (inverse roots of AR characteristics polynomial) lies outside the unit circle, hence the VAR can be inverted and analyzed through the MA representation.

Finally, the lag order of the VAR-model is determined using various information criteria, suggesting that three lags are acceptable for all countries. With three lags, the hypothesis of autocorrelation and heteroscedasticity is rejected for all countries, although some non-normality remained in the system. In a few cases impulse dummies, which take the value of 1 in one quarter and 0 otherwise, were included, to take account of extreme outliers.[6] With these dummies incorporated, some non-normality nevertheless remained, although mainly in the foreign interest rate equation. Robustness to the inclusion of dummies is analyzed in Section 4.

3.1. Cholesky decomposition

For comparison, we start by briefly discussing the results using a standard Cholesky ordering, before turning to the preferred structural decomposition. Fig. 1 shows the impulse responses for the interest rate and the level of the real exchange rate from a monetary policy shock, using two different Cholesky orderings. The solid line corresponds to the baseline Cholesky decomposition (where an exchange rate shock has no immediate effect on the interest rate), whereas the dotted line corresponds to the reverse ordering (where monetary policy shock has no immediate effect on the real exchange rate). In the figures below, the effect of the monetary policy shock is normalised so that the interest rate increases by one percentage point the first quarter. A decrease in the real exchange rate implies appreciation.[7]

Focusing first on the baseline Cholesky ordering (solid line), the figures emphasize that for two of the countries, Canada and New Zealand, there is clear evidence of delayed overshooting. The exchange rate appreciates for a prolonged period (up to 2 years), before

[6] Three dummies were included for Sweden; 1992Q3, 1993Q1 and 1995Q4. The first captures an exceptionally high interest rate increase (500%) implemented by the Riksbank in order to defend the Swedish exchange rate (see also the discussion in Lindé 2003), the second reflects the subsequent floating of the Swedish krona and the final one captures additional turbulence in the exchange rate. For Australia two dummies were included; 1984Q1 and 2000Q3, that reflected a substantial decrease and increase in the inflation rate respectively.

[7] For the Cholesky decomposition, we tried specifying the exchange rate both in first differences and in levels to confirm with conventional VAR studies. The main results remain invariant to either specification.

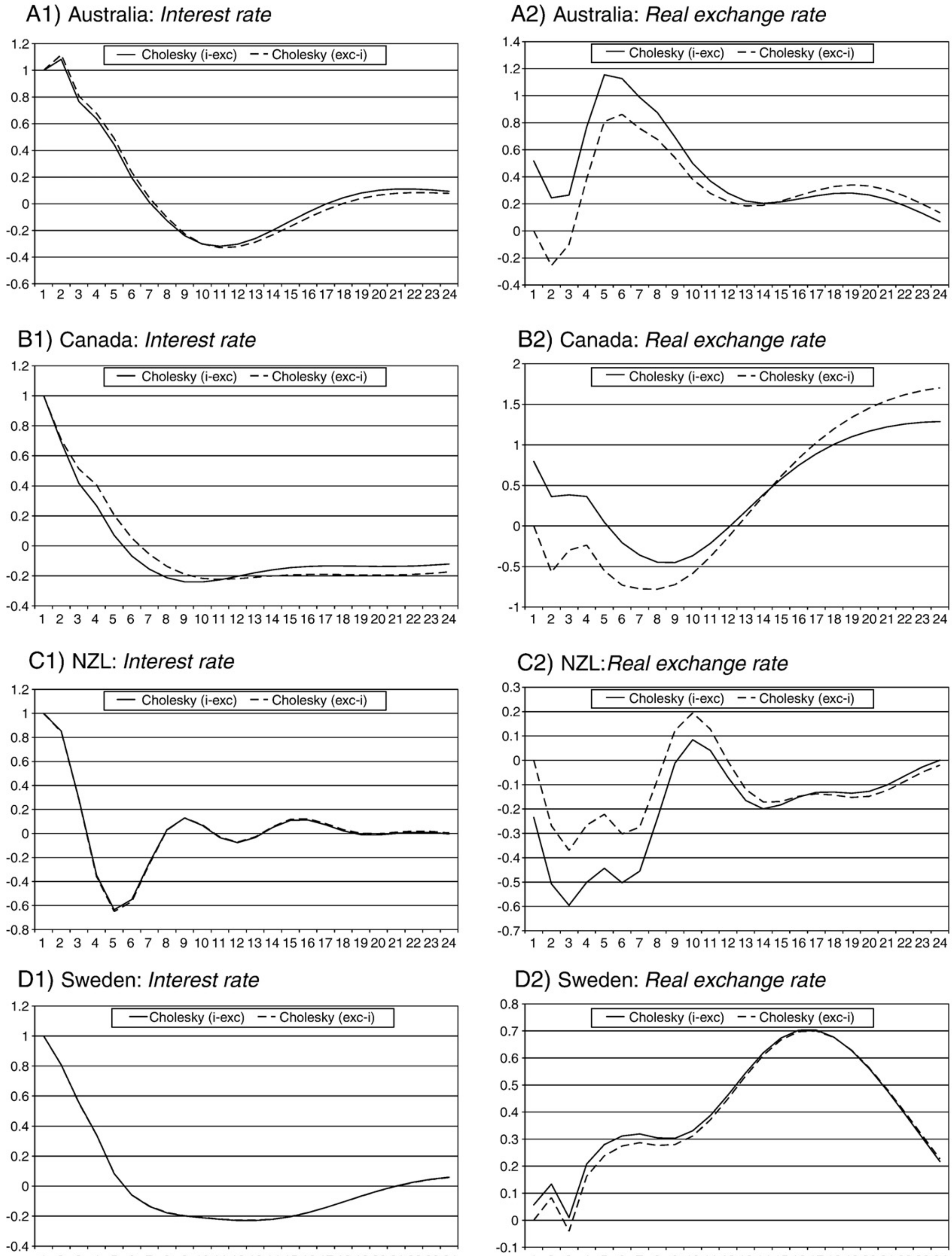

Fig. 1. Response to a monetary policy shock, using two different Cholesky orderings. The solid line denoted Cholesky (i-exc) corresponds to the Cholesky decomposition where the interest rate is ordered before the exchange rate in the VAR, while in the semi-solid line denoted Cholesky (exc-i), the interest rate and the exchange rate swap places.

returning to equilibrium. For Australia and Sweden, the exchange rate moves in the “wrong” direction (exchange rate puzzle), depreciating for 2–4 years, before returning to equilibrium.

Using the alternative Cholesky ordering (dotted line), the initial effect of a monetary policy shock on the exchange rate is forced to zero, thereby generating a “puzzle” by assumption. For New Zealand

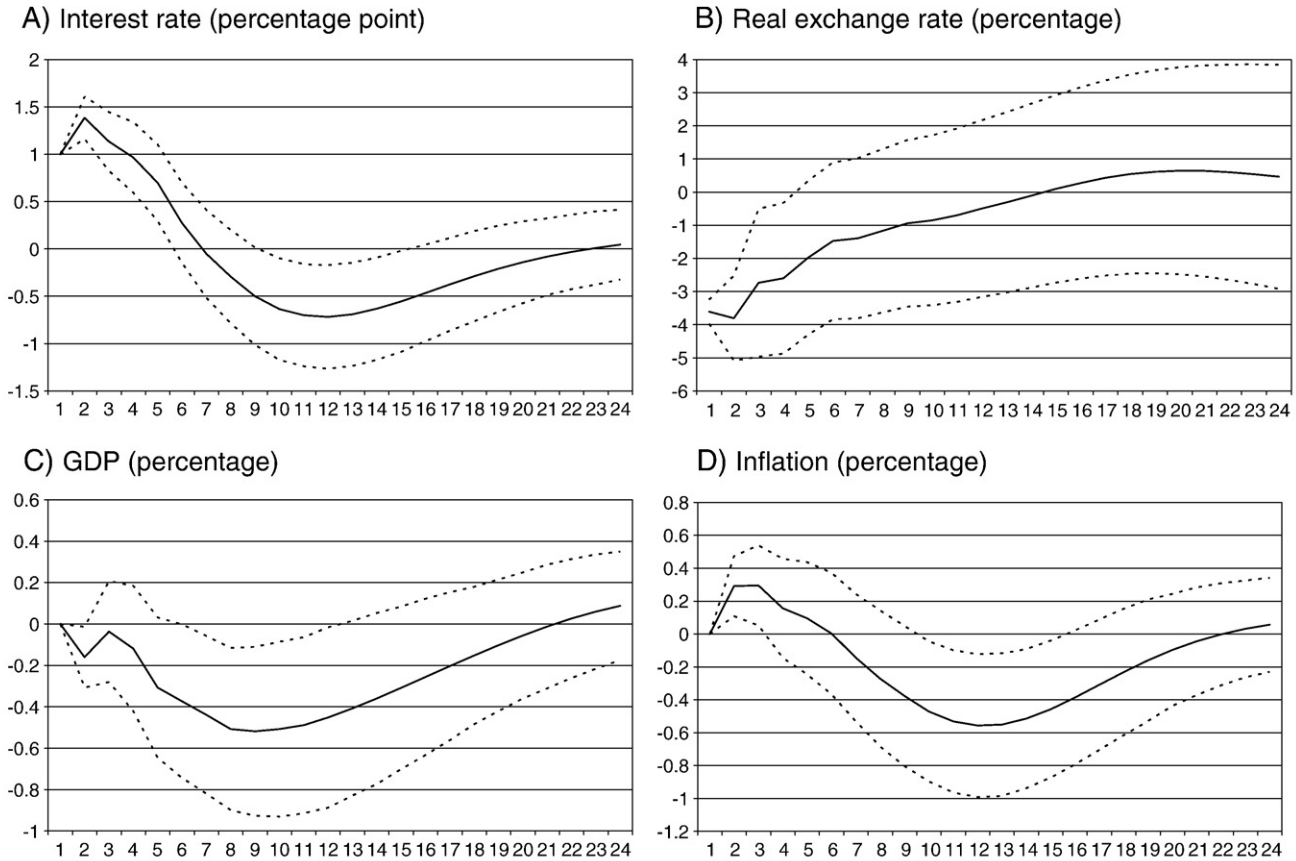

Fig. 2. Australia: response to a monetary policy shock, using the structural VAR.

and Sweden, the alternative orderings do not imply much difference, since the initial effect identified with the baseline Cholesky ordering was close to zero nevertheless. For the other two countries, the impulse responses differ at first, but then follow the pattern of the baseline Cholesky ordering.

The fact that the ordering does not matter could be due to the fact that the covariance between the interest rate and the exchange rate is close to zero. However, as we shall see below, a covariance close to zero could also appear because the effect of the monetary policy shock on the exchange rate is opposite in sign to the effect of the exchange rate shock on the interest rate, thereby essentially cancelling each other out. Only by allowing the contemporaneous interdependence to be different from zero, is one able to recover the true structural shocks.

3.2. Structural identification scheme

We now turn to the preferred structural model outlined in Section 2. Figs. 2–5 graph the impulse responses of a monetary policy shock on the interest rate, the level of the real exchange rate, GDP and inflation for Australia, Canada, New Zealand and Sweden respectively. The effect is again normalised so the response of the interest rate is 1 pp. the first quarter. The upper and lower dashed lines plotted in each graph are the probability bands represented as .16 and .84 fractiles (as suggested by Doan, 2004).[8]

Figs. 2–5 (frame A's) illustrate, as above, that a monetary policy shock increases interest rates temporarily. There is some degree of interest-rate inertia in the model, as a monetary policy shock is only offset by a gradual lowering of the interest rate. The nominal interest rate returns to its steady-state value after 1–2 years and then falls below its steady-state value. Both the interest-rate inertia and the "reversal" of the interest rate stance are consistent with what is considered good monetary policy conduct, see Woodford (2003).

Whereas the effect of a monetary policy shock on the interest rate is consistent with what was found above using the Cholesky decomposition, the effect on the exchange rate (frame B's) has now completely changed. Contrary to the results found above and in most other open economy studies, there is no evidence of any exchange rate puzzle in any of the countries. The monetary policy shock has a strong and immediate effect on the exchange rate, which appreciates by 1.5–4% on impact. The maximum impact of the policy shock occurs instantaneously in Sweden, whereas in the other countries, the maximum impact is delayed by one quarter. However, the adjustment following the initial response is small compared to the impact effect.[9] Following the initial appreciation, the exchange rate thereafter gradually depreciates back to baseline, consistent with the Dornbusch overshooting hypothesis.

Do the reported results appear reasonable? The initial effect seems consistent with what has been found in a series of recent event studies that measure the immediate response of the exchange rate to shocks associated with particular policy actions. For instance, Zettelmeyer (2004), analysing, among other countries,

[8] This is the Bayesian simulated distribution obtained by Monte Carlo integration with 2500 replications, using the approach for just-identified systems. The draws are made directly from the posterior distribution of the VAR coefficients (see Doan, 2004).

[9] Ideally, we could have also estimated the model using monthly data, to examine if there is any overshooting within the quarter. However, Australia and New Zealand only publish quarterly data for inflation. Using monthly data (replacing GDP with industrial production) for Canada, we nevertheless confirm the broad picture. There is some delay overshooting for 3–5 months, before the exchange rate quickly depreciates to equilibrium. This explains why there is a one quarter delay for Canada in the baseline quarterly responses. However, the adjustment following the initial response is small compared to the impact effect. These results can be obtained on request.

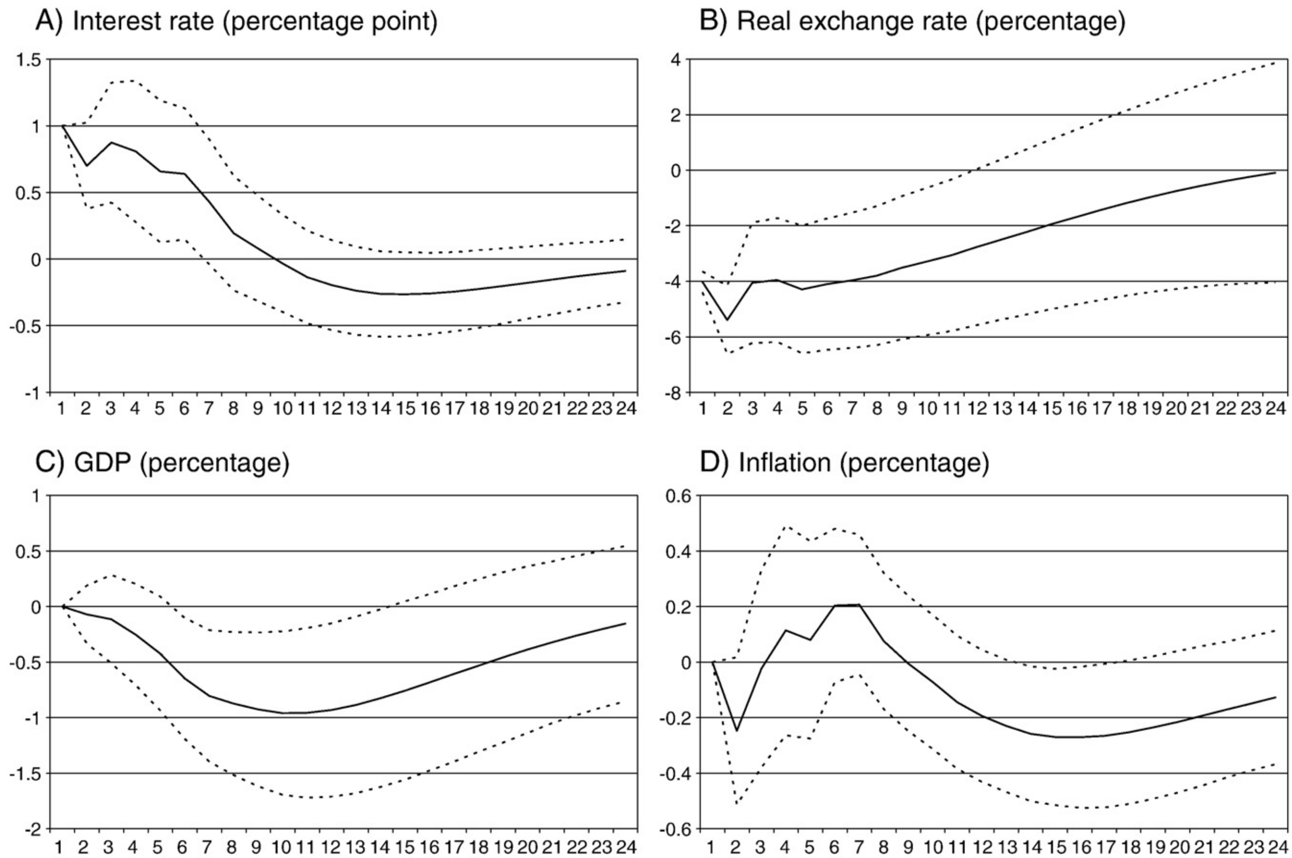

Fig. 3. Canada: response to a monetary policy shock, using the structural VAR.

Australia and Canada using daily data, finds that a one percentage point increase in the interest rate will appreciate the exchange rate by 2–3% on impact. Kearns and Manners (2006) using intraday data find similar results, although the magnitude of the effects of the shocks are smaller. Furthermore, using a structural model that explicitly accounts for the features of a small open economy, Cushman and Zha (1997) also find instant overshooting in an analysis of Canada.

Finally, consistent with the strong impact on the exchange rate, output falls gradually and reaches a minimum after 1.5–2 years. The effect thereafter quickly dies out. The effect on inflation is also negative and reaches a minimum after 2–3 years. For two of the countries, Australia and New Zealand, there is some evidence of an initial price puzzle, where inflation rises following a contractionary monetary policy shock. Such a feature has recently been explained by a cost channel of the interest rate, where the increased interest rate increases borrowing costs for firms and therefore prices, and is less of a problem (see Ravenna and Walsh, 2006; Chowdhury et al., 2006). However, following the initial puzzle, the effect on inflation is eventually significantly negative in all countries, as expected.

Why do our results differ from Cholesky ordering? To cast some light on this issue, we next examine whether there is any (systematic) monetary policy response to exchange rate changes. That is, the impulse responses for interest rates following an exchange rate shock are examined. If monetary policy reacts immediately to exchange rate variation, then one would expect the interaction between interest rates and exchange rates to be important when identifying monetary policy shocks. If, on the other hand, no response is present, this may justify a zero contemporaneous restriction on the interest rate response, as found in many recent VAR studies.

From the impulse responses (Appendix B), we find that an exchange rate shock that depreciates the exchange rate leads to a significant increase in the interest rate in all countries. The effect is largest in Canada and smallest in New Zealand, where a shock that depreciates the exchange rate by 1% increases the interest rate by 0.37 and 0.07 percentage points respectively. Following the maximum response, the effect quickly dies out.[10]

Table 1 provides further evidence of interaction, by quantifying the contribution of the different shocks to the variance in the relevant variables on *impact*. That is, the first row in Table 1 shows the variance decomposition of the real exchange rate for the first quarter with respect to the monetary policy shocks, while in the second row the variance decomposition of the interest rates for the same quarter with respect to the exchange rate shocks is given.

Of the four countries, Canada displays by far the highest degree of interaction between interest rate settings and exchange rate dynamics, as monetary policy shocks explain 41% of the exchange rate variation on impact, while 52% of the interest rate variation is explained by exchange rate shocks on impact.[11] Australia and Sweden also display an important degree of interaction, with monetary policy shocks accounting for 25% of the exchange rate variation while exchange rate shocks account for 23–36% of the interest rate variation. New Zealand displays a more modest degree of interaction, with monetary policy and exchange rate shocks accounting for just less than 10% of the exchange rate and interest rate interaction respectively.

[10] These responses might be motivated both by the central bank's concern about reducing the impact of the shock on aggregate demand by conducting a policy that will offset the exchange rate effects, but also by reducing the impact of the exchange rate shock on exchange rates, thereby diminishing the source of the problem.

[11] Kim and Roubini (2000) also find monetary policy shocks to explain a large share of the exchange rate variation (almost 60%) in Canada. However, whereas the effect found here is immediate, in Kim and Roubini the effect is accumulated over close to a year, as the exchange rate exhibits pronounced delayed overshooting.

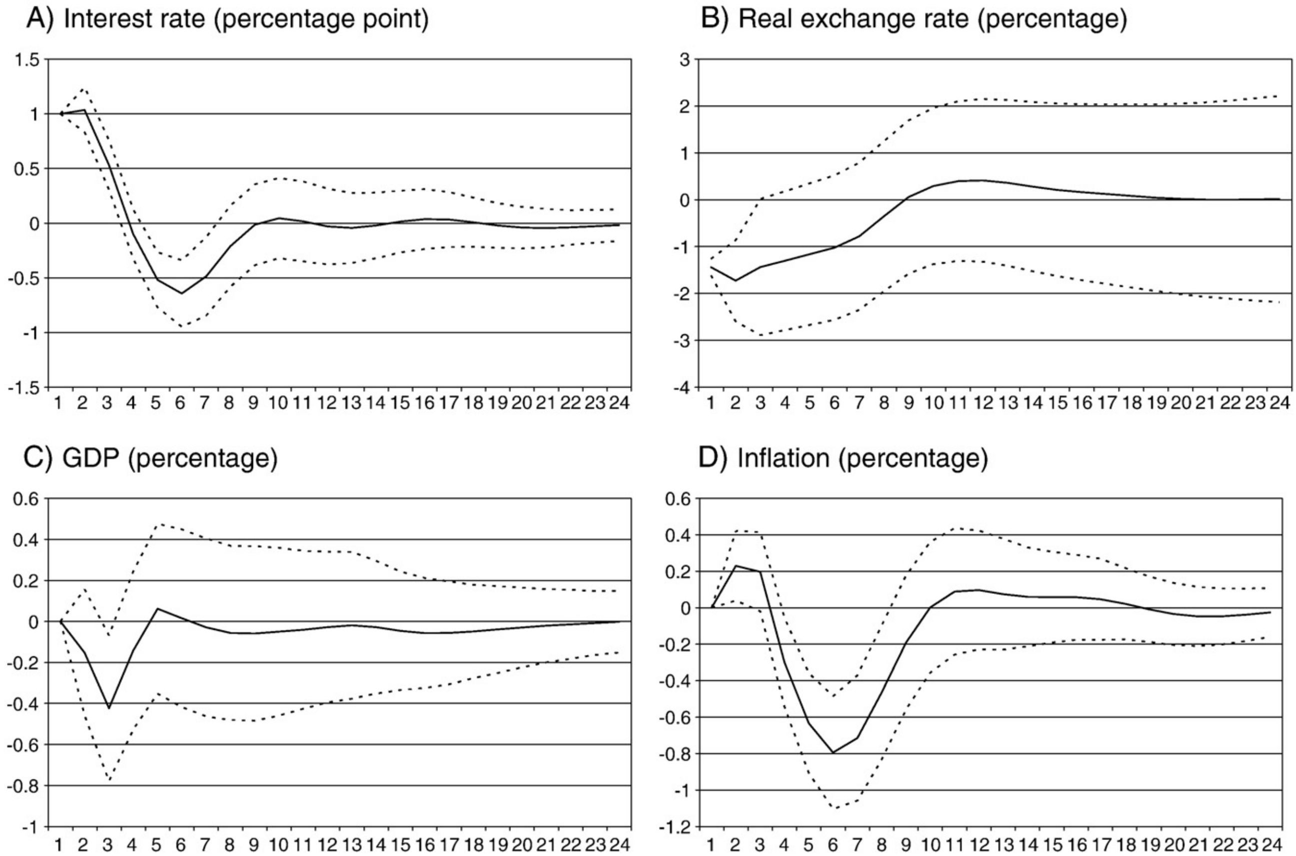

Fig. 4. New Zealand: response to a monetary policy shock, using the structural VAR.

These results emphasise that monetary policy responds systematically to exchange rate movements in all countries, but most notably so in Canada. The results are consistent with what has been found in other part of the literature. For instance, Lubik and Schorfheide (2007) estimate a DSGE model to examine whether small open economies respond to exchange rate movements. They find that in most of the countries they examine, and in particular Canada, the interest rate is increased following exchange rate depreciation.

Hence, we have documented that there is a two-way interaction between monetary policy and the exchange rate. Note, however, that although the results suggest an important response from the monetary policy maker to exchange rate shocks, the interest rate response is not direct evidence of the stabilization of the exchange rate independent of less controversial objectives such as inflation and output. More likely, it is the result of the monetary policymaker reacting to exchange rates due to the monetary policy lag in influencing objectives such as output and inflation, as evident in Figs. 2–5.

With regard to the remaining variables in the model, monetary policy shocks explain approximately 5–15% of output and inflation variation after 1–3 years. These results are in line with what has previously been reported in the literature, although the exact magnitude may be somewhat larger here due to the considerable initial response in the real exchange rate reported.

3.3. Uncovered interest parity (UIP)

Having asserted that the exchange rate behaviour is consistent with Dornbusch overshooting in qualitative terms, we finally turn to examine whether the subsequent response in the exchange rate is consistent with UIP. If UIP holds following a contractionary monetary policy shock, the fall in the interest rate differential $(i_t^* - i_t)$ will be offset by an expected depreciation of the exchange rate between time t and $t+1$. To explore this issue in more detail, we follow Eichenbaum and Evans (1995) and define Ψ_t as the ex post difference in return between holding one period foreign or domestic bonds. Measured in domestic currency, excess return is then given by:

$$\psi_t = i_t^* - i_t + 4^*(s_{t+1} - s_t), \tag{6}$$

where s_t is the nominal exchange rate and s_{t+1} is the forecasted three-month exchange rate response.[12] One implication of UIP is that the conditional expectations of the excess return should be zero:

$$E_t \psi_{t+j} = 0 \tag{7}$$

for all $j \geq 0$, where E_t denotes conditional expectations. Fig. 6 reports the point estimates (with probability bands represented as .16 and .84 fractiles) of the dynamic response function of Eq. (7) on the basis of the estimated VARs. Note that as it is the real exchange rate that is included in the VAR; we have to adjust for the effect of monetary policy shocks on prices to obtain the effect on the nominal exchange rate; $s_t = e_t - p_t^* + p_t$.[13]

The figure shows that, with the exception of Australia and Canada, the responses essentially fluctuate around zero, consistent with UIP. For Australia, there are large deviations from zero in the second

[12] The exchange rate is multiplied by four to be annualized, as the interest rate is measured in annual terms.

[13] To be precise, I can only correct for domestic inflation impulses as foreign prices are not among the endogenous variables in the VAR. This restriction is equivalent to assuming that domestic monetary policy has a negligible effect on foreign prices, which is a common small open economy assumption used among others in Dornbusch (1976). The calculated excess return will therefore only be correct up to the point that this assumption is warranted.

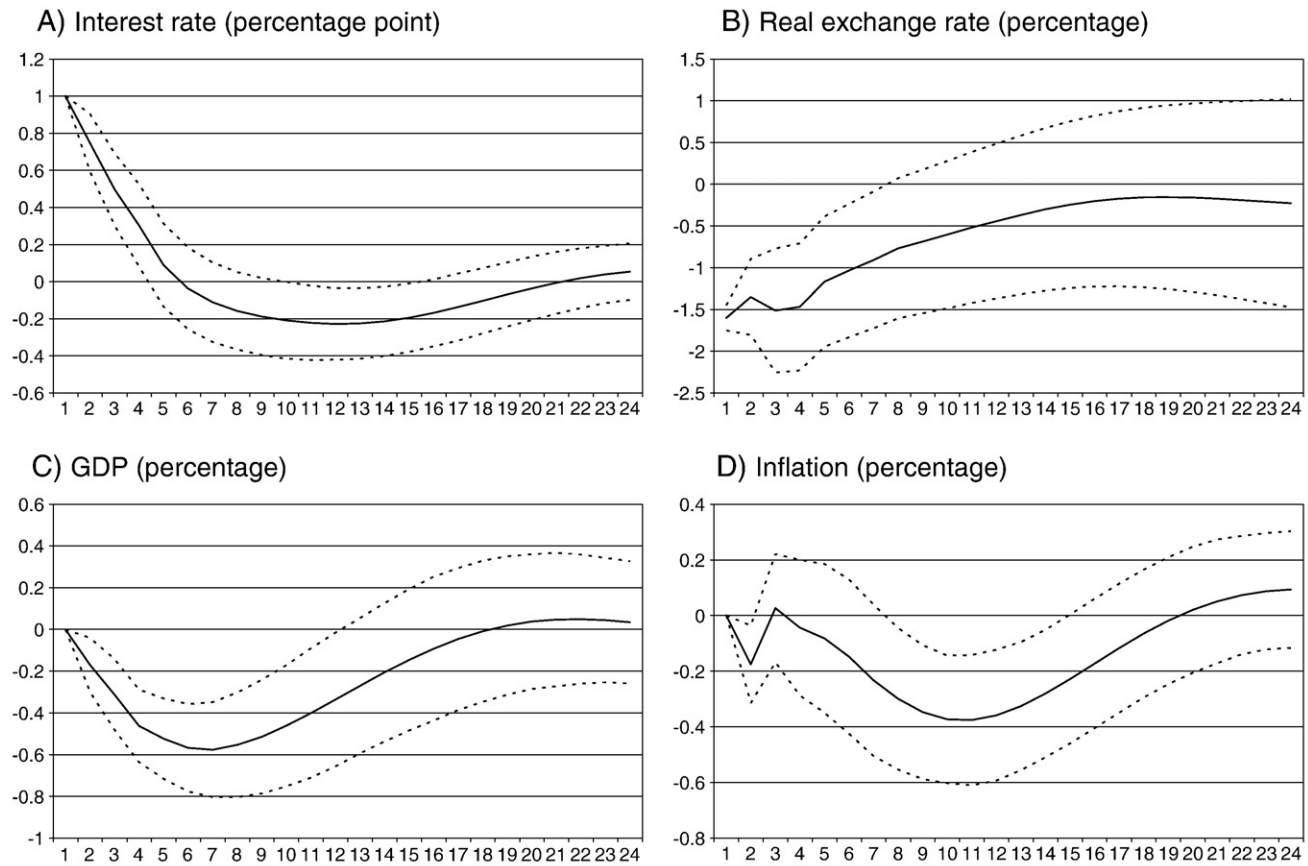

Fig. 5. Sweden: response to a monetary policy shock, using the structural VAR.

quarter, but these deviations are not significantly different form zero. For Canada, on the other hand, there are significant negative deviations from zero in the first quarter (as the exchange rate reacts with a delay of one quarter compared to the other countries, see Fig. 6), but thereafter these responses also fluctuate around zero. Hence, we find basic confirmation of UIP, with the clear exception of the first period (quarter) in Canada. This is in contrast with the results presented in the vast VAR literature, including Eichenbaum and Evans (1995) for a series of countries using traditional recursive restrictions for identification, and more recently Faust and Rogers (2003) using sign restrictions.

Having established that monetary policy shocks generate exchange rate movements largely consistent with UIP, the analysis nevertheless emphasises that a substantial share of exchange rate variation (more than 50%) is due to other non-policy shocks. Following these non-monetary shocks, UIP may not necessarily hold. However, the finding that UIP does not hold unconditionally is not new, see Fama (1984) for a contribution to the international finance literature and Engel's (1996) survey. That said, the policymaker should be confident in the knowledge that conditioned on monetary policy, UIP will hold, which is the relevant policy question to examine.

Table 1
Forecast error decomposition: contribution (on impact) of monetary policy (MP) and exchange rate (ER) shocks to real exchange rate and interest rate variation.

	AUS	CAN	NZL	SWE
Real exchange rate; contribution from MP shocks	26	41	9	25
Interest rate; contribution from ER shocks	36	52	8	23

Percentage.

4. Robustness of results

The robustness of the results reported in the baseline specification deserves discussion on at least three dimensions: specification of the VAR, choice of variables included in the VAR and choice of restrictions used to identify the VAR. In Fig. 7 below, the results are presented with regard to the effect on the real exchange rate only, although where relevant, results for the other variables will be discussed.

Panel A of Fig. 7 tests the robustness of the following *specifications* of the VAR: (i) using four instead of three lags in the VAR (*Lags*); (ii) estimating the model from 1988 instead of 1983 (1988). 1988 is chosen as a starting point, since price stability has been a more explicit focus in many countries since then, starting with Canada and New Zealand in 1988/1989 and subsequently followed by other countries. Furthermore, Bagliano and Favero (1998) have found that with regard to mis-specification, starting the estimation in 1988 yields more stable results in analyses of monetary policy; (iii) using de-trended output instead of output in levels (*output gap*). GDP is de-trended using a quadratic trend; (iv) estimating VARs without dummies (applicable to Australia and Sweden only) (*No dummies*).[14]

[14] Several other model specifications were also tested. For instance, specifying all variables in first differences reduced the impact somewhat. However, these responses are not reported as we believe this to yield an improper representation of data since we then effectively exclude any potential co-integration (long run) relationship. Furthermore, using nominal instead of real exchange rates also produced very similar results.

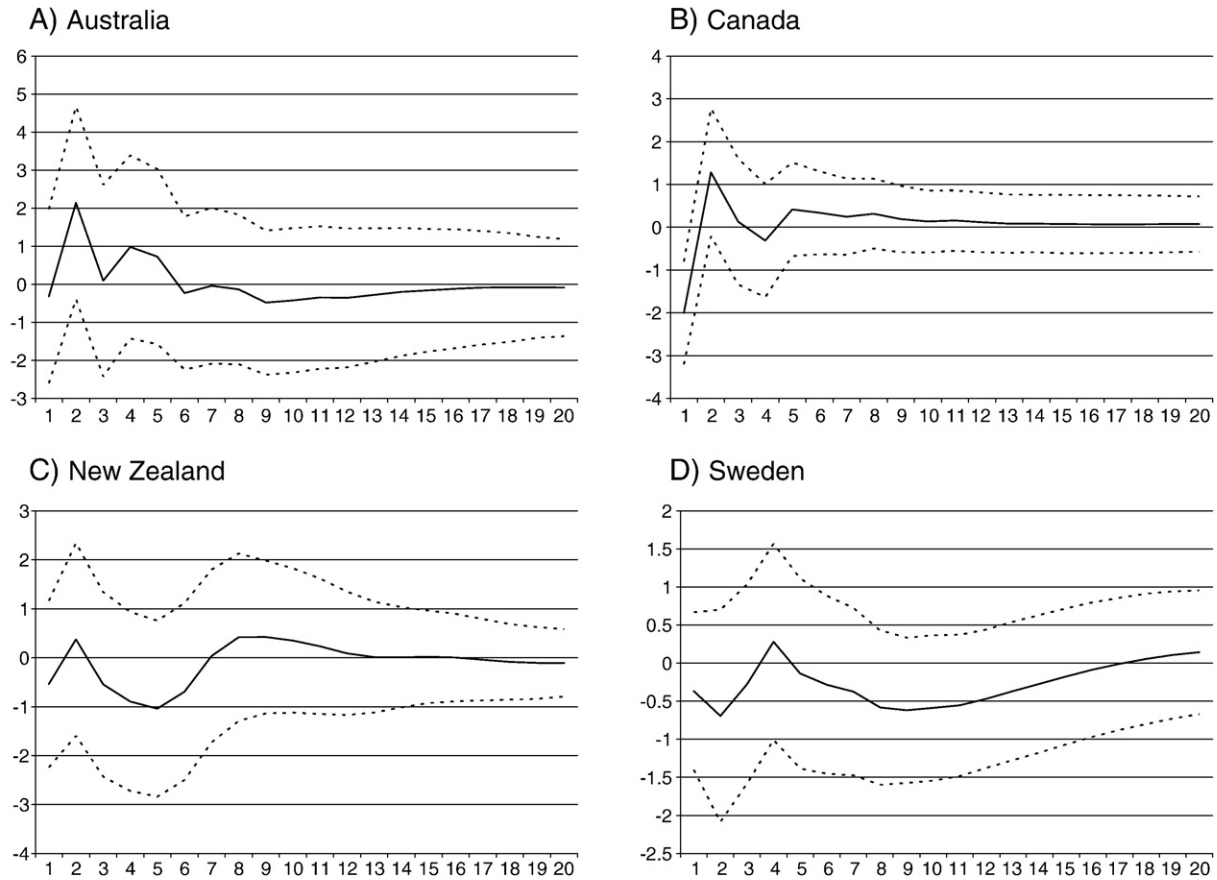

Fig. 6. Excess returns.

Panel B of Fig. 7 analyses the robustness of results by altering the *variables* included in the VAR. VAR models have often been criticised for not being robust to the inclusion of additional variables (see Leeper et al., 1996, among others). Here, we analyse the robustness of: (i) the inclusion of oil price into the VAR (*oil price*). The oil price is an importing leading indicator of inflation that monetary policymakers may react to. Excluding it from the analysis may bias the results. Furthermore, since Canada is an oil exporting country, the oil price may potentially explain a substantial part of the exchange rate variation. The oil price series is included as an exogenous variable, since the countries analysed here are small and have little influence on oil prices; (ii) the exclusion of the foreign interest rate, allowing it to be exogenous to the VAR (*exogenous foreign interest rate*). The idea is that as these counties are small it is legitimate to specify the foreign interest rate as an exogenous variable.

Panel C illustrates the robustness of the *identifying restrictions*. We first test the robustness of the short run restrictions, by specifying: (i) an alternative Cholesky decomposition, where the first three variables in the VAR change order. That is, we let foreign interest rates and inflation swap places, implying a delayed response in GDP and inflation to a foreign interest rate shock (*order*); (ii) Alternative short term (zero) restrictions (*no Cholesky*). We refrain from Cholesky decomposition, and instead let GDP respond contemporaneously to monetary policy and exchange rate shocks, at the expense of having the interest rate and the exchange rate respond with a delay to a shock in GDP.[15] The motivation for such a restriction is that as GDP is published with a lag (up to a quarter), it is also reasonable to have monetary policy and the exchange rate respond with a delay to GDP.

Finally, we test robustness of the long run restriction. We follow an idea from a collaborative paper by Bjørnland and Halvorsen (2008) which shows how one can obtain identification by combining short run and sign restrictions. Here we use *one* sign restriction in place of the long run restriction: following a contractionary monetary policy shock, which increases the interest rate, the exchange rate has to fall immediately, i.e. appreciate. Such a response is consistent with formal empirical evidence from among others the event studies cited above. However, following the initial response, the exchange rate is free to move in any direction. That is, we do not place any restrictions on whether the maximum response should be immediate or delayed. This way we can test for any evidence of delayed overshooting within our present framework. Below we combine the original short term (zero) restrictions from our baseline VAR model with the suggested sign restriction instead of the long run restrictions (*sign*). Since we are now using a Bayesian procedure, all variables are specified in levels. We also specify a model where we remove the trend and instead represent GDP in first differences (*sign (growth rates)*). In both cases, we report the median response in the exchange rate [16].

For ease of exposition, we graph all the alternative robustness tests together with the baseline results in each panel in Fig. 7. Overall, the

[15] The remaining restrictions are the same as in the baseline model.

[16] Technically, what we do is to make candidate draws for S in order to compute the corresponding impulse response functions. Based on the draws from the computed impulse response functions, the impulse responses that satisfy the prior sign restrictions are kept, while the others are discarded, see Bjørnland and Halvorsen (2008).

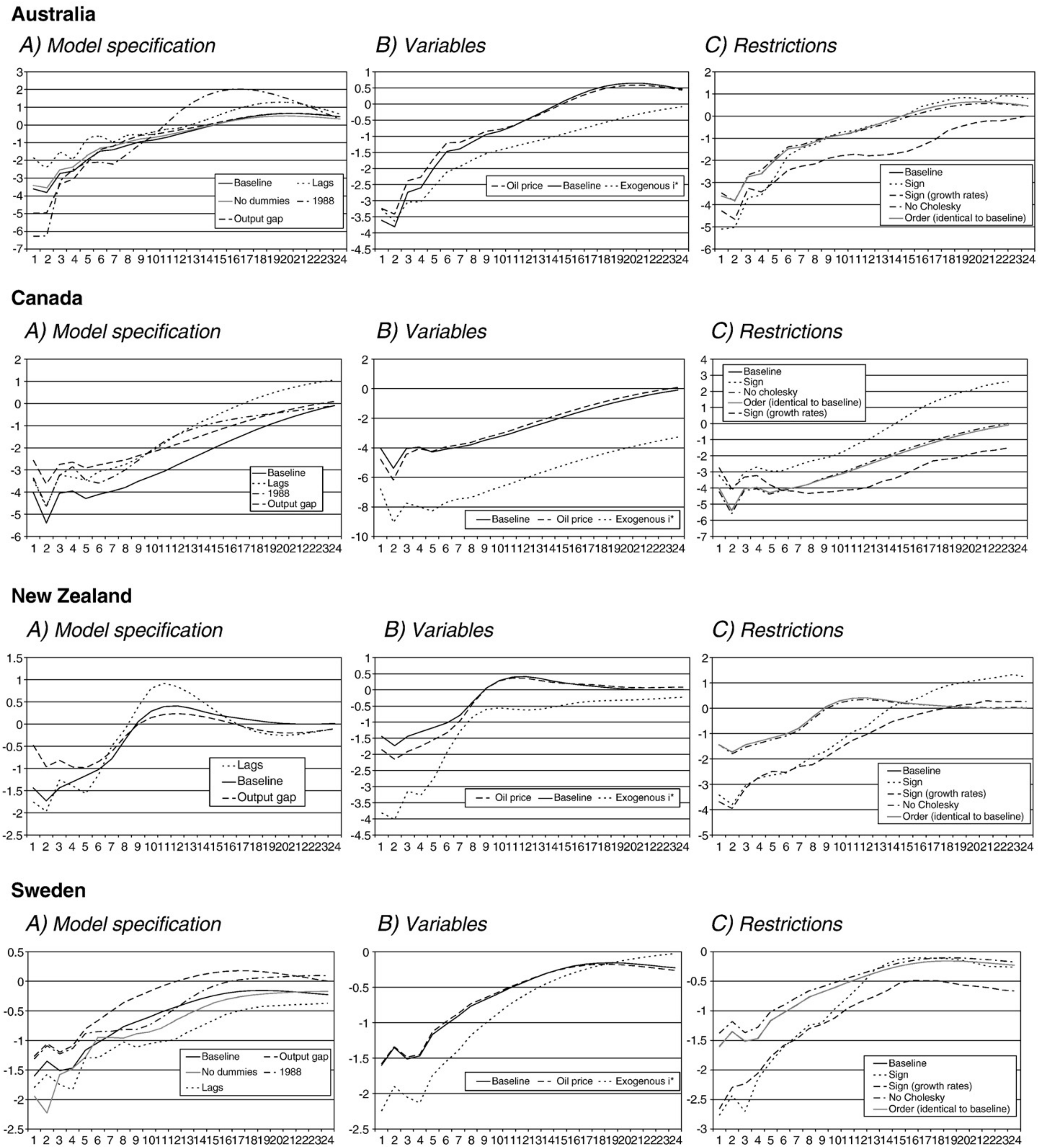

Fig. 7. Robustness in the response in the real exchange rate to a monetary policy shock, percentage.

results remain robust to all of these variations. In particular, using alternative specifications or additional variables, the baseline model has an average response across the models. The most notable difference is found when we use the sign restriction; the responses increase in all countries but Canada where it remains the same. Hence, if anything, the long run restriction provides a lower boundary relative to the more general sign restrictions. There is also evidence that when the foreign interest rate is exogenous to the VAR, the responses again increase in all countries but Australia, as now all 'monetary policy' changes will be attributed to domestic monetary policy.

Regarding alternative short-run restrictions, note that the results are invariant to the ordering of the first three variables (foreign interest rate, output and inflation). This follows from a generalisation of the well known findings in Christiano et al. (1999; Proposition 4.1), stating that when the monetary policy variable (the interest rate) is ordered last in a Cholesky ordering, the responses to the monetary policy shock will be invariant to the ordering of the variables above the interest rate. Instead, the ordering of the variables becomes a computational convenience with no bite. The real bite here is the assumption that the first three variables in the VAR don't respond contemporaneously to a monetary policy shock (or the exchange rate shock). However, using alternative short term (zero) restrictions, for example, by allowing GDP to respond on impact to shocks, also provides small differences.

Hence, although quantitatively the degree of overshooting may change somewhat from one specification to another, the baseline results of instant overshooting remain robust. There is no evidence of any exchange rate puzzle that has commonly been found in other studies. Following a contractionary monetary policy shock, the real exchange rate appreciates on impact, and then within 1–2 quarters, starts to depreciate back to equilibrium!

Regarding the effect on the other variables, the results remain robust. We note that for Canada, the price puzzle initially observed vanishes when oil prices are included in the VAR, implying more precision to the monetary policy responses.

Why do our results differ from Faust and Rogers (2003) and Scholl and Uhlig (2008) with regard to the response in the exchange rate?[17] Neither of these papers restricts the interaction between monetary policy and the exchange rate, but relies instead on a series of sign restrictions for identification. An obstacle to the approach of relying on pure sign restrictions when identifying a structural VAR model, is that the identification scheme will be non-unique. This has been emphasized by Fry and Pagan (2007), who show that due to the weakness of information contained in the sign restrictions, there will be many impulse responses that can satisfy each sign restriction. When a series of impulse responses are compatible with a particular restriction, identification will not be exact. Canova and Paustian (2007) and Paustian (2007) have further shown that sign restrictions can only uniquely pin down the unconstrained impulse responses when the imposed restrictions are sufficiently numerous. Otherwise, the use of sign restrictions could lead to the identified shock being a hybrid of shocks, lacking clear economic interpretations. Hence, the impulse responses of the monetary policy shocks identified here and the median responses reported in their studies may clearly not be the same.[18]

5. Concluding remarks

Dornbusch's (1976) well known exchange rate overshooting is a central building block in international macroeconomics, stating that the nominal exchange rate immediately appreciates with the increase in nominal interest rates, in line with uncovered interest parity (UIP). When confronted with data, however, few empirical studies that analyse the effects of monetary policy shocks have found support for Dornbusch overshooting. Instead they have found that following a contractionary monetary policy shock, the real exchange rate either depreciates, or, if it appreciates, it does so for a prolonged period of up to 3 years, thereby giving a hump-shaped response that violates UIP. From a theoretical point of view, these results are surprising. Delayed appreciation after an interest rate hike may involve “money on the table”, as agents may benefit from both higher interest rates and the appreciation of the exchange rate. Yet, these results have been so pervasive that many recently developed DSGE models have sought to replicate the puzzles themselves, contributing to consensus on the matter of exchange rate puzzles.

The majority of studies that quantify the effects of monetary policy shocks have used the vector autoregressive (VAR) approach. A major problem facing these studies is how to address the simultaneity of monetary policy and the exchange rate. Most of the studies of open economies place zero contemporaneous restrictions on the response of the systematic interest rate setting to an exchange rate shock, or vice versa. However, this is not consistent with established theory on either monetary policy or on exchange rate determination. Furthermore, Faust and Rogers (2003) have recently shown that the delayed overshooting feature of the open economy VAR is highly sensitive to this kind of restriction. VAR models of the open economy should therefore seek to identify monetary policy without restricting the contemporaneous response.

This paper suggests an alternative identification that restricts the long run multipliers of the shocks, but with no restriction on the contemporaneous relationship between the interest rate and the real exchange rate. Identification is achieved by assuming that monetary policy shocks can have no long run effect on the level of the real exchange rate. This is a standard neutrality assumption that holds for a large class of models in the monetary policy literature. In the short run, however, monetary policy is free to influence the exchange rate.

Allowing for full simultaneity between monetary policy and the exchange rate, we find striking results; Contrary to the recent “consensus”, a contractionary monetary policy shock has a strong effect on the exchange rate, which appreciates on impact. The maximal impact occurs almost immediately (within 1–2 quarters), and the exchange rate thereafter gradually depreciates back to baseline. This is consistent with the Dornbusch overshooting hypothesis. Furthermore, the ensuing movement of the exchange rate is with few exceptions consistent with UIP. Hence, we have found no evidence of the typical hump-shaped response found in the empirical literature (i.e. Eichenbaum and Evans, 1995). Instead we find renewed support for the view that policy shocks generate exchange rate responses consistent with UIP.

Appendix A

All data are taken from the OECD database, except the Fed Funds rate that is taken from Eco Win. GDP and inflation are seasonally adjusted (s.a.) by the official sources, the remaining series are unadjusted. The following data series are used:

(π_t) Inflation, measured as annual changes in the consumer price index (CPI).

(y_t) Log real GDP, deflated by the official sources.

(e_t) [CCRETT01.IXOB.Q] Log of the real effective exchange rate, measured against a basket of trading partners. The exchange rate is specified so that an increase implies depreciation.

(i_t) [IR3TBB01.ST.Q] Three-month domestic interest rate.

(i_t*) Trade-weighted foreign interest rate. For Canada, the foreign interest rate is represented by the Federal Funds rate, as the US comprises more than 80% of the foreign trade weight. For Australia, New Zealand and Sweden, the foreign interest is a weighted average of the interest rate in the major trading partners, source: Reserve Bank of Australia (http://www.rba.gov.au/), Reserve Bank of New Zealand (http://www.rbnz.govt.nz/) and Sveriges Riksbank (http://www.riksbank.com/) respectively.

[17] Obviously, some of the differences may be due to the fact that we analyse different samples and countries, but we believe that this is a less important explanation.

[18] For instance, by restricting domestic prices from rising (avoiding “price puzzles” by construction), Scholl and Uhlig (2008) find instead puzzling responses in the other variables, as real output rises and the real exchange rate depreciates following a contractionary monetary policy shock. These impulse responses are hard to interpret all coming from a contractionary monetary shock, making us question whether the identified shocks could be a hybrid of shocks.

Appendix B

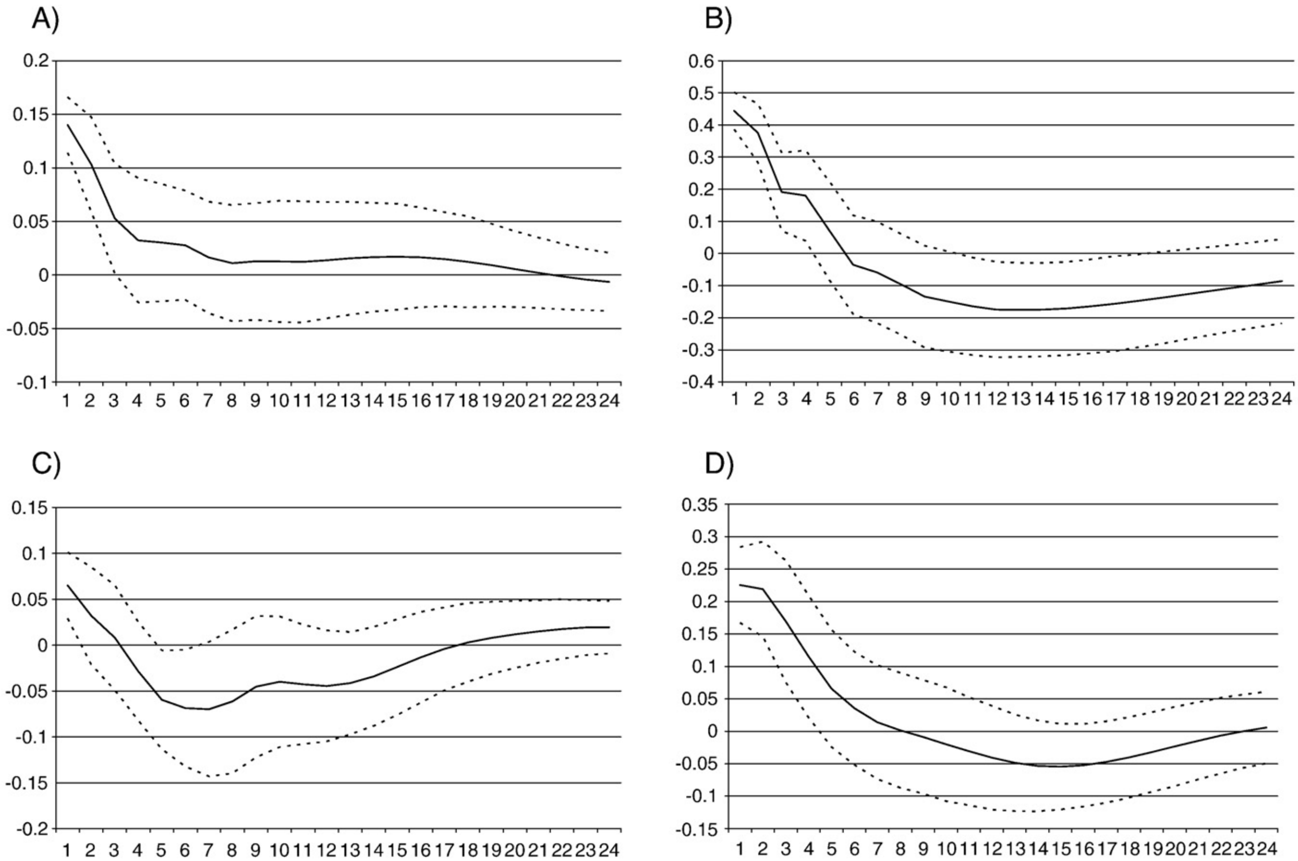

Fig. B1. Response in the interest rate to an exchange rate shock (normalised to increase the exchange rate by 1%), percentage point. A) Australia B) Canada. C) New Zealand D) Sweden.

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