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Working Paper

How Does Monetary Policy Respond to Exchange Rate Movements? New International Evidence

Working Paper, No. 2008/15

Provided in Cooperation with:

Norges Bank, Oslo

Suggested Citation: Bjørnland, Hilde C.; Halvorsen, Jørn Inge (2008) : How Does Monetary Policy Respond to Exchange Rate Movements? New International Evidence, Working Paper, No. 2008/15, ISBN 978-82-7553-455-0, Norges Bank, Oslo, <https://hdl.handle.net/11250/2497770>

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2008 | 15

Working Paper

Research Department

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by Hilde C. Bjørnland and Jørn I. Halvorsen

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How does monetary policy respond to exchange rate movements? New international evidence.*

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October 7, 2008

Abstract

This paper analyzes how monetary policy responds to exchange rate movements in open economies, paying particular attention to the two-way interaction between monetary policy and exchange rate movements. We address this issue using a structural VAR model that is identified using a combination of sign and short-term (zero) restrictions. Our suggested identification scheme allows for a simultaneous reaction between the variables that are observed to respond intraday to news (the interest rate and the exchange rate), but maintains the recursive order for the traditional macroeconomic variables (GDP and inflation). Doing so, we find strong interaction between monetary policy and exchange rate variation. Our results suggest more theory consistency in the monetary policy responses than what has previously been reported in the literature.

JEL-codes: C32, E52, F31, F41.

Keywords: Exchange rate, monetary policy, SVAR, Bayesian estimation, sign restrictions.

*We thank Mardi Dungey, Renee A. Fry, Christian Kascha, Kai Leitemo, Francesco Ravazzolo, participants at the SOEGW conference in Toronto, the CFE conference in Neuchâtel, the MMF conference in London as well as seminar participants at the Norwegian School of Economics and Business Administration for their useful comments and suggestions. The authors thank the *Norwegian Financial Market Fund* under the Norwegian Research Council for financial support. Views expressed are those of the authors and do not necessarily reflect the views of Norges Bank.

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1 Introduction

In 2001, John B. Taylor wrote: *"An important and still unsettled issue for monetary policy in open economies is how much of an interest-rate reaction there should be to the exchange rate in a monetary regime of a flexible exchange rate, an inflation target, and a monetary policy rule."* (Taylor (2001)).

Seven years on, the issue still remains unsettled. Yet, several times a year, the Board of an inflation-targeting central bank meets to analyze the development of a series of economic variables, including the exchange rate. For a small open economy, the exchange rate plays a crucial role in relation to monetary policy. It plays a significant part in the formulation of monetary policy (being an important influence on the overall level of demand and prices), and is itself also influenced by monetary policy. Understanding the role of the exchange rate in the transmission mechanism of monetary policy, as well as quantifying the appropriate interest rate reaction to exchange rate fluctuations, is therefore imperative for the implementation of an efficient monetary policy strategy.

This paper analyzes the interaction between monetary policy and the exchange rate in six open (inflation-targeting) countries, focusing in particular on how monetary policy has responded to exchange rate movements. We address this issue using a structural vector autoregressive (VAR) model that is identified using a combination of sign and short-run (zero) restrictions which preserves the endogenous interaction between the interest rate and the exchange rate commonly observed in the market. The novel feature of our approach is that, instead of the conventional view of using a recursive Cholesky ordering for all of the variables, or the more recent view of relying on only pure sign restrictions, we combine the two approaches in an intuitive way. That is, we allow for a simultaneous reaction between the variables that are observed to respond intraday to news (the interest rate and the exchange rate), but maintain the Cholesky recursive order for the traditional

macroeconomic variables that are observed to respond with delay (output, inflation etc.) to economic shocks. Identified in this way, we believe the VAR approach is likely to give very useful information about monetary policy and exchange rate dynamics in the open economy, that previous studies have been unable to recover.

The standard approach for analyzing monetary policy responses has been to estimate interest rate rules like the simple Taylor rule. For the closed economies, Taylor rules are often estimated using a single equation framework that quantifies the actual interest rate response to observed changes in economic variables such as inflation and the output gap, see e.g. Taylor (1999) for an overview. For open economies, the Taylor rule is frequently augmented to also include the exchange rate. However, the commonly observed simultaneity between the interest rate and the exchange rate implies that the policy rule needs to be estimated simultaneously with a reaction function for the exchange rate. In most cases this is not trivial, and parameters often end up being insignificant.

This has led some to instead favor a multivariate approach when estimating policy rules in the open economy, see e.g. Lubik and Schorfheide (2007) and Dong (2008). Using Bayesian estimation techniques and dynamic stochastic general equilibrium (DSGE) models, they estimate whether monetary policy responds to exchange rate movements. In contrast to the single equation approaches, both find that the interest rate increases systematically in all countries following an exchange rate depreciation. However, the degree of response varies with the assumption underlying the exchange rate behavior. While Lubik and Schorfheide (2007) find a modest interest rate response by assuming the exchange rate follows an exogenous AR process, Dong (2008) reports substantially more evidence using an endogenous specification for the exchange rate.

The focus of this paper will be to specify multivariate VARs to analyze policy reaction (operationalized through short-term interest rates) to shocks in the exchange rate. By investigating the impulse responses and variance decomposition of the policy instrument

in response to the identified shocks, one can get an idea of how central banks use the instrument to reach their goals. While this is not the same as estimating interest rate rules, we believe that the information as to how the interest rates actually react to shocks to be equally interesting, and more to the point, in describing how central banks implement policy. Furthermore, the empirical results may be an important addition to the more theoretically driven structural model responses derived in Lubik and Schorfheide (2007) and Dong (2008), where the chosen exchange rate specification will matter. The paper therefore contributes with new empirical evidence, as well as providing a methodological contribution on how one can identify monetary policy and exchange rate shocks in the open economy.

The analysis is applied to six open economies with floating exchange rates: Australia, Canada, New Zealand, Norway, Sweden and the UK. In all countries, the results suggest that the interest rate increases systematically in response to a shock that depreciates the exchange rate. Furthermore, we find the impact of monetary policy shocks on exchange rates to be non-trivial. In particular, following a contractionary monetary policy shock, the exchange rate appreciates on impact. The exchange rate then gradually depreciates back to baseline, broadly consistent with UIP. These results are in contrast to the results that have been found previously in the literature using recursive restrictions, or, pure sign restrictions, to identify the structural VARs.

The paper is organized as follows. Section 2 motivates and presents our suggested identification scheme (the Cholesky-sign decomposition) that is used to identify the shocks. In Section 3 we present the empirical results and discuss robustness. Section 4 concludes.

2 Identifying monetary policy responses in the structural VAR model

Structural VAR models are increasingly being used as a method to analyze transmission mechanisms of monetary policy. Typically, the focus is on identifying the unsystematic monetary policy shocks and tracing out the effects of these shocks on various macroeconomic and financial variables¹ However, while the method has been successful in providing a consensus with regard to the effects of monetary policy in the closed economy, VAR studies of the open economy have provided several puzzles, in particular with regard to the effects on the exchange rate. For instance, following a contractionary monetary policy shock, the exchange rate is seen to depreciate, or if it appreciates, it does so for a prolonged period of up to three years, thereby giving a hump-shaped response that violates uncovered interest parity (UIP).²

A major challenge when analyzing monetary policy in the open economy, though, is how to identify the structural shocks when there is simultaneity between the interest rate and the exchange rate. Until recently, most of the traditional VAR studies of the open economies have typically ignored this simultaneity, by placing recursive, contemporaneous restrictions on the interaction between monetary policy and the exchange rate. Typically, they either assume a lagged response in the systematic monetary policy setting to exchange rate news (see e.g. Eichenbaum and Evans (1995), Peersman and Smets (2003) and Lindé (2003)), or a lagged response in the exchange rate to monetary policy shocks (see e.g. Kim (2002)³ and Mojon and Peersman (2003)).

¹See e.g. Sims (1980), Bernanke and Blinder (1992) and Christiano, Eichenbaum, and Evans (1999, 2005) for an analysis of the closed economy (i.e. the U.S.), Eichenbaum and Evans (1995) for an analysis of open economies and Bjørnland and Leitemo (2008) for an analysis of the stock market.

²In the literature, the first phenomenon has been referred to as the exchange rate puzzle, whereas the second is termed delayed overshooting (or forward discount puzzle), see Cushman and Zha (1997).

³For some of the countries Kim (2002) also experiments with the reverse restrictions, i.e. that monetary policy responds to the exchange rate with a lag.

This first restriction allows for an immediate exchange rate response to monetary policy shocks, but restricts the policymaker from using all the current information when designing monetary policy. There is, however, no a priori reason for why the monetary policymakers should disregard news on the exchange rate among all available information when deciding the appropriate interest rate response. In fact, many inflation-targeting central banks argue that they specifically look at the exchange rate, to assess to what extent it will impact on import prices and hence the inflation forecast.⁴ Furthermore, the restriction is useless for the purpose of our study, which seeks to quantify this policy response.

The second restriction allows the monetary policymaker to respond immediately to exchange rate news, but imposes strong restrictions on the flexibility of the exchange rate. Daily observations in the market, as well as formal empirical evidence using among others (non-VAR) event studies, typically suggest that the exchange rate responds instantaneously to news, including monetary policy shocks (see e.g. Bonser-Neal, Roley, and Sellon (1998), Zettelmeyer (2004) and Kearns and Manners (2006) among others).

The short-run (zero) restrictions imposed on the contemporaneous interaction between monetary policy and the exchange rate, have recently been scrutinized in Faust and Rogers (2003). Using sign restrictions to *test* the implications of zero restrictions, they find that traditional VARs may have produced a numerically important bias in the estimate of the degree of interdependence. By relaxing the zero restrictions, they find that the exchange rate can appreciate on impact. However, their approach of relying on pure sign restriction can not *identify* the precise exchange rate responses to the monetary policy shocks, which could be immediate or delayed. To do so, one needs to apply additional restrictions, or,

⁴For instance, Heikensten (1998) writes (p.1): In this context I should like to elaborate on the Riksbank's appraisal of the Swedish krona... The Riksbank does not target the krona's exchange rate. But as one of the factors behind inflation, the exchange rate is important for monetary policy in a flexible exchange rate regime. A considerable period with a weak exchange rate might lead to a forecast rate of inflation that exceeds the target, in which case the Riksbank has to respond in order to meet this target.

allow the sign restrictions imposed to be effective for a prolonged period. An example of the latter is found in Uhlig and Scholl (2005), where they impose sign restrictions for up to a year after the shocks. Doing so, however, they find no evidence of instant overshooting as was the case in Faust and Rogers (2003).

An obstacle with 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), which 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. Paustian (2007) has 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 interpretation.

In this paper we suggest instead to combine sign and short-run (zero) restrictions (the Cholesky-Sign decomposition) in an intuitive way to identify the VAR. In particular, we explicitly account for the interdependence between monetary policy and exchange rate movements within a VAR model by applying the sign restriction that following a contractionary monetary policy shock (that 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. It is also in line with results found in Bjørnland (2008), using instead long run (neutrality) restrictions to identify the VAR. It seems therefore reasonable to assume that the restriction is uncontroversial. Note that in the periods 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. Finally, and at the core of this paper, by

restricting the response in the exchange rate only, we leave the issue of how monetary policy responds to exchange rate movements open for testing.

Once allowing for a contemporaneous relationship between the interest rate and the exchange rate, the remaining VAR will be identified using standard recursive zero restrictions on the impact matrix of shocks that are commonly used in the closed economy literature, see e.g. Christiano, Eichenbaum, and Evans (1999). That is, we identify a recursive structure between domestic macroeconomic variables and monetary policy, so that monetary policy can react to all shocks, but the macroeconomic variables (such as output and inflation) react with a lag to monetary policy shocks. These restrictions are less controversial, and studies identifying monetary policy without these restrictions have found qualitatively similar results: see for example Faust, Swanson, and Wright (2004). Below we set out to explain how we impose the restrictions in more detail.

2.1 The Cholesky-sign identification scheme

The choice of variables included in the VAR model is based on small open economies with a New-Keynesian framework, such as the one described in Svensson (2000) and Clarida, Gali, and Gertler (2001). Formally, the variables to be included consist of $X_t = [i_t^*, y_t, \pi_t, i_t, re_t]'$, where i_t^* is the foreign short-term nominal interest rate, y_t is the log of real GDP, π_t is the log of the price differential within a year, i_t the short-term nominal interest rate, and re_t the log of the country's real exchange rate.

The five variables can be estimated jointly in the reduced form VAR(p), which in matrix form (ignoring any deterministic terms) can be expressed as

$$A(L)X_t = e_t, \text{ with } \Sigma_e = E(e_t e_t'), \tag{1}$$

$A(L)$ is here a (5×5) matrix polynomial in the lag operator L , $A(L) = \sum_{i=0}^p A_i L^i$ with

$A_0 = I_5$. e_t is the one step ahead prediction error which is assumed to be normally distributed with a positive semidefinite covariance matrix Σ_e . Given that $A(L)$ is invertible, the VAR model can also be written in terms of its moving average (MA) representation:

$$X_t = B(L)e_t, \tag{2}$$

where $B(L) = A(L)^{-1}$.

We assume that the error term e_t is linearly related to a vector of five independent structural shocks specified as $\varepsilon_t = [\varepsilon_t^{i^*}, \varepsilon_t^y, \varepsilon_t^\pi, \varepsilon_t^{mp}, \varepsilon_t^{ex}]'$. It is common to loosely identify $\varepsilon_t^{i^*}$ as foreign interest rate shocks, ε_t^y as output shocks and ε_t^π as inflation shocks (or cost-push shocks). For the latter two shocks (the main focus of this paper), ε_t^{mp} represents monetary policy shocks and ε_t^{ex} refers to real exchange rate shocks. If we normalize the structural shocks to have unit variance, the relationship between the error term and structural shocks can be written as

$$e_t = A\varepsilon_t, \text{ with } I_5 = E(\varepsilon_t\varepsilon_t'). \tag{3}$$

By substituting for equation (3) into (2), the model can be written in the form of a structural MA-representation

$$X_t = C(L)\varepsilon_t, \tag{4}$$

where $C(L) = B(L)A$. In order to derive the impulse responses and the variance decomposition, the matrix A needs to be identified. So far the only restriction on A comes from equation (3) that implies

$$\Sigma_e = E(e_t e_t') = AE(\varepsilon_t \varepsilon_t')A' = AA'. \quad (5)$$

There are, however, many different decompositions satisfying $AA' = \Sigma_e$, hence we do not have a unique MA representation in terms of the structural shocks. We know, however, that for two different decompositions, $\Sigma_e = AA'$ and $\Sigma_e = \tilde{A}\tilde{A}'$, it must be the case that $A = \tilde{A}Q$ with Q being an orthogonal matrix, i.e. $QQ' = I_5$. A property of this type of matrix is that the columns $Q = [q_1, \dots, q_5]$ are orthonormal which tells us that its vectors are mutually perpendicular, i.e. $\langle q_i, q_j \rangle = 0$ for $i \neq j$, and of unit length, i.e. $\|q_i\|=1$.

For the case of our small open economy model, we will identify the matrix A by using a combination of a Cholesky and sign identification approach. Technically, it amounts to partitioning the matrix X_t into two blocks of variables where the relationship among the structural shocks of the first block is cast in a recursive order while for the second block, a contemporaneous relationship among the structural shocks is allowed for. For our model, the two blocks are specified to be $X_{1t} = [i_t^*, y_t, \pi_t]'$ and $X_{2t} = [i_t, re_t]'$. If we select $\tilde{A} = A^c$, where A^c is equal to the lower triangular product of the Cholesky decomposition, one can verify that the block structure forces Q to be restricted to Q_r such that the relationship between the error term and the structural shock now can be written as

$$A\varepsilon_t = A^c Q_r \varepsilon_t = \begin{pmatrix} a_{11}^c & 0 & 0 & 0 & 0 \\ a_{21}^c & a_{22}^c & 0 & 0 & 0 \\ a_{31}^c & a_{32}^c & a_{32}^c & 0 & 0 \\ a_{41}^c & a_{42}^c & a_{43}^c & a_{44}^c & 0 \\ a_{51}^c & a_{52}^c & a_{53}^c & a_{54}^c & a_{55}^c \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \cos(\theta) & -\sin(\theta) \\ 0 & 0 & 0 & \sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} \varepsilon_t^{i^*} \\ \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^{mp} \\ \varepsilon_t^{ex} \end{pmatrix}$$

From this setup one should note that the zero elements on the fourth and fifth column

of Q_r together with the multiplication of the Cholesky decomposition imply that monetary policy shocks and exchange rate shocks can have a non-immediate impact on the variables belonging in X_{1t} . For monetary policy shocks we find this to be convenient since it represents the conventional view used in the closed economy literature (Christiano, Eichenbaum, and Evans (1999)), namely that monetary policy can react immediately to macroeconomic variables (such as output and inflation), while such a relationship does not exist the other way around (i.e. macroeconomic variables react with a lag to policy shocks).⁵ Similar assumptions pertain to the exchange rate shocks: 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, we will show that the effects of the monetary policy shocks (or the exchange rate shocks) will be invariant to how these variables are ordered. This follows from a generalization of proposition 4.1 in Christiano, Eichenbaum, and Evans (1999), and is discussed further in the robustness section below.

For our second block of variables, we allow for contemporaneous interactions between the interest rate and the exchange rate. By varying the value of θ around the unit circle $(0, 2\pi)$, all potential contemporaneous relationships can be traced out. To identify the monetary policy shocks, we then impose one sign restriction, namely the conditional overshooting hypothesis that a monetary contraction will be met by an immediate appreciation of the real exchange rate.⁶

⁵Having the foreign interest rate in the recursive block should neither be controversial, since shocks to the domestic variables in a small open economy are usually assumed to have little or no influence on foreign variables, at least on impact.

⁶Note that, due to the form of $Q_r(\theta)$, this restriction implies that an unexpected appreciation of the exchange rate must have an immediate non-positive impact on the interest rate.

2.2 Estimation and inference

To estimate the model, we adopt a Bayesian approach. As shown in Uhlig (2005) such a approach is computationally simple and allows for a conceptually clean way of drawing error bands for the statistics of interest (such as impulse responses and variance decomposition). The prior for our reduced form coefficients and covariance matrix is chosen to be non-informative. We let θ have a uniform prior specified as $U(0, 2\pi)$.

Within this setting the first three shock of our VAR model will be identified using the Cholesky decomposition based only on draws from the posterior VAR. For the last two shocks, however, a sign restriction approach must be implemented as in Uhlig (2005). That is, for each of the draw from the VAR posterior we make a uniform draw for θ , calculate the impulse responses and check whether our sign restriction is satisfied. If this is the case, we keep the draw; otherwise the draw is discarded. Error bands are then calculated based on all the draws that are accepted.

3 Empirical results

The model is estimated for six countries: Australia, Canada, New Zealand, Norway, Sweden and the UK, using quarterly data from 1983Q1 to 2004Q4. Using an earlier starting period will make it hard to identify a stable monetary policy regime, as monetary policy prior to 1983 has undergone important structural changes and unusual operating procedures (see Bagliano and Favero (1998) and Clarida, Gali, and Gertler (2000)).

Consistent with most other related studies, the variables, with the exception of prices, are specified in levels. Rather than including prices, we include a measure of inflation, calculated as annual changes in the CPI. We have chosen to focus on annual inflation as it is a direct measure of the monetary policy target in inflation-targeting countries. One may argue (Giordani (2004)) that with the theoretical model of Svensson (1997) as a data-

generating process, 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, as pointed out by Lindé (2003), a practical point that Giordani does not address is how to compute trend output (thereby also the output gap). To overcome this issue, we therefore instead follow Lindé (2003) and include 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. However, as will be seen in the robustness section below, excluding the trend does not change the main results. We choose four lags for all countries. Again, results will be robust to alternative lag orders.

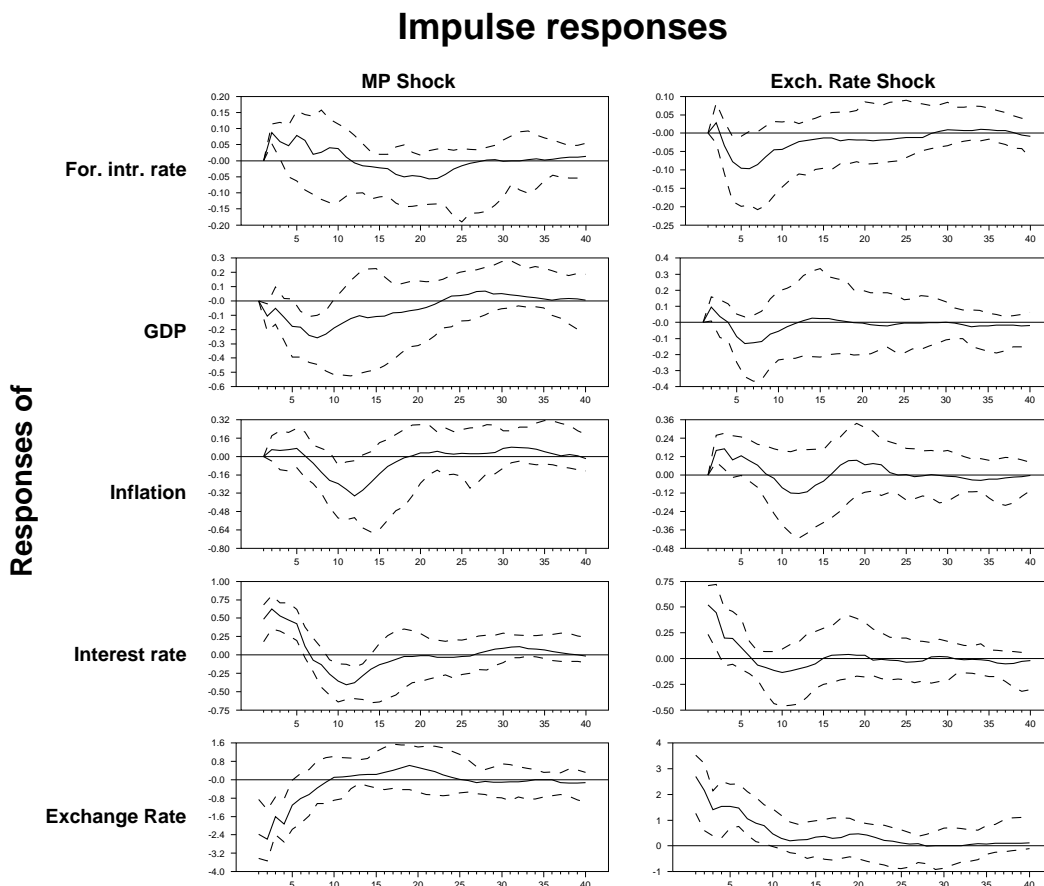
3.1 Empirical results using Cholesky-sign identification

Figures 1-6 show, for each of the six countries: Australia, Canada, New Zealand, Norway, Sweden and the UK respectively, the effect of the monetary policy shock (in the left column) on all five variables and the effect of an exchange rate shock (in the right column) on the same variables, using the Cholesky-sign identification. The solid line represents the median response of the error bands for the impulse responses, while the dotted lines are the 16 and 84 percentiles. Before analyzing the systematic monetary policy response to exchange rate shocks, we discuss the effects of the unsystematic monetary policy shocks on all macroeconomic variables (left column).

The figures suggest that a contractionary monetary policy shock (that increases the interest rate temporarily) has the usual effects identified in other international studies. In particular, output falls gradually for 1-2 years before the effects essentially die out. The effect on inflation is also eventually negative as expected and reaches its minimum after 2-3 years. However, for some countries, and in particular the UK, there is some evidence that consumer prices increase initially, commonly referred to as the price puzzle.⁷ Though,

⁷The puzzle has often been explained by a cost channel of the interest rate, where part of the increase

Figure 1: Australia: The response to monetary policy shocks and exchange rate shocks

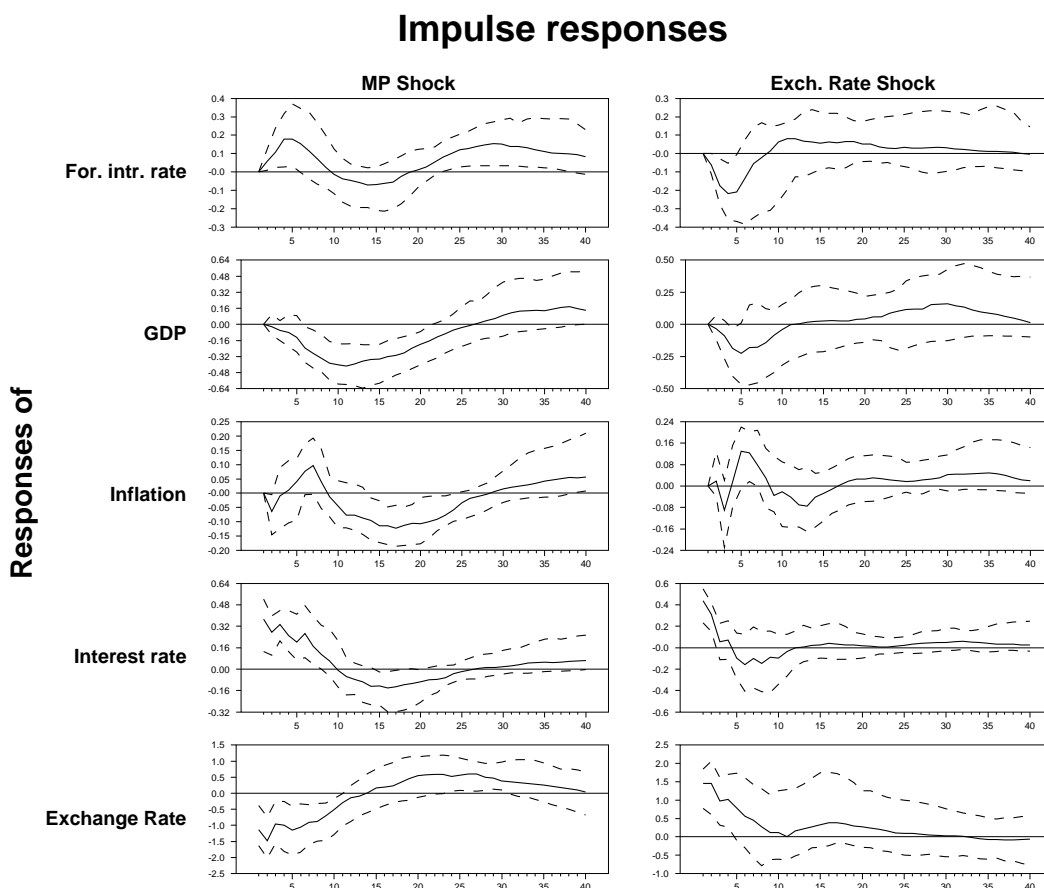


in most cases, this initial response is not significant.

There is a high degree of interest-rate inertia in the model, in the sense that a monetary policy shock is only offset by a gradual reduction in the interest rate. The interest rate response is consistent with what has become known as good monetary policy conduct (see Woodford (2003)). In particular, interest-rate inertia is known to let the policymaker smooth the effects of policy over time by affecting private-sector expectations. Moreover, the reversal of the interest rate stance is consistent with the policymaker trying to offset the adverse effects of the initial policy deviation from the systematic part of policy.

Regarding the exchange rate, the figures show that in all countries the exchange rate in firms' borrowing costs is offset by an increase in prices (Ravenna and Walsh (2006) and Chowdhury, Hoffmann, and Schabert (2006)).

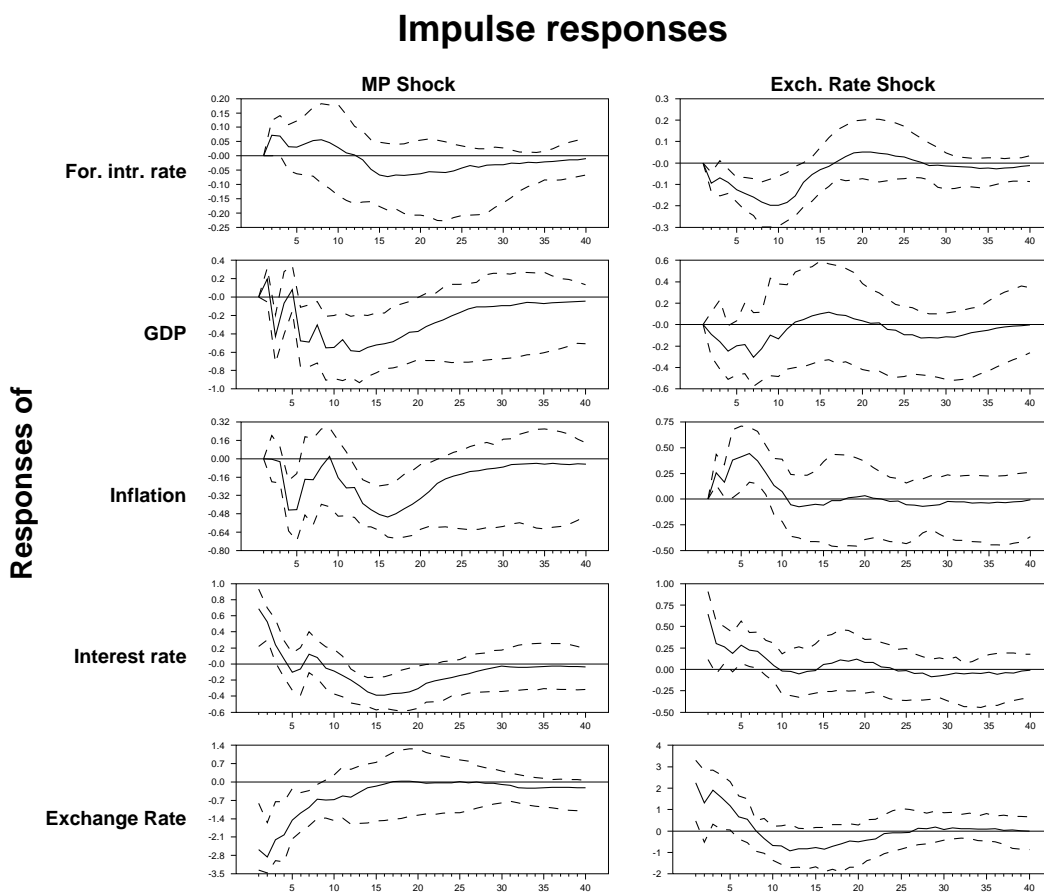
Figure 2: Canada: The response to monetary policy shocks and exchange rate shocks



appreciates on impact (as assumed). However, the response is far from trivial. The median response indicates that the exchange rate may fall by approximately 2.5-4 percent, following (a normalized) one percentage point increase in the interest rate. Furthermore, following the initial effect, the exchange rate thereafter gradually depreciates back to baseline, consistent with the Dornbusch overshooting hypothesis. In most cases, the maximum effect is felt initially, or at most, delayed by one quarter. This seems to be a robust feature of the data, as indicated by the 16-84 percentiles error band around the median responses.

Hence, we find no evidence of delay overshooting that has often been found in open economy VAR applications identified using recursive restrictions. Instead, our results are consistent with main conclusion from Faust and Rogers (2003) which, using sign restric-

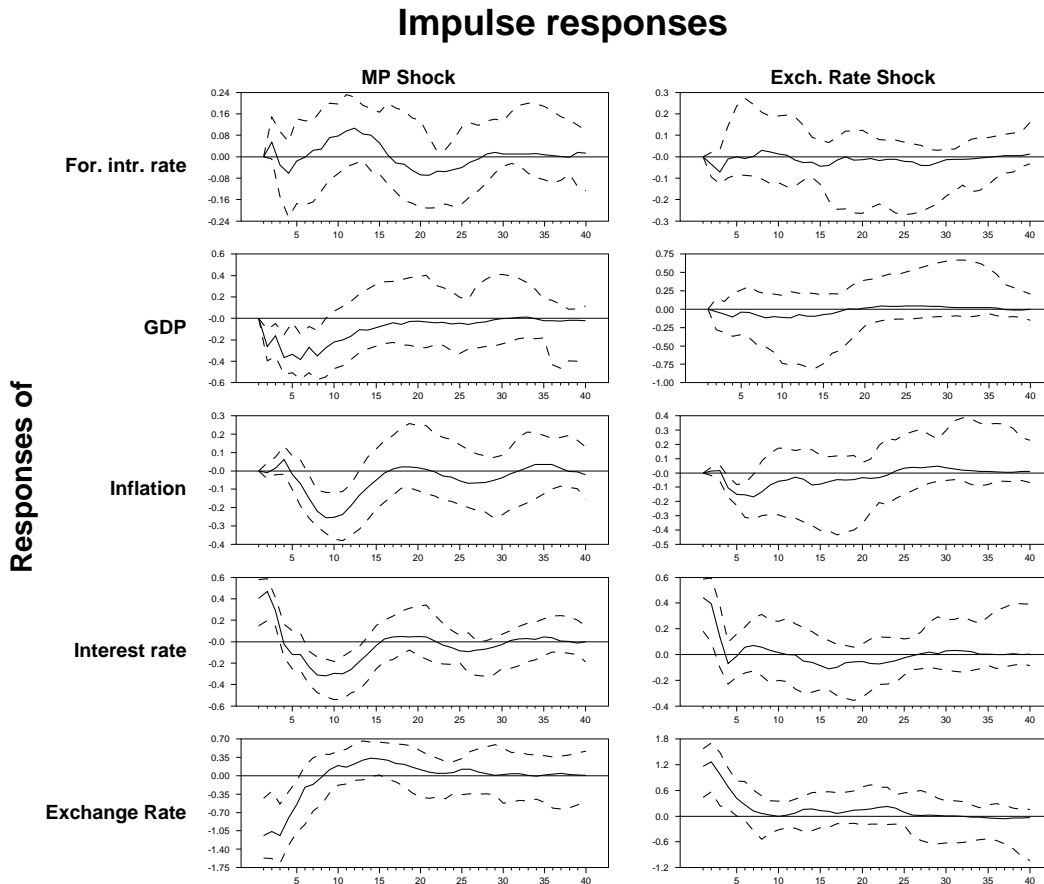
Figure 3: New Zealand: The response to monetary policy shocks and exchange rate shocks



tions only, could not rule out that there was an early peak in the exchange rate following a monetary policy shock.⁸ However, whereas they could not determine whether the maximum response was immediate or delayed, our results suggest the maximum response to be within a quarter. This result of instant overshooting is also consistent with findings in Bjørnland (2006, 2008) and Cushman and Zha (1997), using either long-run (neutrality) restrictions or a structural approach to identify the VARs. Finally, the magnitude of the response found here is consistent with (non-VAR) event studies that measure the imme-

⁸In contrast, Uhlig and Scholl (2005) find no evidence of overshooting, using also sign restrictions. However, by restricting, among others, domestic prices from rising (thereby avoiding "price puzzles" by construction), they find instead puzzling responses in the other variables, as real output rises and the real exchange rate depreciates on impact following a contractionary monetary policy shock. These impulse responses are hard to interpret as all resulting from a *contractionary* monetary shock, making us question whether the identified shocks could be a hybrid of shocks, lacking clear economic interpretations.

Figure 4: Norway: The response to monetary policy shocks and exchange rate shocks

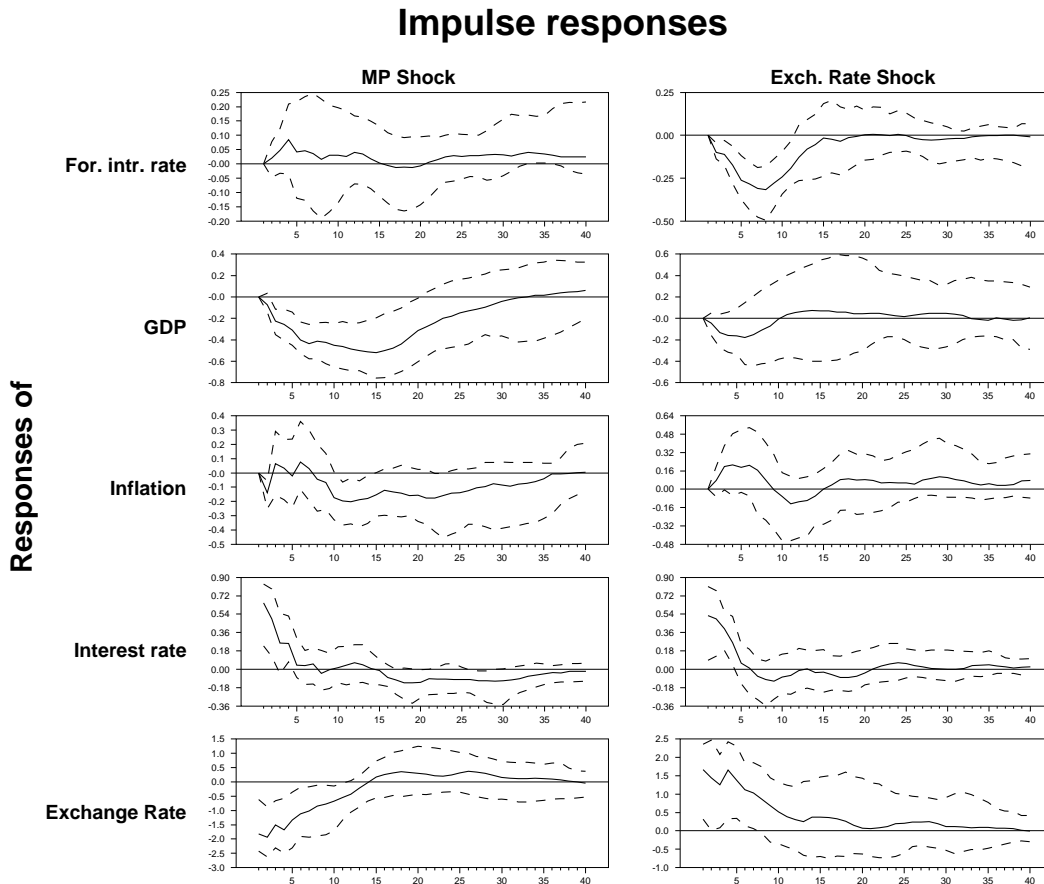


mediate response of the exchange rate to shocks associated with particular policy actions.⁹ Hence, we feel confident to conclude that by allowing the interest rate and the exchange rate to respond simultaneously to news, the exchange rate behaves closer to economic theory than what previous VAR studies have reported.

Having examined the response in the variables to a (unsystematic) monetary policy shock, we now turn to address the core question in this paper, namely the systematic response in monetary policy to an exchange rate shock (right column). All figures emphasize that following an exchange rate shock that depreciates (increase) the real exchange rate

⁹For instance, Zettelmeyer (2004) analyzing Australia, Canada and New Zealand using daily data, finds that a one percentage point increase in the interest rate will appreciate the exchange rate on impact by 2-3 percent. Kearns and Manners (2006) using intraday data for the same three countries plus the UK find similar results, although the magnitude of the effects of the shocks is somewhat smaller.

Figure 5: Sweden: The response to monetary policy shocks and exchange rate shocks

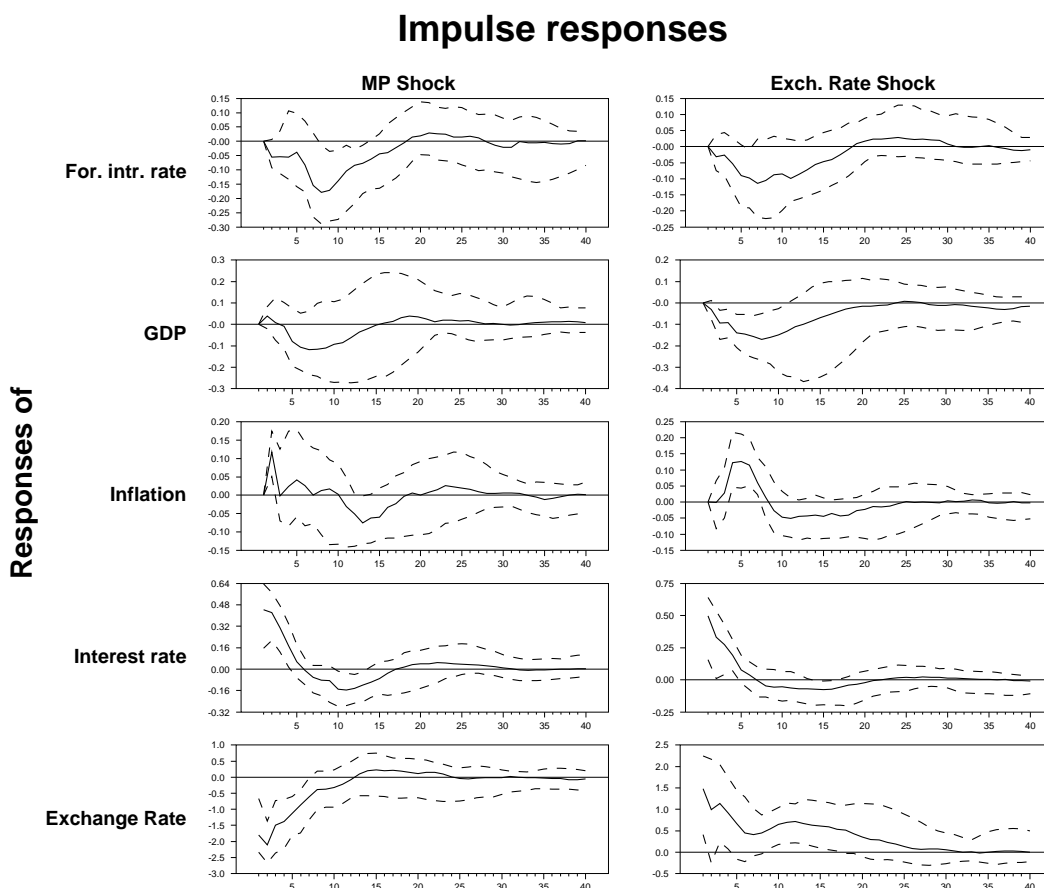


by one percent, interest rates increase by 20-40 basis points. In all countries, the maximum interest rate response is immediate and then dies quickly out, within a year or so. Hence, if the central banks respond to the exchange rate, they do so mainly on impact. Failing to account for this interaction will therefore probably bias all other results.

Interestingly, the interest rate response could be (indirectly) related to the effect of the exchange rate on inflation, which increases temporarily in most countries. Output, on the other hand, responds very little at first, but as the monetary contraction intensifies, it starts to fall. Eventually monetary policy is eased, and output returns to equilibrium.

Are these results plausible? From a theoretical point of view, central banks may want to respond to real exchange rate movements in order to smooth international relative price fluctuations that could affect their international competitiveness and have an effect on

Figure 6: UK: The response to monetary policy shocks and exchange rate shocks



aggregate demand for domestic goods. This is the inherent feature of the DSGE model in Lubik and Schorfheide (2007), which finds that in two of the four countries they examine (Canada and the UK), do the central banks include the exchange rate in their policy rules. Using a similar model, but allowing the exchange rate to be fully endogenously determined, Dong (2008) finds larger responses, as measured by the marginal likelihood values. Now the Reserve Bank of Australia, the Bank of Canada and the Bank of England have all responded to real exchange rate movements in the past.¹⁰

Finally, we examine the quantified contribution of the different shocks to the variance

¹⁰Normative studies also suggest that if monetary policy should offset the effects of exchange rate fluctuations, it should respond immediately. For instance, Ball (1999) finds that a depreciation of the exchange rate of 1 percent would call for an immediate interest rate response of 37 basis points, followed by a partial offset by 15 basis points the period after. Similar responses are also suggested in Svensson (2000), but there the response is offset the next period.

Table 1: Variance decomposition of the interest rate, 1,4 and 8 quarter horizon

Shocks	Monetary policy shock	Exchange rate shock	Other shocks
AUSTRALIA			
1-step	0.44	0.47	0.09
4-step	0.45	0.22	0.33
8-step	0.30	0.14	0.56
CANADA			
1-step	0.30	0.41	0.29
4-step	0.21	0.15	0.64
8-step	0.19	0.18	0.63
NEW ZEALAND			
1-step	0.42	0.38	0.20
4-step	0.25	0.19	0.56
8-step	0.16	0.16	0.68
NORWAY			
1-step	0.33	0.39	0.28
4-step	0.22	0.18	0.60
8-step	0.17	0.13	0.70
SWEDEN			
1-step	0.50	0.34	0.16
4-step	0.34	0.33	0.33
8-step	0.22	0.24	0.54
UNITED KINGDOM			
1-step	0.34	0.42	0.24
4-step	0.36	0.32	0.32
8-step	0.29	0.23	0.48

in the interest rate at different horizons. That is, Table 1 displays for each country the variance decomposition of the interest rate with respect to the (median) effect of the different shocks. We focus on the effect on impact, after four quarters and after eight quarters. The table demonstrates that the exchange rate explains a large share (34-47 percent) of the variation in the interest rate on impact. In fact, in four of the countries, Australia, Canada, Norway and the UK, the exchange rate shocks are the most important shocks for explaining the variation in the interest rate on impact. However, the contribution of these shocks thereafter quickly dies out, so that already after two years, the exchange rate shocks explain no more than 10-20 percent of the interest rate variation.

Hence, we can conclude that the interest rate responds systematically to exchange

rate shocks. However, this does not necessarily imply that the exchange rate has an independent role in the monetary policy rule. The fact that a depreciated exchange rate also increased inflation implies that we can not exclude the possibility that the systematic monetary policy response to exchange rate shocks could just reflect that exchange rates have an impact on less controversial objectives such as inflation. In particular, we have no evidence that the exchange rate has an independent role in the monetary policy rule other than as a leading indicator for variables such as inflation. The magnitude of the response, however, indicates that the exchange rate is an important variable in interest rate determination. Furthermore, accounting for this interaction may be important when identifying monetary policy in open economies. In particular, VAR studies that assume a lagged response in (the systematic) monetary policy setting to exchange rate news would most likely underestimate the responses. This issue is explored further in the next section.

3.2 Comparing Cholesky-sign with Cholesky identification

If monetary policy reacts immediately to exchange rate shocks and the exchange rate reacts on impact to monetary policy shock, then one would expect the interaction between interest rates and exchange rates to be important when identifying the various shocks. Below we examine the implications of our restrictions versus a pure Cholesky decomposition where we restrict the interest rate to respond to exchange rate shocks with a lag.

Figures 7-12 reported in the appendix show for Australia, Canada, New Zealand, Norway, Sweden and the UK respectively, a comparison of the recursive Cholesky identification and our suggested Cholesky-sign restriction. Note that solid line is the impulse responses found using the Cholesky decomposition with the exchange rate now ordered below the interest rate, while the dotted line is the median response following our suggested Cholesky-sign decomposition reported above. For ease of exposition, the effect of the monetary policy shock (left column) is normalized to increase the interest rate by one

percentage point initially, while the exchange rate shock (right column) is normalized to increase (depreciate) the exchange rate by one percent initially.

Starting with the effects of a monetary policy shock (left columns). The figures demonstrate that when monetary policy is identified using the traditional recursive Cholesky identification, four of the countries suggest virtually no exchange rate response to a monetary policy shock (Australia, Canada, Norway and the UK) while in the remaining two countries (New Zealand and Sweden), the exchange rate responds on impact, but shows evidence of delay overshooting.

Recall that to obtain these responses, we have restricted the interest rate from responding initially to exchange rate shocks. However, since our suggested Cholesky-sign identification found exactly the opposite, i.e. monetary policy will react immediately to exchange rate shocks, one could expect the interaction between interest rates and exchange rates to be important when identifying monetary policy shocks. Failing to account for this interaction may therefore likely have biased the results.

The right column, mapping out the effects of the exchange rate shocks, illustrates this. The figures suggest that when the recursive Cholesky identification is used, the interest rate does not respond to an exchange rate shock in any of the countries, even after a year. In fact, none of the countries, with the possible exception of New Zealand, suggest any systematic monetary policy response to the exchange rate shock at all.

Hence, whereas the Cholesky-sign identification has uncovered a clear interaction between the interest rate and the exchange rate, the conventional Cholesky identification would fail to recover any simultaneity between the interest rate and the exchange rate. This is important, as many researchers would argue that by restricting the policy response from responding by one period only, one can still allow possible monetary policy reactions to the exchange rate, but with a lag. However, as suggested from the figures above, the policy reaction will in most cases be severely underestimated.

Finally, note also that when the Cholesky identification is used, the effect of the monetary policy shock on the remaining variables will also be underestimated, suggesting more of a price puzzle and less of an output response relative to the median response found using the Cholesky-sign identification. Hence, accounting for an interaction between monetary policy and the exchange rate is imperative not only for estimating the systematic response in the interest rate to exchange rate shocks, but also for establishing the role of the exchange rate in the monetary policy transmission.

3.3 Robustness

Below we check robustness of our results to the following six changes. We first examine two alternative model specifications: (i) We estimate the model in levels but without the trend and (ii) we check robustness to the lag order, using two instead of four lags in the estimated VAR. (iii) We then test robustness to the order of variables in the recursive (Cholesky) block. That is, we reverse the order of the first three variables, so that inflation is ordered above output which is ordered above the foreign interest rate. Now output and inflation will respond with a lag to both domestic and foreign monetary policy. (iv) Next we check robustness to the inclusion of an oil price. An objection to our set up is that many of the countries examined are net oil exporters (in particular Canada, Norway and the UK). By including the oil price, we can examine if oil is an important contributor to exchange rate variations. To save on the degrees of freedom, we let the oil price be exogenous to the VAR (since these are small countries with little effect on oil prices), although allowing it to enter as an endogenous variable provides about the same results. (v) We then check robustness to how we have included the foreign interest rate. Since the countries in our sample are small open economies, they have little effect (if any at all) on the foreign interest rate. We can therefore allow the foreign interest to be exogenous to the VAR. (vi) Finally, we re-estimate the model from 1988, using all variables. The period

after 1988 is considered to be a more stable monetary policy regime, with more countries adopting inflation-targeting as a monetary policy strategy. Due to the relatively short sample, we let GDP, inflation, interest rates and exchange rate be endogenous (using two lags in the VAR), while the foreign interest rate and oil prices are included as exogenous variables.

Figures 13-18 in Appendix A graph the impulse responses from the robustness exercises respectively. The results are illustrated for Canada, but similar findings can be obtained for the other countries at request. Clearly the main results are robust to these changes. In particular, the interdependence between monetary policy and exchange rate fluctuations remains intact. The main changes are found when we remove the trend from the analysis, as now the effect of monetary policy on output is more persistent than in the basic case. However, this is not surprising as the relevant measure in the central bank's reaction function is the output gap, and not the level of output.

Regarding the test of the ordering of the first three variables, the results remain unchanged. This is interesting, as it suggests that the order of the variables in the recursive block does not play any role. This follows from a generalization of the well known findings in Christiano, Eichenbaum, and Evans (1999). There, proposition 4.1 states 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 above the policy equation becomes a computational convenience with no bite. The real bite here is the short-term (zero) restriction that the first three variables in the VAR don't respond contemporaneously to a monetary policy shock. The same argument will hold for the exchange rate shock since the first three variables don't respond contemporaneously to this shock either.

4 Conclusions

Empirical evidence using intraday data has shown that exchange rates react immediately to news, including news about monetary policy. If monetary policy also reacts quickly to surprise changes in the exchange rate, one would expect the interaction between interest rates and exchange rates to be important in applied analysis of monetary policy.

This paper has demonstrated that monetary policy and exchange rate interaction matter. By estimating VAR models that are identified using a combination of sign and short-term (zero) restrictions (the Cholesky-sign identification), we have analyzed how monetary policy has responded to exchange rate movements in six open economies. Our suggested identification preserves the contemporaneous interaction between the interest rate and the exchange rate, without extensively deviating from the established literature of identifying a monetary policy shock as an exogenous shock to an interest rate reaction function.

The novel feature of such an approach is that, instead of the conventional view of using a recursive Cholesky ordering for all of the variables, or the more recent view of relying on only pure sign restrictions, we combine the two approaches in an intuitive way. That is, we allow for a simultaneous reaction between the variables that are observed to respond intraday to news (the interest rate and the exchange rate, but maintain the Cholesky recursive order for the traditional macroeconomic variables that are observed to respond with delay (output, inflation etc.) to economic shocks.

Doing so, we find great interaction between monetary policy and the exchange rate. In particular, an exchange rate shock that depreciates the exchange rate by one percent, increases the interest rate on impact (within a quarter) by 20-40 basis points. Furthermore, we find the impact of monetary policy shocks on exchange rates to be non-trivial and consistent with Dornbusch overshooting. In particular, a contractionary monetary policy

shock that increases the interest rate by one percentage point, appreciates the exchange rate on impact by 2.5-4 percent. The exchange rate thereafter gradually depreciates back to baseline, broadly consistent with UIP. These results are in contrast to what has been found in traditional VAR studies.

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5 Appendix

Figure 7: Australia: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

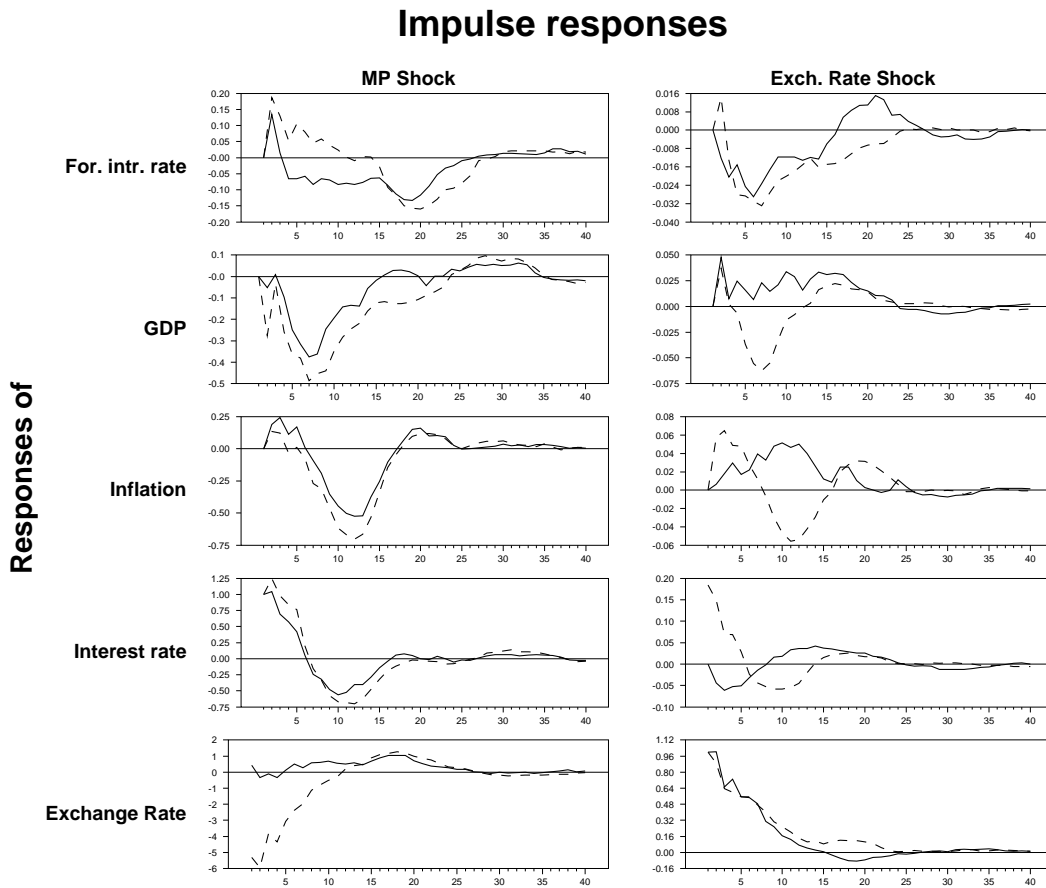


Figure 8: Canada: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

Impulse responses

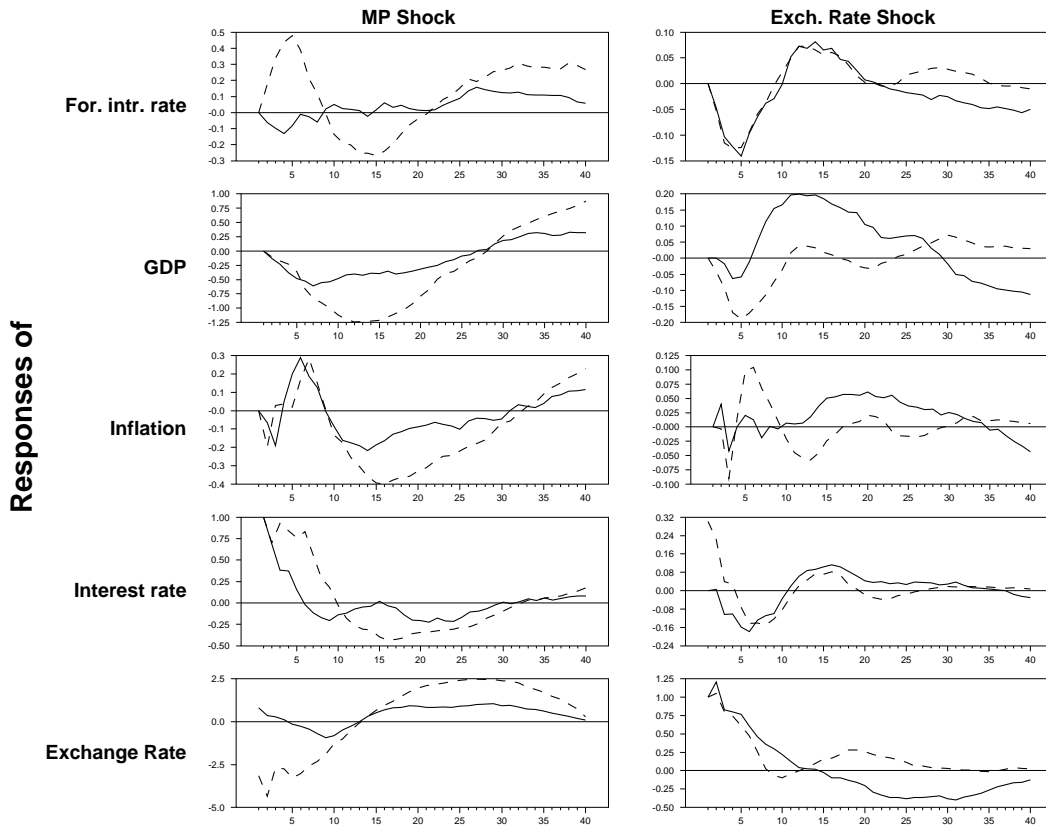


Figure 9: Norway: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

Impulse responses

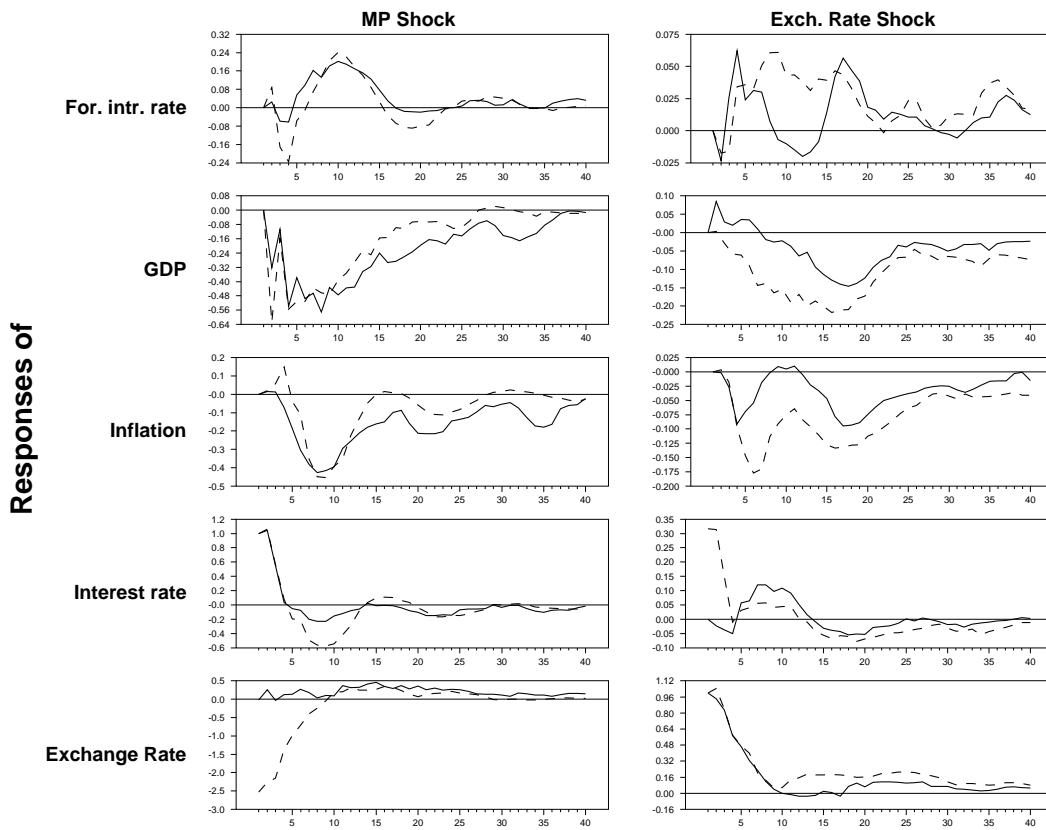


Figure 10: New Zealand: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

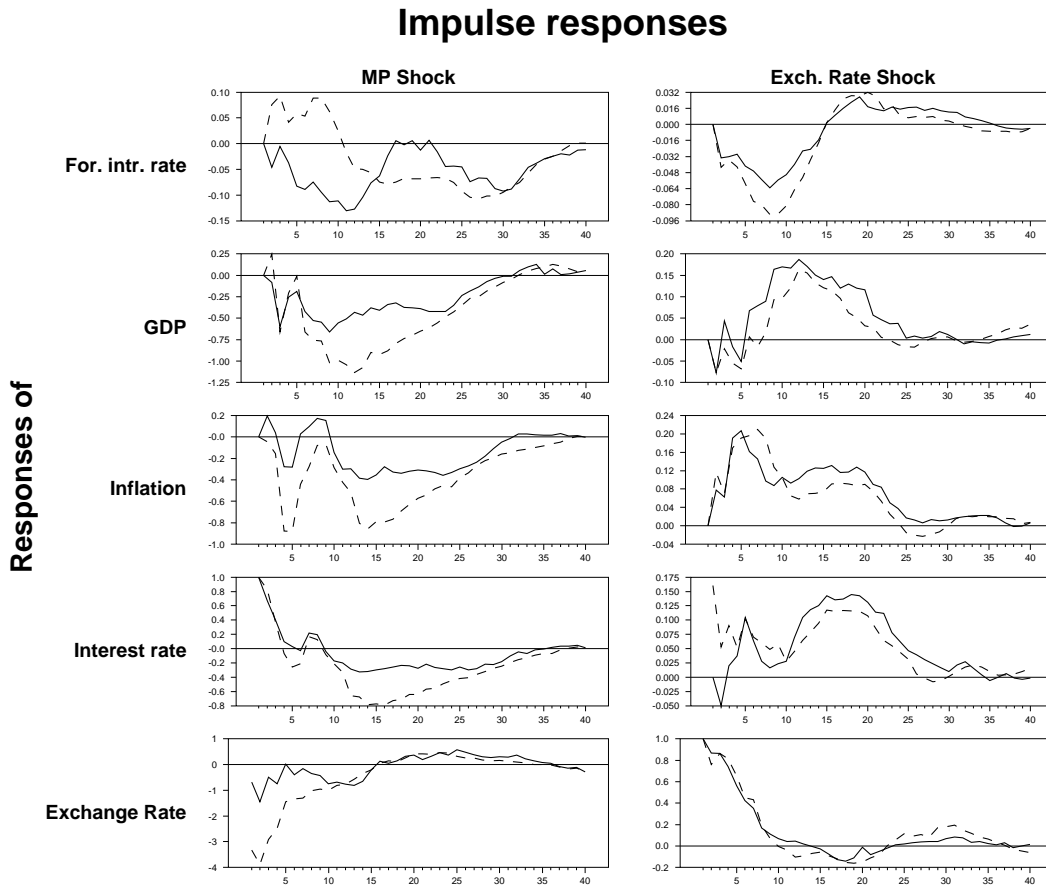


Figure 11: Sweden: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

Impulse responses

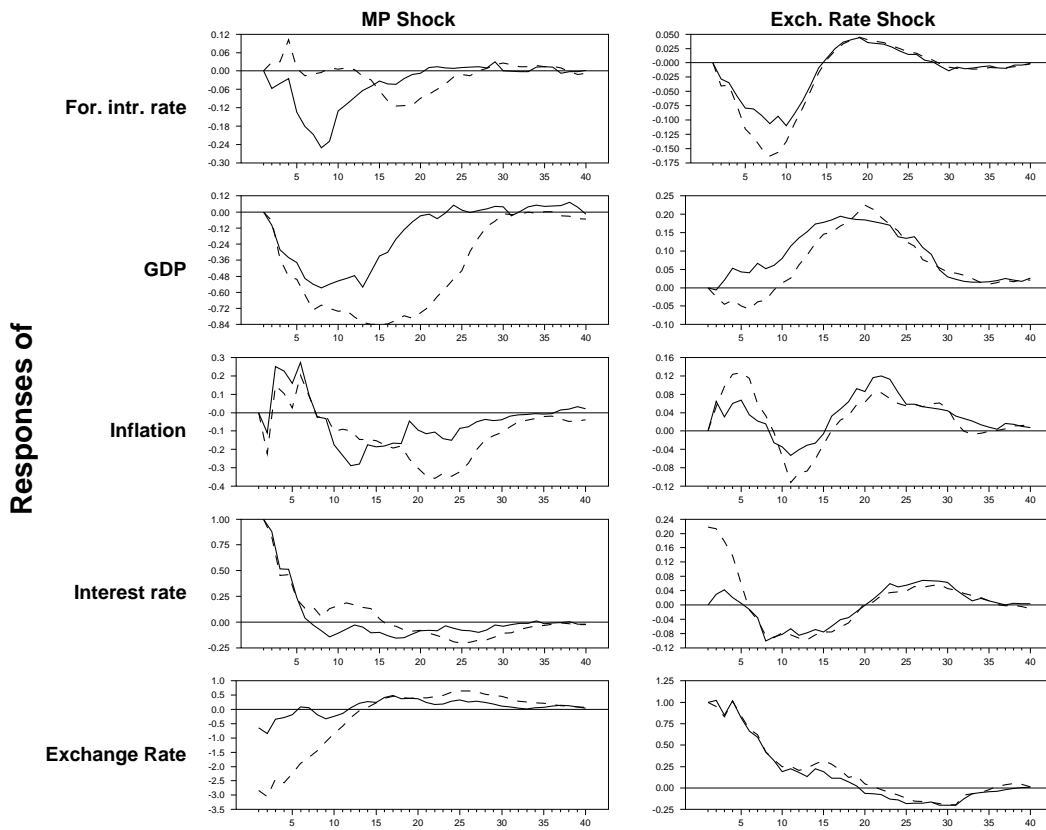


Figure 12: UK: The response to monetary policy shocks and exchange rate shocks; Cholesky versus Cholesky-sign

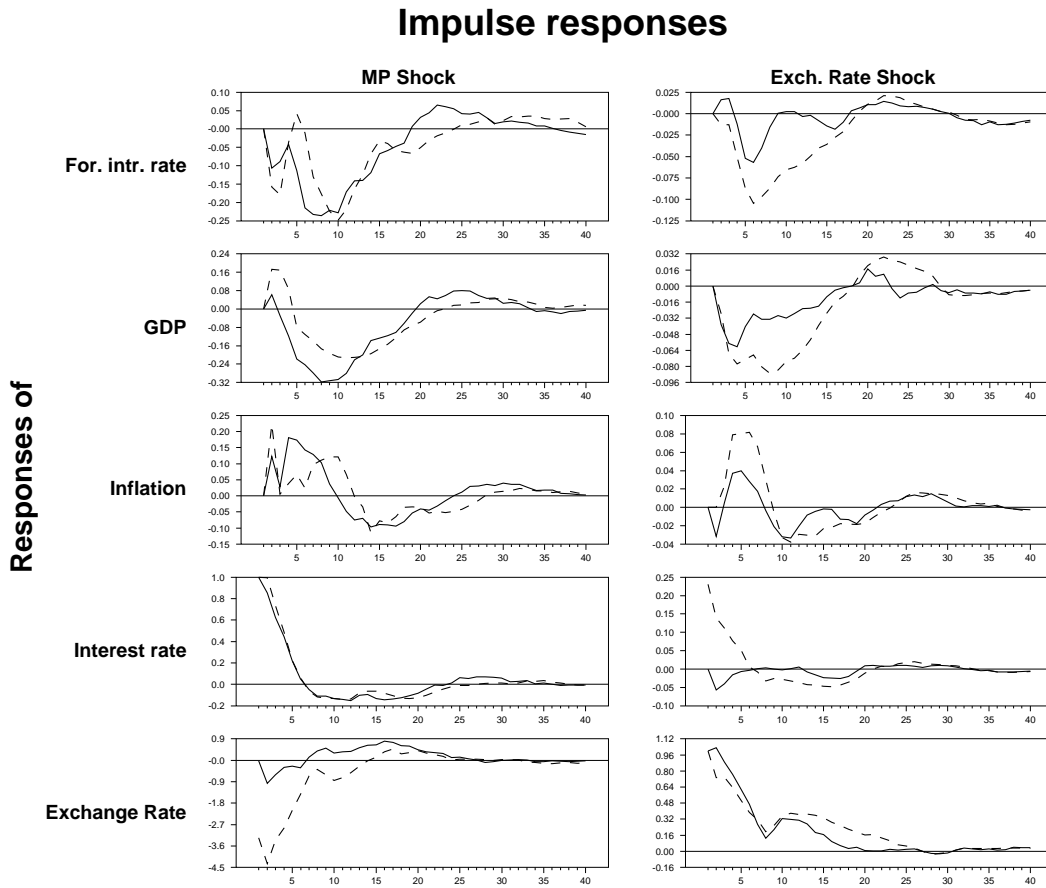


Figure 13: Canada: The response to monetary policy shocks and exchange rate shocks;
 Robustness: Model without trend

Impulse responses

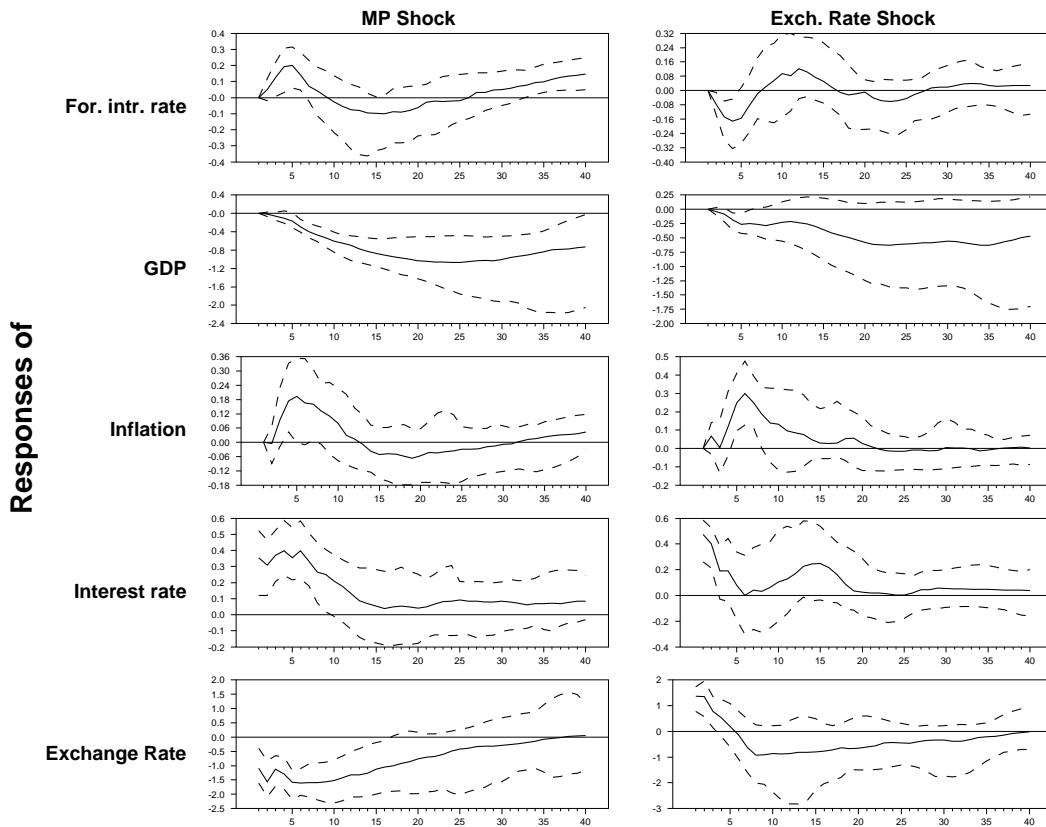


Figure 14: Canada: The response to monetary policy shocks and exchange rate shocks;
 Robustness: Model with 2 lags

Impulse responses

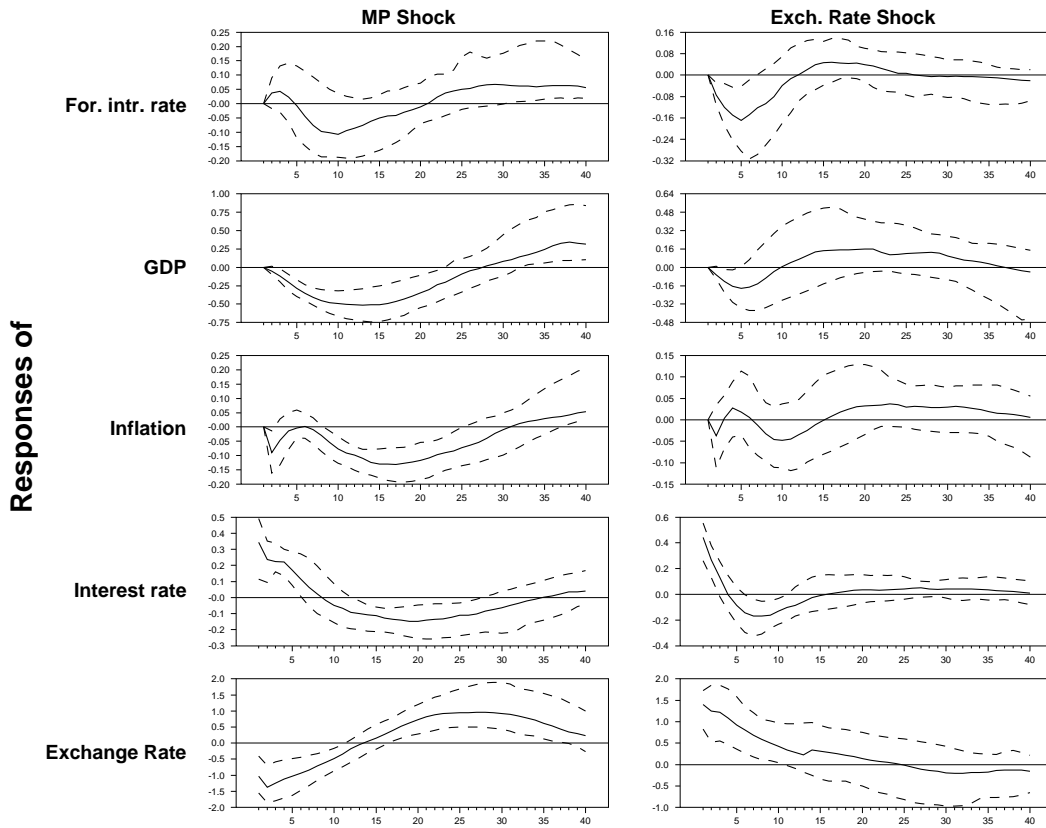


Figure 15: Canada: The response to monetary policy shocks and exchange rate shocks;
Robustness: Alternative recursive order

Impulse responses

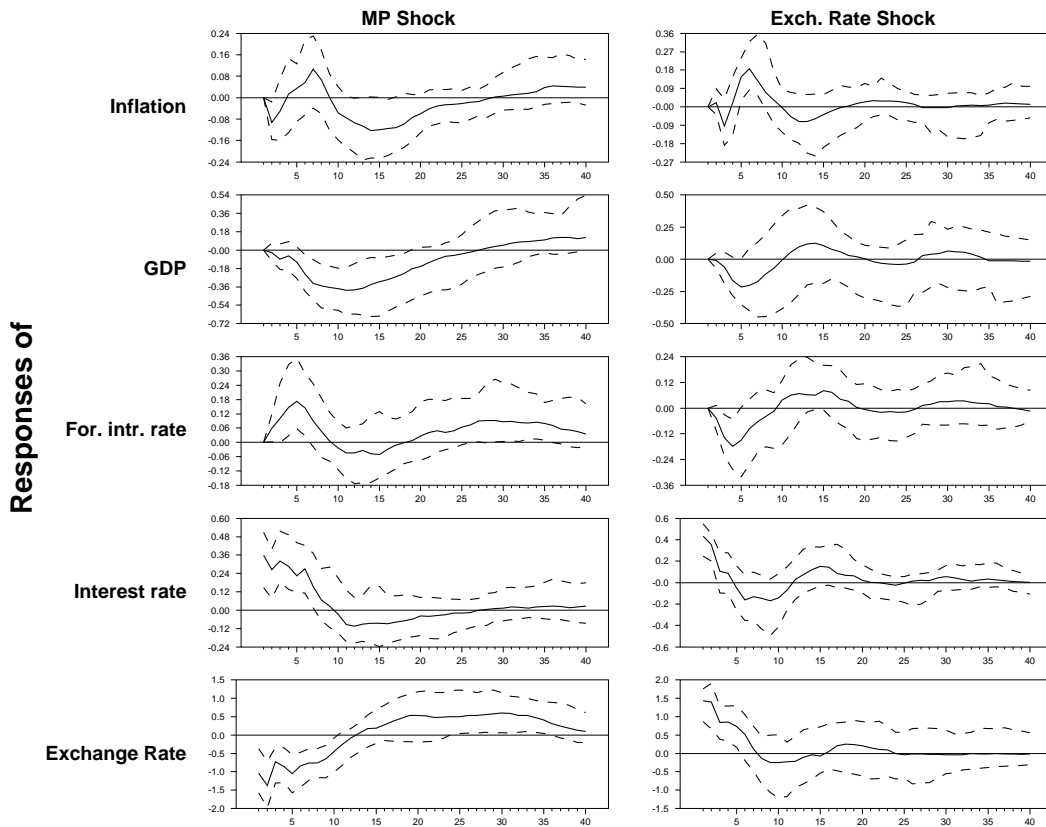


Figure 16: Canada: The response to monetary policy shocks and exchange rate shocks;
Robustness: Exogenous oil price

Impulse responses

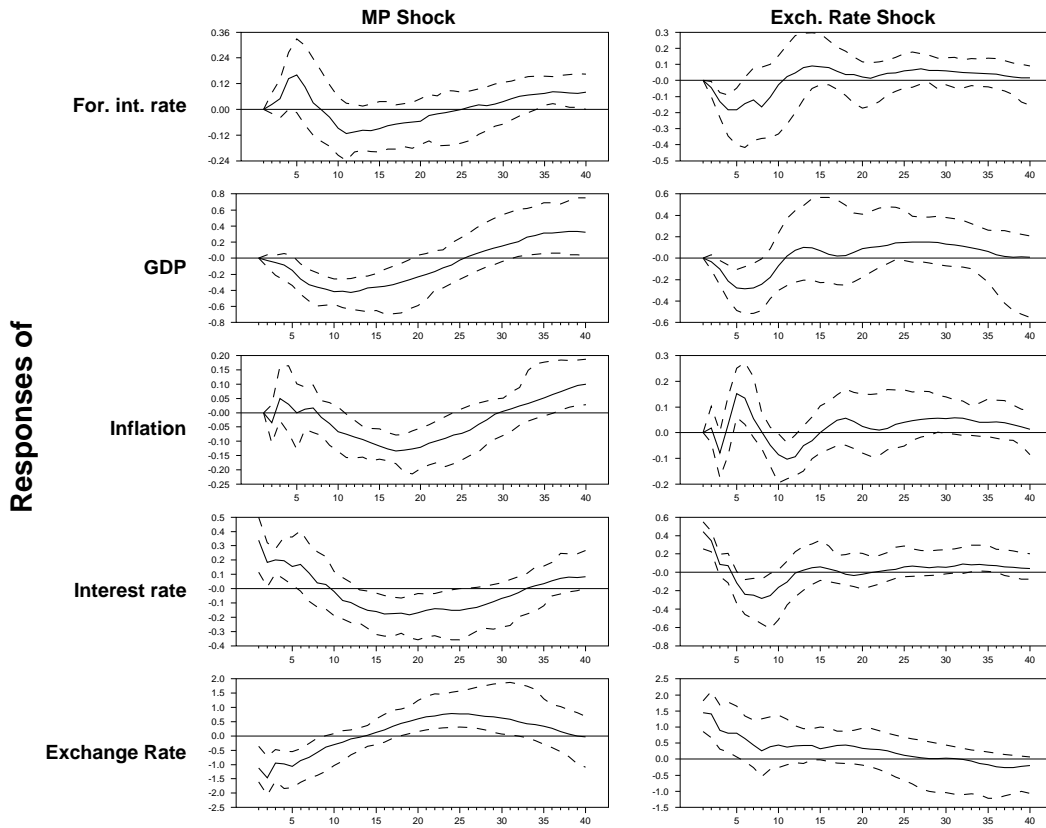


Figure 17: Canada: The response to monetary policy shocks and exchange rate shocks;
 Robustness: Exogenous foreign interest rate

Impulse responses

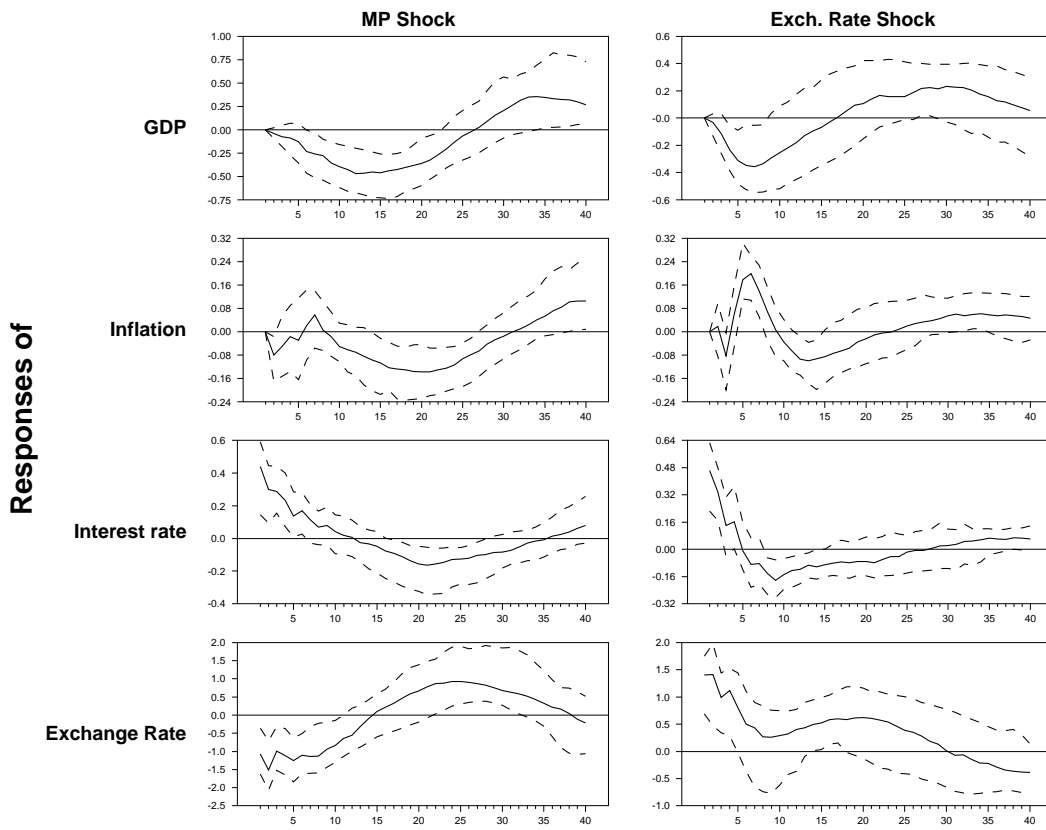
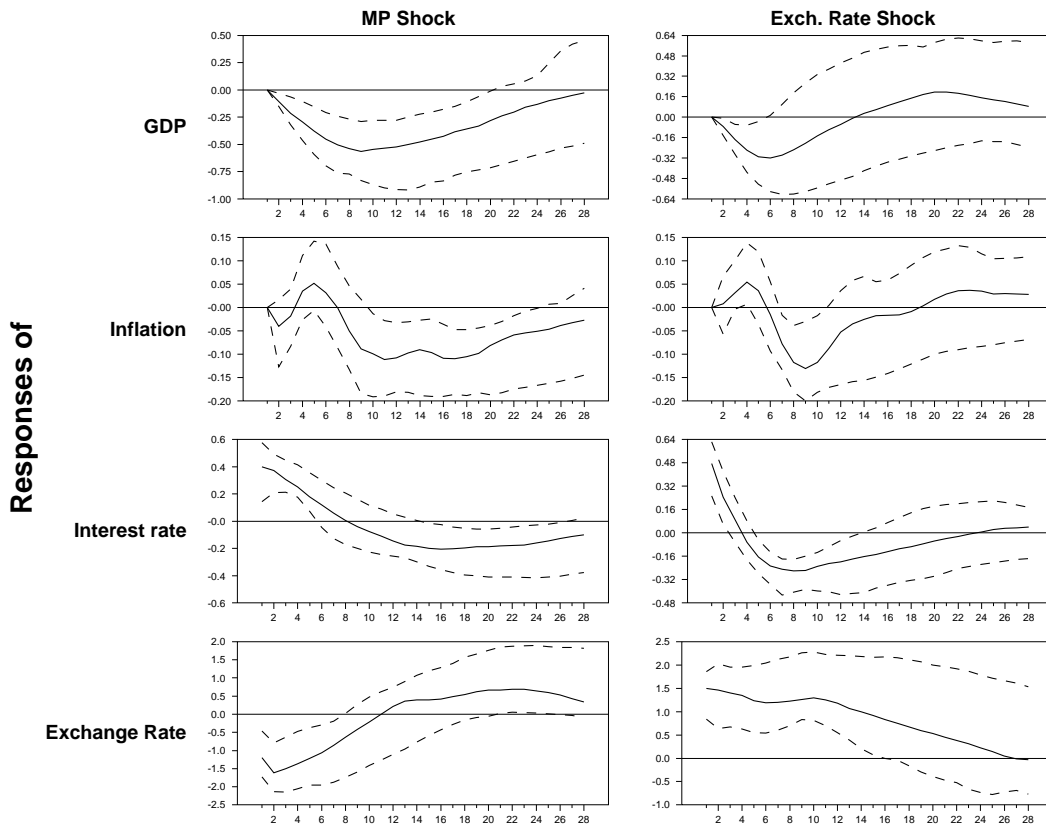


Figure 18: Canada: The response to monetary policy shocks and exchange rate shocks;
 Robustness: Model from 1988

Impulse responses



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