

# The Effect of Monetary Policy on Exchange Rates: How to Solve the Puzzles

by  
Francis Y. Kumah\*

## **Abstract:**

Recent empirical research on the effects of monetary policy shocks on exchange rate fluctuations have encountered the *exchange rate puzzle* and the *forward discount bias puzzle*. The *exchange rate puzzle* is the tendency of the domestic currency (of non-US G-7 countries) to depreciate against the US dollar following domestic monetary tightening. *Forward discount bias puzzle* is the failure of empirical research to find results consistent with the requirement that if uncovered interest parity holds then domestic monetary tightening (given that foreign monetary policy remains put) should be associated with an initial impact appreciation of the domestic currency followed by a gradual depreciation. This paper takes the current debate in the monetary policy literature on the measurement of monetary policy shocks a step further into international finance. The main objective here is to assess the relative performance of monetary policy identification schemes in helping solve (or generate) the puzzles mentioned above. The identification schemes considered include a fully recursive identification scheme, a semi-recursive identification scheme and a structural VAR model that explicitly incorporates international monetary policy interdependence into the identification of monetary policy shocks. The structural VAR identification scheme yields very plausible contemporaneous and dynamic estimates of the effects of monetary policy shocks on bilateral exchange rates for the data-set of the respective countries considered; and the puzzles largely disappear.

**Key Words:** Monetary policy shocks, exchange rates, identification schemes, Structural VARs and impulse responses

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## *Correspondence address:*

CentER for Economic Research, Tilburg University,  
P. O. Box 90153,  
5000 LE Tilburg, The Netherlands.  
Tel. # + 31 13 466 8221; Fax. # + 31 13 466 3066;  
Email address: F.Kumah@kub.nl

## 1. Introduction

In response to the opportunity offered by the post Bretton Woods period of generalized floating and excessively volatile exchange rates a substantial literature on the linkages among macroeconomic variables and how these linkages explain observed exchange rate volatility has emerged. We shall be concerned here with only that strand of the literature that models responses of exchange rates to monetary policy shocks. In particular our reference models involve those based on asset markets. Most of the empirical results obtained from tests of these models leave much to be desired. Dornbusch(1979) and Frenkel(1984) however are able to find evidence in support of the flexible price monetary model of exchange rates even though their results are not robust to sample period extensions. MacDonald and Taylor(1993) use cointegration methods (viewing the monetary model as a long-run equilibrium condition to which the exchange rate converges) to empirically test the implications of the monetary approach to exchange rates. The portfolio balance model (PBM) has been empirically tested by Branson, Halttunen and Masson(1977) using a reduced form exchange rate equation derived from the PBM - the results revealed insignificant coefficients and the persistence of autocorrelation in the residuals. As we discuss below recent attempts at empirical analysis of the effects of monetary policy shocks on exchange rate fluctuations has encountered a number of puzzles.

We propose in this paper a new method for estimating the contemporaneous and dynamic relationships between monetary policy shocks and movements in bilateral exchange rates - nominal and real - based on the current state of the debate in the monetary policy literature on the measurement of policy shocks. Traditionally, the stance of monetary policy is measured by the use of monetary aggregates (the monetary base,  $M1$  and/or  $M2$ ). This measure however is plagued by the *liquidity puzzle* (where positive innovations in

these aggregates are associated with interest rate increases, contrary to what theory suggests) as documented by Leeper and Gordon(1992) as well as by Christiano *et al*(1992). Leeper and Gordon adopt a Wold causal interpretation of the data-set (on the rate of growth of the monetary base,  $\Delta M0_t$ ; interest rates,  $R_t$ ; consumer prices,  $P_t$ ; and industrial production,  $Y_t$ ; in the ordering given by [ $\Delta M0_t, R_t, P_t, Y_t$ ]) in which orthogonalized innovations in the rate of growth of the monetary base is considered a monetary policy shock. In a search for a solution to this puzzle Bernanke and Blinder(1992) as well as Sims(1992) identify monetary policy shocks directly with innovations in interest rates. However, quoting from Strongin(1992), "without any demonstrated empirical linkage between Federal Reserve actions and interest rate movements, it is unclear how innovations in interest rates can be reasonably attributed to monetary policy". It is this recognition that prompted Christiano *et al*(1992) - using various measures of money and of identification schemes (based on various Wold causal orderings of the data-set) to measure monetary policy shocks - to argue for the use of innovations in nonborrowed reserves as monetary policy shocks. But this implies, contrary to the empirical facts, that the Federal Reserve does not accommodate reserve demand shocks. The Strongin(1995) measure of innovations in the mix of borrowed and nonborrowed reserves as monetary policy shocks is therefore intended to address this conceptual shortcoming of Christiano *et al*(1992). Strongin's findings are not conclusive though. Bernanke and Mihov(1995) suggest a linear combination of innovations in total reserves, nonborrowed reserves and the federal funds rate as monetary policy shocks - implying that the Federal Reserve accommodates both borrowing and demand shocks in its monetary policy measures. Their identification scheme encompasses those of Bernanke and Blinder(1992), Christiano *et al*(1992) and Strongin(1995). We take this debate on the identification of monetary policy shocks a step further into the dynamics of exchange rates in response to monetary policy shocks. Our main concern here

is with the issue of monetary policy interrelatedness and the extent to which an explicit modelling of the monetary policy arena of nations can help enhance our understanding of exchange rate fluctuations.

We follow the lead of Eichenbaum and Evans(1995) who use vector autoregressions (VAR) to analyze the effects of monetary policy shocks on bilateral exchange rate movements with the help of recent methods for identifying monetary policy shocks. We carry their analyses further in the light of the current state of the monetary policy innovations identification debate following Bernanke and Mihov(1995) who advocate a semi-structural VAR approach that does not only reflect the actual operating procedures of the federal reserve system but also nests all hitherto attempts - of Bernanke and Blinder(1992), Christiano and Eichenbaum (1992) and Strongin(1995) - at measuring monetary policy shocks. To address the pertinent issue of monetary policy interrelatedness and its effects on exchange rate fluctuations we introduce an exactly identified structural VAR model. Monetary policy interrelatedness is then explicitly modelled and tested, within the context of our VAR model, as over-identifying restrictions. Based on these two identification schemes we try to answer questions bordering on the extent to which earlier, rather unsatisfactory, empirical performance of the broad asset-market-based models of exchange rate determination can be attributed to the mode of identification of monetary policy shocks.

Using our identification schemes - one based on the actual conduct of monetary policy in the US and the other based on a structural VAR specification that explicitly incorporates international policy interrelatedness - we attempt to address the following questions/puzzles in the literature. Firstly, we investigate the extent to which our monetary policy identification schemes are able to solve the *forward discount bias puzzle*. Forward discount bias is

the requirement that if uncovered interest parity holds then positive domestic interest rate innovations (relative to foreign interest rate innovations) should be associated with an initial impact appreciation of the domestic currency; followed by a persistent depreciation. This is because, given uncovered interest parity, the positive interest rate differential has to be associated with an anticipation of a depreciation of the domestic currency in order for agents to continue holding foreign assets. Empirical findings not consistent with this requirement are said to yield a puzzle - the *forward discount bias puzzle*. This puzzle is encountered in Eichenbaum and Evans(1995) and Sims(1992) where (for some of the countries considered) positive domestic interest rate innovations are followed by large and persistent depreciations of the domestic currency. Secondly, could the *exchange rate puzzle* (which is the tendency of the domestic currency of the non-US G-7 countries to depreciate against the US dollar following contractionary domestic monetary policy shocks) that shows up in most empirical results in the literature be due to the specific schemes used to identify monetary policy shocks? This puzzle shows up in Sims(1992) as well as in Grilli and Roubini(1995) where - in a non-structural VAR approach - innovations in short term interest rates and monetary aggregates are used in the respective papers as monetary policy shocks. And finally, given our new identification schemes, we investigate the relative importance of the monetary policy shocks in explaining bilateral exchange rate fluctuations.

In an attempt to provide answers to the questions raised above we structure the paper as follows. The second section provides a brief review of the asset market based theories of exchange rate determination. This is meant to provide us with a reference theoretical framework that underlies subsequent empirical results. In the third section we briefly review the Bernanke-Mihov monetary innovations identification scheme and discuss our structural VAR model. The former approach - which we refer to in the rest of the

paper as exemplifying the semi-recursive identification scheme - proposes innovations to an estimated linear combination of policy indicators as a measure of monetary policy shocks. The policy indicators used include total reserves normalised by the level of total reserves in the prior month, ( $TR_t$ ), a measure of the mix of non-borrowed to total reserves ( $NBR_t$ ) and the federal funds rate ( $FF_t$ ). In section three we present and discuss our empirical results derived from estimating a seven-variable VAR in the logarithm of US industrial employment, the logarithm of the foreign country's industrial employment, the US total reserves, the US nonborrowed reserves, the US federal funds rate, a foreign monetary policy variable and the logarithm of the bilateral exchange rate (measured as the foreign country's currency per unit of the US dollar) respectively. The foreign countries considered are Canada, Germany, Japan and the UK. The estimated impulse response functions and variance decompositions of the logarithms of the nominal and real bilateral exchange rates are presented and discussed in the light of the general class of asset market models. The final section presents a summary of the approach adopted in the paper as well as of our empirical findings.

## **2. A Brief Review of Theory**

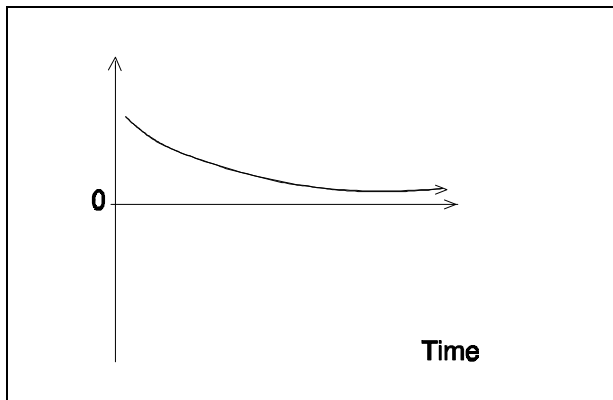
In many standard textbooks in international finance - see for instance Obstfeld and Krugman(1994) or De Grauwe(1989) - the asset market based theoretical framework is introduced as a way to understanding exchange rate fluctuations. The monetary approach to exchange rate modelling encompasses both sticky-price models (of Dornbusch(1976) for instance) and flexible price models. One of the common elements of both of these variants of the monetary approach is that they are characterized by the implicit assumption of perfect substitutability between domestic and foreign money and bonds. In the vein of the latter model under this approach positive

domestic monetary policy shocks lead to domestic price increases that depreciate the exchange rate given that purchasing power parity (PPP) holds in the short run. For the sticky-price models, where it is assumed that PPP does not hold in the short run, monetary policy operates through the interest rate channel. Thus positive domestic monetary policy shocks (implying an initial increase in the real money supply given that prices are sticky in the short run) reduce the domestic interest rate. Given uncovered interest parity and free capital mobility the policy shocks instigate an anticipation of an appreciation of the domestic currency in the long run. The fall in the domestic interest rate coupled with the expected appreciation of the domestic currency makes domestic assets unattractive. Domestic capital outflows - so long as the expected rate of appreciation of the domestic currency is greater than the interest rate gain (the interest rate differential) - and the domestic currency depreciates. A short run equilibrium is reached when equality is attained between the expected returns on foreign and domestic assets (i.e when uncovered interest parity holds). In the medium term however prices begin to rise as a result of the monetary expansion, the real money supply falls and domestic interest rate increases set in to gradually appreciate the domestic currency moving it to its long run purchasing power parity level. Thus according to this approach effects of positive monetary policy shocks are dominated in the short term by expectations and capital mobility in the asset market as well as by the exchange rate overshooting it's long run purchasing power parity level.

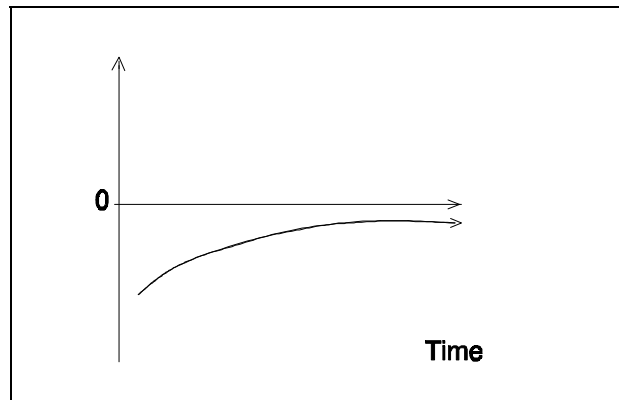
The second class of models under the broad class of asset market models - the portfolio balance model (PBM) - does not make the assumption of perfect substitutability between domestic and foreign financial assets. The PBM emphasizes wealth effects on asset demands and the role of the exchange rate and expectations about its future movements in the asset demand decisions. Some versions

of the PBM introduce the current account balance in its role as allocating wealth among countries. A surplus/deficit in the current account represents a rise/fall in net domestic holdings of foreign assets which in turn affects the level of wealth and the real exchange rate. See for instance Branson(1983), and/or Taylor(1995) for an exposition of this approach. Following this approach the effects of monetary policy shocks are felt through agents' attempts to re-balance their portfolios by purchasing both foreign money and domestic bonds. Given that the supply of the domestic bonds is fixed (at least in the short run) the increase in its demand induces an increase in its price (i.e a reduction in the domestic interest rate) and depreciates the domestic currency.

Without explicitly discussing the dynamics of the exchange rate following a monetary policy shock we deem it sufficient for the purposes of this paper to present the expected shape of estimated impulse response functions of the exchange rate. Figures 1a and 1b below present the expected path of the exchange rate following US and foreign monetary tightening respectively.



**Figure 1a.** The expected path of the exchange rate following US monetary tightening.



**Figure 1b:** The expected path of the exchange rate following foreign monetary tightening.



The graphs depicted in figures 1a and 1b above are based on the expected responses of the exchange rate on the basis of the overshooting phenomenon (under both theories discussed above) as well as from the predictions of uncovered interest parity under the sticky price model. One characteristic of these theories that comes out clearly in figure 1a is that, as a result of US monetary tightening, the US dollar appreciates on impact followed by a gradual depreciation. A corresponding expected path of the exchange rate following foreign monetary tightening is shown in figure 1b.

### 3. Identification Schemes

To state the problems in identifying monetary policy shocks, it is useful to briefly review the theory. Suppose the data generation mechanism for a covariance stationary  $X_t$  can (excluding deterministic components) be written as  $G(L)X_t = v_t$ , where  $G(L)$  is a matrix lag polynomial of finite order, and  $v_t$  are economically meaningful, structural innovations, which we assume to be serially uncorrelated and to have a diagonal contemporaneous covariance matrix,  $E[v_t v_t'] = \Sigma$ . If  $G_0$  is invertible, the data generating mechanism can be written as a reduced form VAR,  $C(L)X_t = u_t$ , where  $C_0 = I$  is the identity matrix of a suitable order and where  $\Omega = E[u_t u_t'] = G_0^{-1} \Sigma G_0^{-1}$  is the covariance matrix of the one-step ahead prediction errors,  $u_t$ . The identification is essentially to reverse this process: using estimates of  $C(L)$  and  $\Omega$  to find  $G(L)$  and  $\Sigma$ . We shall use contemporaneous *a priori* exclusion restrictions on  $G_0$  to identify the structural innovations. These restrictions are imposed such that the sum of  $n(n+1)$  free parameters in  $G_0$  and  $\Sigma$  are reduced to no more than  $n(n+1)/2$  distinct elements in  $\Omega$ . To begin with  $n$  restrictions are obtained as normalizations that define the variance of the structural shocks by setting the  $n$  diagonal elements of  $G_0$  to 1s. For the remaining  $n(n-1)/2$  restrictions various researchers have used different schemes. The fully

recursive scheme implies the normalization assumption of a lower triangular  $G_0$  matrix. The use of this normalization implies that variables pre-dating others are assumed to have contemporaneous effects on those coming after them but not vice versa. Thus the system is forced into taking on a contemporaneous recursive structure in a Wold causal fashion. We refer to this identification scheme as the fully recursive scheme in the rest of the paper.

Blanchard(1986) and Sims(1986) initiated a generalized method of allowing non-recursivity into the structure of  $G_0$  and thereby allowing for more flexibility in modelling feedback effects among the set of variables and helps researchers impose more economic structure on the  $G_0$  matrix thereby<sup>1</sup>. This way of identifying the  $G_0$  matrix of contemporaneous effects has come to be known in the literature as the structural (or the identified) VAR approach as applied for instance by Bernanke and Mihov(1995)<sup>2</sup> in measuring monetary policy shocks in the US based on the actual operating procedures of the Federal Reserve System.

### ***3.1 Monetary Policy Identification Schemes***

A number of researchers have suggested various measures of monetary policy shocks as alternatives to the strategy of using

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<sup>1</sup>. Apart from the exclusion restrictions generally favoured by researchers any set of restrictions can be imposed on the  $G_0$  matrix to identify the structural innovations. Blanchard and Quah(1989) and W. D. Lastrapes(1992) use long-run restrictions whereas Faust and Leeper(1994) use a combination of both long run and short run restrictions to identify the underlying structural model.

<sup>2</sup>. More appropriately, the approach adopted by Bernanke and Mihov(1995) could also be classified as 'semi-structural' since they do identify their VAR by imposing restrictions derived from the actual operating procedures of the federal reserve system of the US (leaving the relationship among the non-policy variables unrestricted) and not just by the use of the fully recursive identification scheme under which  $G_0$  is imply assumed to be lower triangular. However, to distinguish this approach from our structural VAR approach we denote the identification scheme exemplified by the Bernanke-Mihov(1995) approach as the semi-recursive identification scheme in the rest of the paper.

orthogonalized innovations in such broad monetary aggregates as  $M0$ ,  $M1$ ,  $M2$  or  $M3$  as monetary policy shocks. These suggestions are put forward as attempts at solving the *liquidity puzzle*, the *exchange rate puzzle* and the *forward discount bias puzzle* encountered in earlier empirical work using innovations in these broad monetary aggregates as monetary policy shocks. Bernanke and Blinder(1992) argue for the use of innovations to the federal funds rate as monetary innovations. The analyses of Christiano et al(1994) as well as of Christiano and Eichenbaum(1992) argue for the use of innovations to nonborrowed reserves as monetary policy shocks whereas empirical evidence provided by Strongin(1995) suggest innovations to a mix of borrowed and nonborrowed reserves. Extending the discussion further Bernanke and Mihov(1995) suggest a measure of monetary policy shocks that encompasses the earlier measures.

We present here only that part of Bernanke-Mihov that is relevant for our purposes - i.e the identification of monetary policy shocks. Bernanke and Mihov partition the matrices in the structural equation  $G(L)X_t = v_t$  into the portion relating to a vector of non-policy macroeconomic variables,  $Y_t$ , and the part pertaining to the stance of monetary policy,  $P_t$ , such that  $X_t = [Y_t, P_t]'$ . Under the assumption that the contemporaneous portion of the policy authority's feedback rule contains information on the state of the economy (measured by the non-policy variables) we can derive the reduced-form relationships specified in (2) below for a given VAR( $k$ ) specification for  $X_t$ . The causal ordering adopted here, in  $X_t$ , implies that policy shocks do not have contemporaneous effects on the non-policy variables, and also that monetary policy authorities do have (and react to) contemporaneous information on the state of the economy. Given this specification a particular form of our general structural equation  $G(L)X_t = v_t$  can be written

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$$\begin{aligned}
Y_t &= \sum_{i=0}^k B_i Y_{t-i} + \sum_{i=1}^k H_i P_{t-i} + A^y v_t^y \\
P_t &= \sum_{i=0}^k D_i Y_{t-i} + \sum_{i=0}^k \Gamma_i P_{t-i} + A^p v_t^p
\end{aligned} \tag{1}$$

And the corresponding particular reduced form is derived as

$$\begin{aligned}
Y_t &= (I - B_0)^{-1} \left\{ \sum_{i=1}^k B_i Y_{t-i} + \sum_{i=1}^k H_i P_{t-i} + A^y v_t^y \right\} \\
P_t &= (I - \Gamma_0)^{-1} \left\{ \sum_{i=1}^k [D_i + D_0(I - B_0)^{-1} B_i] Y_{t-i} + \sum_{i=1}^k [\Gamma_i + D_0(I - B_0)^{-1} H_i] P_{t-i} \right. \\
&\quad \left. + D_0(I - B_0)^{-1} A^y v_t^y + A^p v_t^p \right\}
\end{aligned} \tag{2}$$

where  $v_t = [v_t^y, v_t^p]'$  is a vector of unobserved structural innovations. More specifically the structural policy shocks vector  $v_t^p$  contains the elements  $v_t^d$ ,  $v_t^b$  and  $v_t^s$  indicating total reserves demand shocks, borrowing shocks and non borrowed reserves supply shocks respectively. From the reduced-form above we infer that the component of observable innovations of  $P_t$  that are orthogonal to the non-policy vector can be indicated as

$$U_t^p = (I - \Gamma_0)^{-1} A^p v_t^p \tag{3}$$

The problem of identifying the stance of monetary policy involves the characterization and estimation of the matrix  $(I - \Gamma_0)^{-1} A^p$ . Bernanke and Mihov do this by using a simple conventional model of the bank reserve market as in Strongin(1995) but this time introducing borrowing shocks,  $v^b$ , as an additional element in nonborrowed reserves innovation ( $U_{NBR}$ ). Viewing the federal funds

rate as the opportunity cost of total reserves (the sum of required reserve and excess reserve holdings) held by banks they let innovations in the demand for reserves ( $U_{TR}$ ) react negatively to innovations in the federal funds rate ( $U_{FF}$ ). The rest of the model describing the behaviour of the federal reserve is as specified in (4) below

$$\begin{aligned}
 U_{TR} &= -\alpha U_{FF} + v^d \\
 U_{BR} &= \beta U_{FF} + v^b \\
 U_{NBR} &= \phi^d v^d + \phi^b v^b + v^s
 \end{aligned}
 \tag{4}$$

where  $\alpha$ ,  $\beta$ ,  $\phi^d$  and  $\phi^b$  are parameters to be estimated whereas  $v^d$ ,  $v^b$  and  $v^s$  are as defined above. From the set of equations in (4) above we can solve for the observable policy innovations ( $U^p = [U_{FF}, U_{TR}, U_{NBR}]'$ ) as functions of borrowing, demand and policy shocks -  $v^b$ ,  $v^d$  and  $v^s$  - respectively as in equation (5) below using the identity,  $TR = NBR + BR$ .

$$\begin{bmatrix} U_{TR} \\ U_{FF} \\ U_{NBR} \end{bmatrix} = \begin{bmatrix} -\frac{\alpha}{\alpha + \beta}(1 - \phi^d) + 1 & \frac{\alpha}{\alpha + \beta} & \frac{\alpha}{\alpha + \beta}(1 - \phi^b) \\ \phi^d & 1 & \phi^b \\ \frac{1}{\alpha + \beta}(1 - \phi^d) & -\frac{1}{\alpha + \beta} & -\frac{1}{\alpha + \beta}(1 + \phi^b) \end{bmatrix} \begin{bmatrix} v^d \\ v^s \\ v^b \end{bmatrix}
 \tag{5}$$

This equation contains seven unknowns (if we include the variances of the structural shocks) to be estimated from six covariances between the observable policy innovations,  $U^p$ . Thus we need at least one identifying assumption to be able to pin down the monetary policy shock,  $v^s$  which is a combination of the elements of the policy innovations matrix  $U^p$ . In Strongin(1995) it is argued that the Fed accommodates reserve demand shocks through the provision of nonborrowed reserves or through the discount window so that shocks to total reserves reflect only changes in the demand for reserves at least in the short run. This implies, in the

context of model in (5) above, that  $\alpha$  and  $\phi^b$  be set to zero. The Bernanke-Mihov exactly identifying assumption which yields the monetary policy shock as a linear combination of innovations in total reserves, nonborrowed reserves and the federal funds rate after setting only  $\alpha$  to zero as specified in (6) below.

$$v^s = -(\phi^d + \phi^b)U_{TR} + (1 + \phi^b)U_{NBR} + \beta\phi^b U_{FF} \quad (6)$$

Notice that by setting  $\phi^b = 0$  into equation (6) above we obtain the Strongin(1995) scheme where monetary policy shocks are identified as a mix of innovations in total and nonborrowed reserves. Bernanke and Mihov also show that the identification schemes of Bernanke and Blinder(1992) as well as that of Christiano *et al.*(1992) can be derived as special cases of their general model for which  $\alpha$  is non-zero<sup>3</sup>. We adopt Bernanke-Mihov's exactly identified model - as an example of the semi-recursive identification scheme - in the analysis of exchange rate fluctuations in response to monetary policy shocks in subsequent sections of this paper.

### **3.2. International Policy Interdependence**

There are certain relevant issues bordering on the contemporaneous feedback structure of our application of the Bernanke-Mihov identification scheme - issues of international monetary policy interdependence and of the feedback from exchange rates to monetary policy formulation and vice versa. To address these issues we introduce a structural VAR that explicitly incorporates policy interdependence and the reaction of monetary policy authorities to

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<sup>3</sup>. Notice that for a non-zero  $\alpha$  equation (6) can be replaced by

$$v^s = -(\phi^d + \phi^b)U_{TR} + (1 + \phi^b)U_{NBR} - (\alpha\phi^d - \beta\phi^b)U_{FF} \quad (6')$$

and the required restrictions in the case of the Bernanke-blinder specification of attributing innovations in interest rates to monetary policy are for  $\phi^d = 1$  and  $\phi^b = -1$ . The Christiano *et al* case requires setting  $\phi^d = \phi^b = 0$  implying that innovations in nonborrowed reserves represent monetary policy shocks.

exchange rate movements as verifiable hypotheses. We then compare the performance of the semi-recursive identification scheme, as exemplified by the Bernanke-Mihov scheme, with that of our structural VAR approach. For both identification schemes we use the seven variable VAR with the variables as defined earlier on. We follow the lead of most researchers in this area of international finance and use VARs that imply asymmetric treatment of the non-US countries vis-a-vis the US. This could be justified by the fact that monetary institutions and the conduct of monetary policy do differ between countries. Hence there is not much reason to expect innovations in a linear combination of total reserves, nonborrowed reserves and the federal funds rate (or some other relevant interest rate) to adequately measure monetary policy shocks in the non-US countries just because this metric measures monetary policy adequately well in the US. In Canada the relevant monetary policy indicators that adequately reflect the operational behaviour of the monetary authority are excess settlement cash and the overnight rate. In fact Armour *et al*(1996) provide empirical evidence to the effect that the innovations in the overnight rate adequately reflects the stance of monetary policy in Canada. To empirically investigate the assertion above we apply the Bernanke-Mihov approach to German data. We run a five variable VAR using monthly data on the logarithm of industrial production, the consumer price index, total reserves, nonborrowed reserves and the day-to-day interest rate (tagesgeld) over the period 1974:1 - 1994:9. The empirical results, based on Bernanke-Mihov's exactly identified model (that is the model with  $\alpha=0$  in equation (5) in the text; implying that innovations in total reserves are independent of the funds rate) yields a *liquidity puzzle* where positive monetary policy shocks are associated with significant increases in the interest rates. Hence, based on the empirical evidence cited above and also to escape this *liquidity puzzle* that we do not directly address in this paper, we use innovations to short term interest rates in the non-US countries as monetary policy shocks.

Considering the high degree of interdependence among economies through trade and capital movements; as well as the fact that exchange rate fluctuations have much influence on domestic economic activity (especially in the highly open economies that we consider here) we deem it informative to introduce international monetary policy interdependence explicitly into the model<sup>4</sup>. The dependence of domestic monetary policy on foreign macroeconomic variables and policy could be attributable to a common reaction to global shocks. Conscious efforts by policymakers to stabilize their respective currencies on the global financial market are also fertile grounds for this type of interdependence among nations. We favour the second channel in this paper. The issue of international transmission of domestic monetary policy is not new in the literature. In an open economy, with a flexible exchange rate system, unanticipated money supply shocks are associated with movements of short-term interest rates and bilateral exchange rates because of changes in interest parity relationships after the policy announcement. The divergence from covered interest parity so created can only be attained by a movement in the forward rate or of the foreign short-term interest rate. The interdependence that we consider here are those among policy shocks and non-policy variables. We specifically categorize these interdependence as follows:

- i. the impact of the exchange rate on US monetary policy and vice versa,
- ii. the impact of the exchange rate on foreign monetary policy and vice versa, and finally
- iii. the impact of US monetary variables on foreign monetary policy and vice versa.

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<sup>4</sup>. The idea of considering policy interdependence in empirical policy analysis in the context of open economies is not completely new. It has been demonstrated in the monetary policy interdependence literature (see Sephton(1989) for instance) that due to structural linkages among economies monetary policy authorities can attain trend-stationarity in the price level and exchange rates by optimally conditioning their policy rules on foreign monetary policy innovations.



The necessary restrictions ( $= n(n-1)/2$ ) for exactly identifying our structural VAR are introduced as exclusion restrictions on the contemporaneous structural parameters in  $G_0$ . Following Bernanke(1986) and our discussion of interdependence above these restrictions yield a particular form of our  $G_0$  matrix (we refer to it as  $\Phi$  in the rest of the paper) as summarized in the set of relationships in equation (7) below.

$$\begin{bmatrix} v_{emp}^{US} \\ v_{emp}^F \\ v_{TR}^{US} \\ v_{NBR}^{US} \\ v_{FF}^{US} \\ v_M^F \\ v_{XR} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ g_{21} & 1 & 0 & 0 & 0 & 0 & 0 \\ g_{31} & 0 & 1 & 0 & 0 & 0 & 0 \\ g_{41} & 0 & g_{43} & 1 & g_{45} & g_{46} & g_{47} \\ g_{51} & 0 & g_{53} & g_{54} & 1 & g_{56} & g_{57} \\ 0 & g_{62} & 0 & g_{64} & 0 & 1 & g_{67} \\ g_{71} & g_{72} & g_{73} & g_{74} & g_{75} & g_{76} & 1 \end{bmatrix} \begin{bmatrix} U_{emp}^{US} \\ U_{emp}^F \\ U_{TR}^{US} \\ U_{NBR}^{US} \\ U_{FF}^{US} \\ U_M^F \\ U_{XR} \end{bmatrix} \quad (7)$$

From our structural model above identifies monetary policy in the foreign country and in the US with innovations in short term interest rates and the ratio of nonborrowed reserves to total reserves respectively. Following Bernanke and Blinder(1992) we assume that monetary policy variables respond contemporaneously to innovations in domestic macroeconomic variables - this is to say that monetary authorities have contemporaneous information on the state of the economy. The sixth equation in our system of equation (7) refers to the foreign monetary authority's contemporaneous feedback rule for setting  $r^F$ . Foreign monetary authorities react to contemporaneous information on the exchange rate and the stance monetary policy in the US. The contemporaneous policy interaction parameter measuring the feedback from US monetary policy to the

foreign country's policy stance is  $g_{64}$ . Similarly US monetary policy is assumed to react contemporaneously to the stance of foreign monetary policy and the exchange rate with the interaction parameters given by  $g_{46}$  and  $g_{47}$  respectively. This specification - that the US reacts to foreign monetary policy and vice versa - is worth some empirical scrutiny. We test the particular over-identifying restriction implied by relaxing any one of our assumptions pertaining to policy interrelatedness in turns and condition subsequent estimations and analyses on the results of the tests.

The interdependence that appear in our structural model above is the key difference between our identification scheme and those of researchers using the fully recursive schemes and semi-recursive schemes (as exemplified by Strongin (1995) and Bernanke and Mihov(1996)). We think that once we introduce international aspects of monetary policy formulation into the debate of measuring monetary policy shocks the issues that are of the most interest are those of interdependence between policy and non-policy variables as outlined above. These interdependence are naturally not addressed in the semi-recursive scheme of Bernanke and Mihov obviously because they are not concerned with international linkages. Also, given the high degree of international interdependence among nations through the effects of exchange rate fluctuations on trade and capital movements, any monetary policy identification scheme aimed at explaining exchange rate fluctuations should necessarily incorporate this interdependence. The fully recursive scheme as used in Eichenbaum and Evans(1995) implies allowing all non-policy variables to influence all policy variables, but fails to address the relevant issues of interdependence as listed above. Of particular significance in this paper is the impact of our structural identification scheme to the dissolution of the exchange rate and forward discount bias puzzles encountered in the literature.

The rest of our identifying restrictions are as follows. We assume that monetary policy shocks have no contemporaneous effects on non-policy variables<sup>5</sup>. The last line of our contemporaneous feedback matrix regards the exchange rate as a forwardlooking asset price and hence models exchange rate shocks as a combination of innovations in all the variables in our model.

#### 4. Empirical Results

The empirical evidence presented below are based on seven variable (S)VARs estimated using monthly data for Canada, Germany, Japan and the UK over the period 1974:01 to 1994:05. A lag length of twelfth months is used in each case. The choice of the lag length is based on evidence regarding the non-existence of serial correlation in the error terms as measured by the Ljung-Box Q statistics as in Doan(1992). Insofar as the error terms in our estimated (S)VARs behave normally we do think that testing for co-integration and basing subsequent estimations on the cointegration vector, if any, would not yield any significantly different results in terms of the impulse responses. Neither would the use of first differences of the data yield any significant differences in our estimates. The data are presented and described in appendix A. For each country the (S)VARs include, as endogenous variables, the logarithm of employment in the United States and in the country being considered (i.e.  $\log. emp_t^{US}$  and  $\log. emp_t^F$  respectively) measured in weekly hours of work in manufacturing, US total reserves  $TR_t$ , US nonborrowed reserves  $NBR_t$ , US federal funds rate  $FF_t$ , the foreign country's short-term interest rate,  $r_t^F$  and the logarithm of the nominal bilateral exchange rate  $S_t^{(/\$)}$  measured as the foreign

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<sup>5</sup>. This assumption is perhaps the only common ground between our structural model, the fully recursive and semi-recursive identification schemes that we consider in this paper. The variable orderings adopted by Bernanke and Blinder(1992), Bernanke-Mihov(1995), Christiano *et al*(1992) and Eichenbaum and Evans(1995) - to mention but a few - imply this very assumption.

country's (domestic) currency price of one US dollar. When we include the logarithm of the real bilateral exchange rate instead of the logarithm of the nominal the former is measured as the difference between  $S_t^{(/\$)}$  and the logarithm of the ratio of the US consumer price index to the foreign country's. Defined this way an increase in  $S_t^{(/\$)}$  implies an appreciation of the dollar (or equivalently, a depreciation of the foreign currency). We include eleven monthly seasonal dummies as well in the (S)VARs.

We present three sets of empirical evidence from our estimations. Our first set of empirical evidence is for a fully recursive scheme using the ordering as in

$$X_t = \left[ \log.emp_t^{US} \log.emp_t^F TR_t NBR_t FF_t r_t^F s_t^{(/\$)} \right]'. \quad \text{The second set of results}$$

is based on the semi-recursive identification scheme as exemplified by the Bernanke-Mihov monetary policy identification scheme. The third set of empirical results is based on our structural identification scheme where we incorporate policy interrelatedness by way of exclusion restrictions on the contemporaneous reactions matrix,  $\Phi$ . Preliminary tests for over-identifying restrictions based on the assumptions either of US policy independence of foreign policy shocks and vice-versa for each of the countries considered yield very low levels of statistical significance. Hence, under our structural VAR identification scheme, we estimate seven variable structural VAR based on the exactly identified model presented in equation (7) explicitly incorporating the assumption of international monetary policy interdependence.

To regenerate the exchange rate puzzle and the forward discount bias puzzle we use the fully recursive identification scheme since it is the most common scheme applied in this area of research. The Wold causal ordering used in this experiment is the same as that in  $X_t$  above. This particular ordering implies, among others, that included in the US monetary policy reaction function are domestic

and foreign economic conditions; but not the foreign monetary policy variable. Secondly it implies the assumption that foreign monetary authorities' incorporate information on US domestic economic conditions and the stance of US monetary policy in formulating their policies. And finally, the exchange rate is assumed to be affected contemporaneously by innovations in all the variables in the system.

Our empirical results as presented in figure 2a and 2b are based on the fully recursive identification scheme. The estimated impulse responses show that a positive monetary policy shock in the US leads to a fall in the federal funds rate and depreciates the dollar (except in the case of the UK) over the entire horizon of our impulse response experiments. However, from the estimated impulse responses reported in the first column of figure 5b for the exchange rate, an expansive foreign monetary policy (measured as a positive innovation to the foreign short term interest rate) generally leads to an impact appreciation of the dollar vis-a-vis the foreign currency over the first five months following the policy shock. Thus the triangular identification scheme results in the exchange rate puzzle encountered in the literature. This evidence suggests the need for a re-examination of the data using more flexible identification schemes that accord some weight to international policy interdependence. Grilli and Roubini(1995) suggest however that the exchange rate puzzle could be blamed on identification schemes that imply the assumption of the US as a 'leader' - and all other countries are 'followers' - in the international policy arena. They argue further that short term interest rate innovations in non-US G-7 countries are endogenous policy reaction to inflationary shocks that in themselves cause domestic currency depreciations. Our empirical results cast some doubts on the plausibility of their explanations of the source of the puzzle however. As we show below using the semi-recursive identification structure that implies treating the US as an

international policy 'leader' and the rest of the world as 'followers' the exchange rate puzzle largely disappears - even in the presence of the 'leader-follower' characterization. This finding suggests that the use of the fully recursive scheme for identifying monetary policy shocks is one likely source of the puzzles. Secondly, to the extent that policymakers are aware of the negative implications of domestic inflationary shocks on the domestic currency, it seems rather unlikely that they would not incorporate this knowledge (of the reaction of exchange rates to domestic inflation) into the formulation of policy.

#### **4.1 Measuring Policy Innovations and Policy Interdependence**

The estimates of some of the parameters of our exactly-identified seven-variable structural VAR are presented in table 1 below<sup>6</sup>. We utilize these estimates in investigating the extent to which our estimated monetary policy shocks display characteristics that qualify them as such. Generally, on a *a priori* theoretical grounds, we do expect an expansionary monetary policy shock in the US to lead to a fall in the federal funds rate and - following the predictions of asset-market-based models of exchange rate determination (the overshooting sticky-price model of Dornbusch(1976) for instance) - to, *ceteris paribus*, depreciate the dollar on impact just as a contractionary foreign monetary policy shock would. To investigate the extent to which our identified innovations can be regarded as plausibly representing what one would expect from the normal operation of the federal funds market we present and discuss the estimated impact effects of innovations in nonborrowed reserves on the federal funds rate - i.e the estimates of  $g_{54}$ . Estimates of the respective contemporaneous

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<sup>6</sup>. We present only a subset of the estimates here in order to concentrate on the parameters of direct interest to us in discussing issues of policy identification as well as of international policy interrelatedness. All the  $n(n-1)/2=21$  parameter estimates are reported in table B1 in appendix B.

effects of innovations in US nonborrowed reserves and in the foreign short term interest rate on the exchange rate - i.e  $g_{74}$  and  $g_{76}$  respectively. To fix some ideas about international policy interrelatedness we also present and discuss the estimates of  $g_{64}$  in the light of theoretical predictions. Two entries are presented under each estimated parameter in table 1 below. The first entry shows the estimates from our seven variable structural VAR in  $X_t$  with the bilateral nominal exchange rate as the last element whereas the second entry is when the bilateral real exchange rate is used<sup>7</sup>.

*Table 1: Estimates of contemporaneous policy/exchange rate interaction parameters*

| Country | Parameter Estimates |          |          |         |          |         |          |         |
|---------|---------------------|----------|----------|---------|----------|---------|----------|---------|
|         | $g_{54}$            |          | $g_{64}$ |         | $g_{74}$ |         | $g_{76}$ |         |
| Canada  | -1.095*             | -0.149*  | -0.226   | -1.697* | -0.014   | -0.099* | -0.007*  | -0.006* |
|         | (-)                 | (-)      | (0.477)  | (-)     | (0.274)  | (-)     | (-)      | (-)     |
| Germany | -0.508*             | -13.782* | -7.202*  | -0.130  | -0.118*  | -0.147* | -0.013*  | -0.013* |
|         | (-)                 | (-)      | (1.225)  | (0.857) | (-)      | (-)     | (-)      | (-)     |
| Japan   | -0.206              | -0.184*  | 1.965    | -0.065  | -0.142*  | -0.269* | -0.003*  | -0.008* |
|         | (0.488)             | (-)      | (2.691)  | (0.791) | (-)      | (-)     | (-)      | (-)     |
| UK      | -0.167*             | -0.142*  | -0.206   | -0.214  | -0.110   | -0.113* | -0.002   | -0.001  |
|         | (-)                 | (-)      | (0.675)  | (0.501) | (0.378)  | (-)     | (0.009)  | (0.005) |

**Notes:** The estimates presented in this table are based on our exactly-identified structural identification scheme. The standard errors of the estimates in parentheses. A \* indicates significance at the 95% confidence level. The estimates are obtained using the Simplex Algorithm and the results used as initial values in the Bernanke procedure as in the RATS 4.0 manual. Figures indicated by " - " are standard errors less than  $1 \times 10^{-3}$ .

<sup>7</sup>. For the Bernanke-Mihov identification scheme as used in this paper the parameters of interest include  $\beta$ ,  $\phi^b$  and  $\phi^d$ . The estimates of these parameters are 0.0323, 0.7125 and -0.0299 respectively for Canada; 0.0414, 0.6362, and 0.0860 respectively for Germany; 0.0339, 0.7115 and 0.0036 for Japan; and finally 0.0362, 0.7229 and -0.0025 for the UK. The estimates for  $\beta$  indicate, as predicted by theory, that increases in the federal funds rate (i.e. the rate at which borrowed reserves can be lent in at the federal funds market) increases banks' demand for borrowed reserves - see equation (4) above. These estimates are obtained for VARs including nominal bilateral exchange rates - the estimates are not significantly different from these when we use real bilateral exchange rates.

From the table presented above we deduce the following. First, we advance sufficient evidence in support of the use of our identified structural innovations to nonborrowed reserves,  $v_{NBR}^{US}$ , as US monetary policy shocks. Secondly, we investigate the relationship between these shocks and the policy innovations of the respective foreign countries. Finally, we investigate the extent to which the domestic and foreign policy shocks so identified have the desired (impact) effects on the exchange rate. To address the first issue it is worth noting that for all countries and for both cases considered expansive innovations in nonborrowed reserves significantly reduce the federal funds rate on impact. In addition to this evidence the estimate of  $g_{53}$  (the impact effect of total reserves innovations on the federal funds rate) as presented in table B1 of appendix B is generally significantly negative indicating that demand shocks do increase the federal funds rate on impact. Then comes the issue of international policy interdependence. Using estimated innovations in the foreign short term interest rate as foreign policy shocks yields the plausible result that foreign monetary policy shocks respond, on impact, negatively to a positive US monetary policy innovation - except for Japanese data with the nominal exchange rate ordered last. This empirical finding together with the results of our formal tests of policy interdependence suggest the existence of some form of policy interrelatedness between the US on one hand and each of the countries considered on the other. A second way of verifying the plausibility of our estimated monetary policy shocks is to examine whether their impact effects on bilateral exchange rates are in accordance with a priori theoretical predictions. From the estimates of  $g_{74}$  and  $g_{76}$  given in the table above the US dollar depreciates on impact following expansionary US monetary policy shocks and positive foreign interest rate shocks respectively. These results indicate that, given our structural VAR identification scheme, it is reasonably justifiable to consider the estimated linear combination of innovations in total reserves, the



federal funds rate, the exchange rate and foreign monetary policy as monetary policy shocks in the US. For the non-US countries considered here monetary policy shocks in this case can be reasonably represented by a linear combination of short term interest rate innovations, US nonborrowed reserves innovations and exchange rate innovations.

#### **4.2 *Dynamic Responses***

The foreign exchange market and the international policy arena - including those of strategic monetary policy aimed at exchange rate stabilization as considered in this paper - are best understood within a dynamic setting. In this section therefore we present an analysis of our estimates of the dynamic effects of monetary policy shocks on real and nominal bilateral exchange rates using estimated impulse responses and forecast error variance decompositions based on the identification schemes discussed above. We also examine the extent to which these schemes help explain the puzzles encountered in the literature.

##### ***Estimated Impulse Responses and Variance Decompositions***

Based on the semi-recursive identification scheme, figure 3a depicts the estimated responses for the respective countries following a one standard deviation US monetary policy shock. Figure 3b presents equivalent estimates of the responses to a one standard deviation foreign monetary policy shock. Figures 4a and 4b are the exact parallels of figures 3a and 3b except that in this case the estimated impulse responses are based on our structural identification scheme. Columns 1 to 4 of figures 2 through 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds

rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation monetary policy shock as indicated in the title. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar. To conserve space we do not present the estimated responses for the logarithm of employment in the figures mentioned above. Figures 5a and 5b assist us in the discussion of the estimated exchange rate responses as well as in assessing the relative performance of the various identification schemes considered in helping solve or generate the puzzles. The rows of figure 5a refer to the estimated responses of the nominal exchange rate to a one standard deviation foreign monetary policy shock obtained using Canadian, Japanese, German and British data respectively. The columns correspond to the various identification schemes used in estimating the responses. Figure 5b presents a corresponding information except that in this case the estimated responses are with respect to a one standard deviation foreign contractionary monetary policy shock. One-standard-error bands of the estimated impulse responses over 48 months time span - shown as dashed lines in the figures referred to above - are calculated by generating 500 random draws from the estimated asymptotic distribution of the VAR coefficients and the covariance matrix of the innovations<sup>8</sup>. The x-axis of each of the estimated responses shows the time horizon over which the impulse response experiments are performed.

Considering the estimated effects of expansive monetary policy disturbances in the US, as presented in figures 3a and 4a, a number

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<sup>8</sup>. In the case of exactly identified models, unlike in the case of over-identified VAR models, there is a one-to-one mapping of draws from the set of possible reduced form models into a set of possible structural interpretations. Hence our estimated error bands - calculated using the Monte Carlo procedure packaged with the RATS software - cannot be improved upon using the corrective adjustments suggested in Sims and Zha(1994). Killian(1995) establishes, using Monte Carlo simulations, that a bias-corrected bootstrap interval outperforms the Monte Carlo interval as well as the standard bootstrapping interval and the asymptotic interval in accounting for the bias observed in estimated small-sample impulse responses. His arguments however are valid only in the context of exactly identified *bi-variate* structural VAR models however; and hence are of no consequence for our results.

of important results emerge. Firstly, the negative response of the federal funds rate to US monetary policy shocks shows up under both identification schemes and for all countries considered. Secondly, it turns out that generally, as the federal funds rate falls following expansive monetary policy in the US, the short term interest rate of the respective foreign countries considered here also falls significantly. We interpret this as an indication of policy interrelatedness. Since foreign monetary authorities' monetary reaction function includes the US federal funds rate, as US interest rates fall foreign monetary authorities intervene to mitigate the envisaged subsequent fall in the dollar (alternatively an appreciation of their domestic currency) and the train effects of worsening trade balance. Finally, an expansive monetary policy in the US, depreciates the dollar - in real and nominal terms - on impact. The depreciation is however not as persistent under the structural identification scheme as it is for the semi-recursive identification scheme. Given our structural identification scheme, except for Canada and Japan, we do not observe persistent depreciation of the dollar following US expansive monetary policy shocks. In fact, from the estimated impulse responses as in figure 5a, the minimum level of depreciation of the dollar, following US monetary policy shocks, occurs a little after a month in the case of Germany and the UK. However, whereas the minimum depreciation is attained eventually (after roughly 25 months for the nominal exchange rate and 9 months for the real exchange rate) for Canadian data, Japanese data exhibits persistence in the depreciation of the dollar. Thus, in terms of consistency with the hypothesis of uncovered interest parity and overshooting models of exchange variability following monetary policy shocks, the structural identification scheme (incorporating policy interdependence) performs relatively better than the semi-recursive scheme. There is, under the latter scheme, a general tendency towards persistent depreciation of the dollar following expansionary US monetary policy shocks. This is generally the case under the fully recursive

identification scheme as well.

Next, consider figures 3b, 4b and 5b which report corresponding results following contractionary foreign monetary policy shocks. Observe the *exchange rate puzzle* distinctly exhibited under the fully recursive identification scheme shown in the first column of figure 5b.. Generally, for the semi-recursive and structural identification schemes and for all the countries considered foreign contractionary monetary policy shocks lead to an impact depreciation of the dollar (or equivalently, an appreciation of the domestic currencies of these countries). Except for the case of Japan the pattern looks very similar in all the countries under the semi-recursive scheme. On the other hand our structural identification scheme again yields results consistent with the predictions of uncovered interest parity under which the increase in the domestic interest rate following domestic monetary tightening must be associated with a domestic currency appreciation upon impact followed by a gradual depreciation. The impact dollar depreciations, following foreign short term interest rate shocks, are followed at least by gradual appreciations of the dollar. More specifically, following contractionary foreign monetary policy shocks the minimum depreciation of the dollar occurs after the first month in Japan. Again, in consonance with the hypothesis of uncovered interest parity. The process is however gradual for the rest of the countries considered - the minimum depreciation rate occurs after 10, 9 and 15 months for Canada, Germany, and the UK respectively. Thus even though the expected depreciations of the domestic currency do not occur right after the impact appreciations, our results are far from the persistent appreciations for periods of up to two years observed by earlier researchers.

We turn next to assessing the relative importance of the identified monetary policy shocks - under each identification scheme - in

explaining exchange rate fluctuations. Table 2 above summarizes the estimated proportions (in percentages) of forecast error variances of the exchange rate over the indicated horizons (indicated in months). In the exception of a few instances where exchange rate innovations account for less than 50% of the forecast error variances the largest proportion of the forecast error variance is generally explained by exchange rate innovations themselves.

*Table 2: Estimated Forecast Error Variance Decompositions for Nominal Exchange Rates*

| Horizon | Shocks         | Semi-Recursive Identification Scheme |         |       |       | Structural Identification Scheme |         |       |       |
|---------|----------------|--------------------------------------|---------|-------|-------|----------------------------------|---------|-------|-------|
|         |                | Canada                               | Germany | Japan | UK    | Canada                           | Germany | Japan | UK    |
| 1       | $v_{NBR}^{US}$ | 3.04                                 | 4.01    | 4.75  | -     | 29.99                            | 50.93   | 20.85 | 0.31  |
|         | $v_M^F$        | 7.10                                 | 2.49    | 0.14  | 0.21  | 9.11                             | 0.78    | 1.60  | 64.88 |
|         | $v_{XR}$       | 85.84                                | 84.65   | 91.51 | 96.23 | 57.14                            | 47.47   | 39.47 | 24.13 |
| 2       | $v_{NBR}^{US}$ | 4.02                                 | 5.41    | 8.46  | -     | 30.94                            | 51.04   | 24.69 | 0.48  |
|         | $v_M^F$        | 4.89                                 | 1.65    | 0.11  | 1.87  | 8.64                             | 0.82    | 1.26  | 60.41 |
|         | $v_{XR}$       | 85.31                                | 79.84   | 88.49 | 90.74 | 56.64                            | 47.33   | 39.85 | 28.31 |
| 4       | $v_{NBR}^{US}$ | 3.47                                 | 5.91    | 8.42  | 0.44  | 30.81                            | 51.03   | 25.01 | 1.54  |
|         | $v_M^F$        | 3.93                                 | 0.89    | 1.05  | 5.45  | 8.99                             | 0.83    | 0.91  | 52.23 |
|         | $v_{XR}$       | 86.09                                | 74.55   | 88.03 | 80.06 | 56.39                            | 47.34   | 38.12 | 36.09 |
| 6       | $v_{NBR}^{US}$ | 5.78                                 | 5.25    | 9.10  | 0.34  | 31.98                            | 51.02   | 30.11 | 3.82  |
|         | $v_M^F$        | 3.47                                 | 0.65    | 1.49  | 7.40  | 8.48                             | 0.82    | 2.28  | 44.28 |
|         | $v_{XR}$       | 81.43                                | 72.79   | 84.95 | 71.17 | 55.49                            | 47.37   | 33.89 | 40.50 |
| 12      | $v_{NBR}^{US}$ | 5.61                                 | 3.28    | 11.49 | 0.39  | 31.06                            | 51.17   | 41.75 | 7.25  |
|         | $v_M^F$        | 1.78                                 | 0.50    | 1.92  | 17.08 | 8.92                             | 0.91    | 11.01 | 35.80 |
|         | $v_{XR}$       | 77.41                                | 70.38   | 76.10 | 51.41 | 55.78                            | 47.17   | 20.15 | 42.97 |

**Notes:** The numbers presented in this table are in percentages. A '-' is used to represent numbers less than  $1 \times 10^{-3}$ .

Further, the results indicate that the estimated forecast error variance decompositions vary quite substantially not only across

countries and schemes but also between the two monetary policy shocks. Aspects of the general picture as depicted by the table above are summarized in the couple of points below:

i) US monetary policy shocks generally explain a relatively larger proportion of the forecast error variance of the bilateral exchange rates than the foreign monetary policy shocks do. In particular, under our structural identification scheme, US monetary policy shocks explain roughly 31.06% of the forecast error variance for Canadian data whereas foreign monetary policy shocks explain only about 8.92% over a 12 month horizon. The corresponding figures for German and Japanese data are {51.17% and 0.91%} and {41.75% and 11.01%} respectively. Given the semi-recursive identification scheme the figures drop to barely {3.28% and 0.50%} for German data and {11.49% and 1.92%} for Japanese data. This evidence is however not supported by the data-set for the UK under both identification schemes where the relative potency is switched in favour of foreign monetary policy innovations.

ii) Generally the sum of the proportion of the forecast error variance explained by both US and foreign monetary policy shocks are perceptibly higher for our structural identification scheme than for the semi-recursive scheme. Again, this is an indication that the former identification scheme incorporating international monetary policy interdependence performs better than the scheme that regards the US as a policy 'leader' and all other countries as 'followers'.

Based on the evidence presented so far the more flexible structural identification scheme that explicitly incorporates policy interdependence among countries can be said to encompass the semi-recursive identification scheme to a very large extent.

## 5. Summary and Conclusion

Earlier empirical research on the effects of exchange rate fluctuations in response to monetary policy shocks encountered a number of puzzles including the *exchange rate puzzle* and the forward discount bias puzzle. This paper introduces current findings in the debate in monetary economics - on the measurement of monetary policy shocks - into an open economy context. The main objective here is to investigate the extent to which the documented puzzles could be attributable to the particular monetary policy identification schemes used. The main finding of this paper is that the puzzles could be attributable to the use of the fully recursive identification scheme in VARs applied in the open economy. The low degree of flexibility of the fully recursive identification scheme rarely delivers models that reflect the complexities of the arena of policy-making. We regard international policy interdependence as one of these complexities that the recursive identification scheme is unable to capture. In particular, the scheme, as is well-known, restricts the reaction functions of monetary authorities in such a way that such necessary factors as exchange rate and foreign monetary policy variables cannot enter the policy reaction function of the US while at the same time allowing these same variables to react contemporaneously to US monetary policy shocks. This non-flexibility is addressed in this paper by introducing a structural identification scheme that allows us to incorporate contemporaneous exchange rate movements and international policy interrelatedness into the monetary authorities' reaction functions.

As the empirical results reveal the structural identification schemes used in this paper are able to add to our understanding of the effects of monetary policy shocks on exchange rate fluctuations and yield results consistent with *a priori* theoretical predictions. One of these identifications schemes - called the semi-recursive identification scheme in the paper - is based on the actual

operating procedures of the US federal reserve system. The second scheme follows the structural VARs tradition by isolating a set of independent shocks by way of theoretically meaningful restrictions. In particular our empirical findings suggest that indeed monetary policy identification schemes, especially those incorporating international policy linkages, could help solve the puzzles hitherto encountered in the literature.



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## **Appendix A: *Data Sources and Description***

The data used in the estimations are monthly data obtained from OECD MEI Database for the period 1974:1 to 1994:12 (unless otherwise indicated). The various variables include the following for the respective countries.

1. Employment (measured in weekly hours of work in manufacturing unless otherwise stated):

- a) Canada ..: Canhours
- b) Germany...: Deumhour
- c) United Kingdom...: Gbrhours
- d) Japan...: Jpnhours
- e) United States...: Usahours

2. Monetary policy indicators/variables:

- a) Canada ..: Canprime (Prime Interbank Rate - Commercial Banks)
- b) Germany...: Deucall (the German Call Money Rate)
- c) United Kingdom...: Gbrcall (Call Money Rate)
- d) Japan...: Jpngbond (Central Gov't Bond Yields)
- e) United States...: TR (Total Reserves - CITIBASE Data)  
NBR (Nonborrowed Reserves - CITIBASE Data)  
FF (Federal Funds Rate - CITIBASE Data)

3. Exchange rates: (All exchange rates used are indicated as domestic currency per unit of the US dollar; monthly averages).

- a) Canada...: Canusxau
- b) Germany...: Deusxav
- c) United Kingdom...: Gbrusxav
- d) Japan...: Jpnusxav

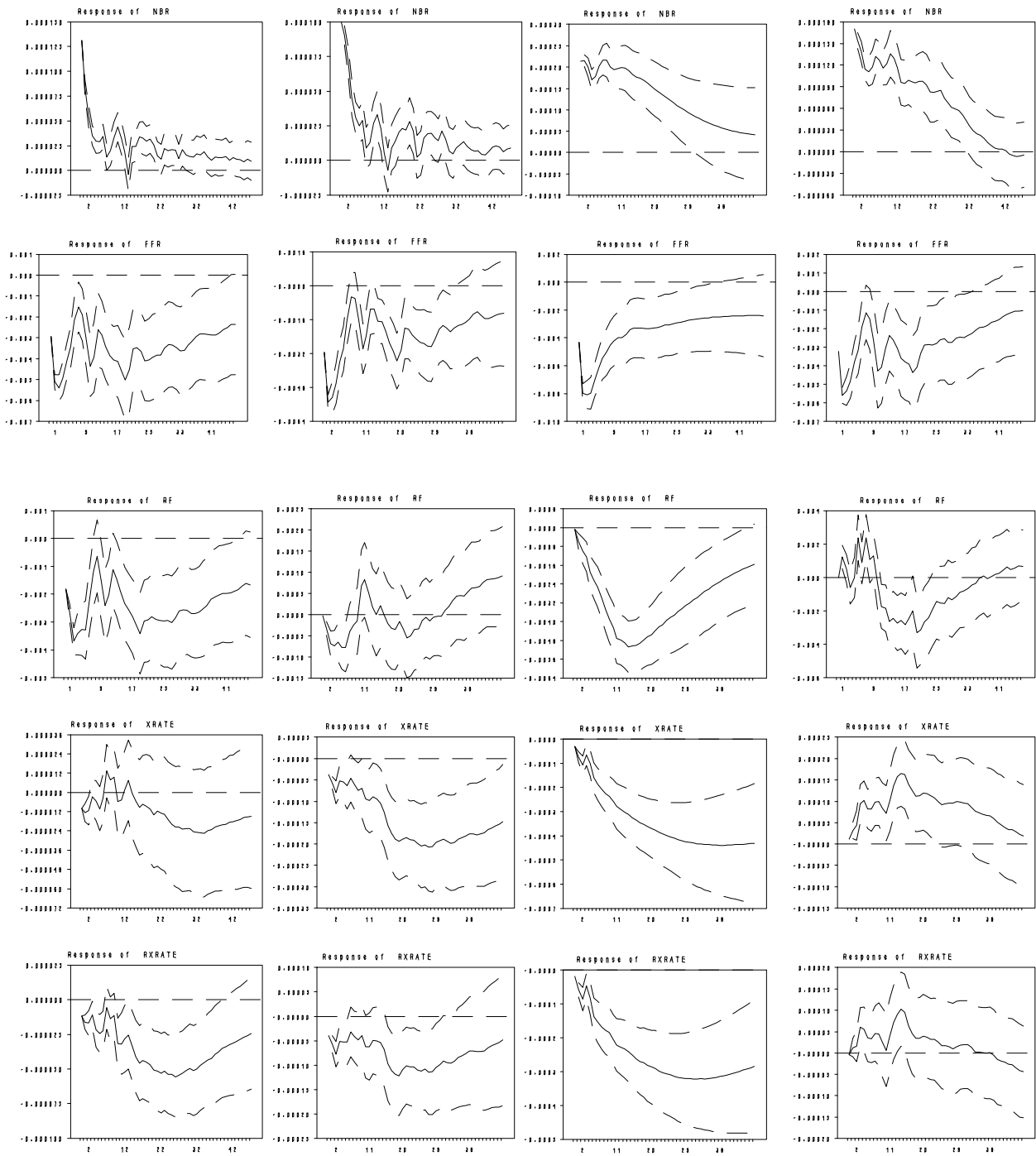
**Appendix B: Parameter Estimates of the Structural VAR model**

**Table B1** *Parameter Estimates of the Structural VAR model*

| Parameter Estimates | Country           |                   |                    |                   |                   |                   |                   |                   |
|---------------------|-------------------|-------------------|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                     | Canada            |                   | Germany            |                   | Japan             |                   | UK                |                   |
| $g_{21}$            | -0.173<br>(0.048) | -0.177<br>(0.048) | 0.021<br>(0.372)   | 0.142<br>(0.372)  | -1.574<br>(0.222) | -1.466<br>(0.217) | 0.035<br>(0.059)  | 0.025<br>(0.059)  |
| $g_{31}$            | 0.185<br>(0.088)  | 0.189<br>(0.087)  | 0.061<br>(0.083)   | 0.078<br>(0.083)  | -0.079<br>(0.075) | -0.086<br>(0.074) | 0.021<br>(0.076)  | 0.009<br>(0.077)  |
| $g_{41}$            | -0.083<br>(0.068) | -0.072<br>(-)     | -0.139<br>(0.099)  | -0.135<br>(0.070) | -0.087<br>(0.064) | -0.076<br>(-)     | -0.065<br>(0.063) | -0.063<br>(0.071) |
| $g_{43}$            | -0.852<br>(0.063) | -0.811<br>(-)     | -0.833<br>(0.079)  | -0.820<br>(0.072) | -0.832<br>(0.103) | -0.828<br>(-)     | -0.849<br>(0.097) | -0.872<br>(0.061) |
| $g_{45}$            | 0.015<br>(-)      | 0.014<br>(-)      | 0.013<br>(-)       | 0.016<br>(-)      | 0.012<br>(0.005)  | 0.012<br>(-)      | 0.013<br>(-)      | 0.013<br>(-)      |
| $g_{46}$            | -0.001<br>(0.001) | 0.000<br>(-)      | 0.012<br>(0.004)   | 0.003<br>(0.004)  | -0.001<br>(0.003) | 0.000<br>(-)      | -0.001<br>(0.001) | -0.001<br>(0.001) |
| $g_{47}$            | 0.092<br>(0.348)  | 0.072<br>(-)      | 0.033<br>(-)       | 0.028<br>(-)      | 0.034<br>(-)      | 0.043<br>(-)      | 0.016<br>(0.274)  | 0.035<br>(-)      |
| $g_{51}$            | -0.006<br>(0.946) | -0.015<br>(-)     | -16.106<br>(3.996) | -0.001<br>(-)     | -2.640<br>(0.689) | -0.275<br>(0.724) | -0.003<br>(0.789) | -0.061<br>(0.016) |
| $g_{53}$            | -0.015<br>(-)     | 0.012<br>(-)      | -0.095<br>(-)      | -0.015<br>(-)     | -6.905<br>(0.206) | -0.034<br>(-)     | -0.003<br>(-)     | -0.003<br>(-)     |
| $g_{54}$            | -1.095<br>(-)     | -0.149<br>(-)     | -0.508<br>(-)      | -13.782<br>(-)    | -0.206<br>(0.488) | -0.184<br>(-)     | -0.167<br>(-)     | -0.142<br>(-)     |
| $g_{56}$            | -0.664<br>(-)     | -0.669<br>(-)     | -0.389<br>(-)      | -0.011<br>(0.077) | 0.102<br>(0.264)  | -0.043<br>(-)     | -0.066<br>(0.062) | -0.036<br>(0.053) |
| $g_{57}$            | -1.106<br>(-)     | -0.848<br>(-)     | -1.063<br>(0.598)  | -1.254<br>(-)     | -1.273<br>(0.403) | -0.985<br>(-)     | -1.303<br>(-)     | -1.036<br>(-)     |
| $g_{62}$            | 0.002<br>(0.582)  | -0.007<br>(0.870) | -0.091<br>(-)      | 0.516<br>(0.515)  | -2.499<br>(0.640) | -0.001<br>(0.569) | 0.000<br>(0.827)  | -0.005<br>(0.672) |
| $g_{64}$            | -0.226<br>(0.477) | -1.697<br>(-)     | -7.202<br>(1.225)  | -0.130<br>(0.857) | 1.965<br>(0.691)  | -0.065<br>(0.791) | -0.206<br>(0.675) | -0.214<br>(0.501) |
| $g_{67}$            | 0.174<br>(0.439)  | -4.272<br>(-)     | -0.311<br>(-)      | 0.019<br>(-)      | 0.011<br>(0.789)  | -0.003<br>(-)     | 1.769<br>(0.454)  | 0.018<br>(0.181)  |
| $g_{71}$            | 0.032<br>(0.065)  | 0.003<br>(-)      | 0.036<br>(-)       | 0.052<br>(-)      | 0.221<br>(0.144)  | 0.227<br>(-)      | 0.011<br>(0.143)  | 0.018<br>(0.262)  |
| $g_{72}$            | 0.009<br>(0.067)  | -0.022<br>(-)     | -0.038<br>(0.030)  | -0.039<br>(-)     | -0.001<br>(0.043) | 0.004<br>(-)      | 0.189<br>(0.058)  | 0.017<br>(0.025)  |
| $g_{73}$            | -0.022<br>(0.230) | 0.041<br>(-)      | 0.045<br>(-)       | 0.083<br>(-)      | 0.006<br>(-)      | -0.001<br>(-)     | -0.148<br>(1.115) | -0.086<br>(-)     |
| $g_{74}$            | -0.014<br>(0.274) | -0.099<br>(-)     | -0.118<br>(-)      | -0.147<br>(-)     | -0.142<br>(-)     | -0.269<br>(-)     | -0.110<br>(0.378) | -0.113<br>(-)     |
| $g_{75}$            | 0.001<br>(0.006)  | 0.000<br>(-)      | -0.011<br>(-)      | -0.013<br>(-)     | -0.008<br>(-)     | -0.009<br>(-)     | -0.001<br>(0.014) | -0.002<br>(0.012) |
| $g_{76}$            | -0.007<br>(-)     | -0.006<br>(-)     | -0.013<br>(-)      | -0.013<br>(-)     | -0.003<br>(-)     | -0.008<br>(-)     | -0.002<br>(0.009) | -0.001<br>(0.005) |

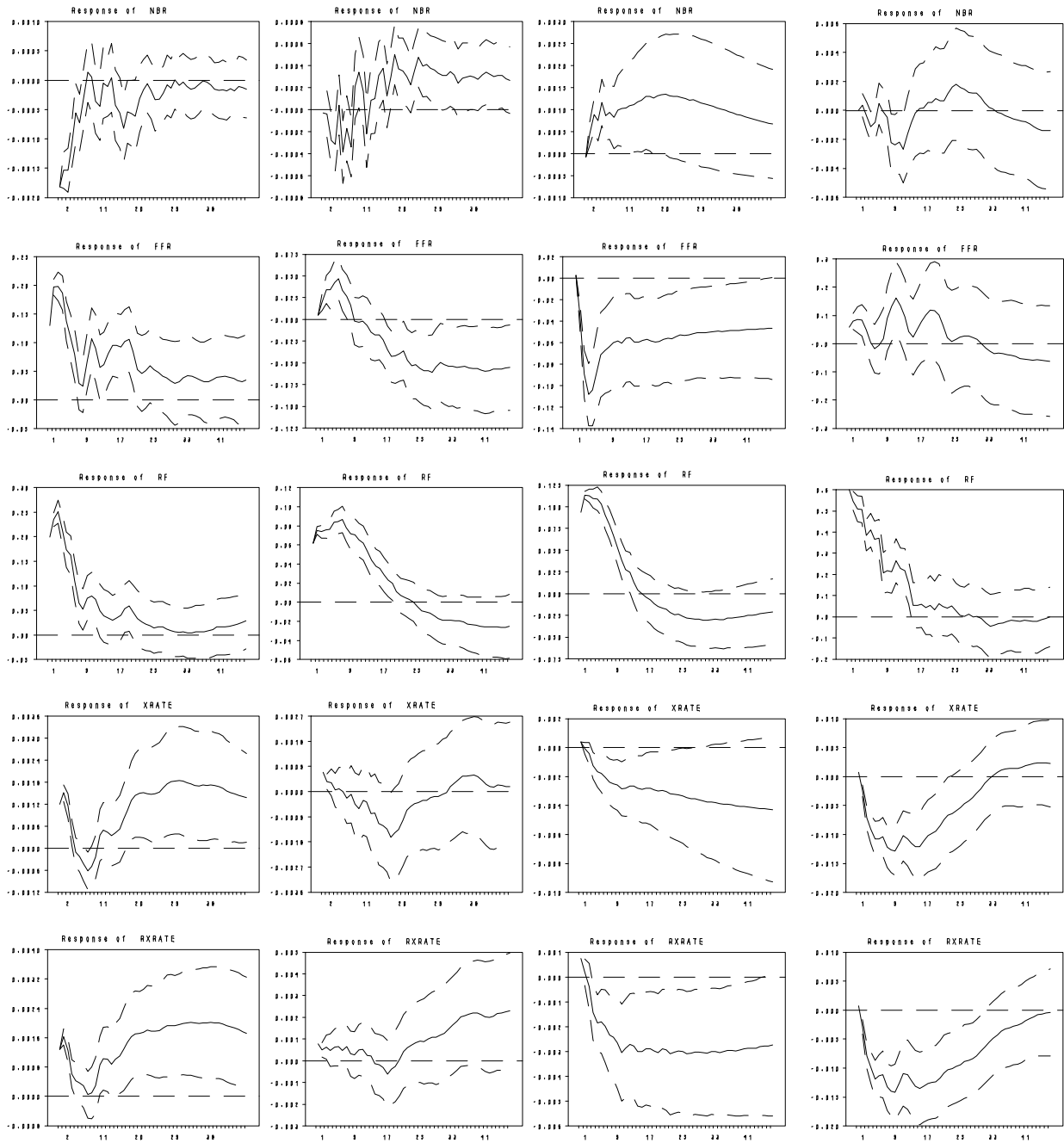
**Notes:** The estimates in parentheses are standard errors. A \* indicates significance at the 95% confidence level. Two elements are presented for each country. The first entry shows the estimates from a VAR including the bilateral nominal exchange rate as the last element whereas the second entry is when the bilateral real exchange rate is used. The estimates are obtained using the Simplex Algorithm and the results used as initial values in the Bermanke procedure as in the RATS 4.0 manual. Figures indicated by "-" are less than  $1 \times 10^{-3}$ . We use 12 lags in all the estimations.

Figure 2a. Estimated impulse responses to US monetary policy shocks under the fully recursive identification scheme.



**Notes:** Columns 1 to 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation US monetary policy shock. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar.

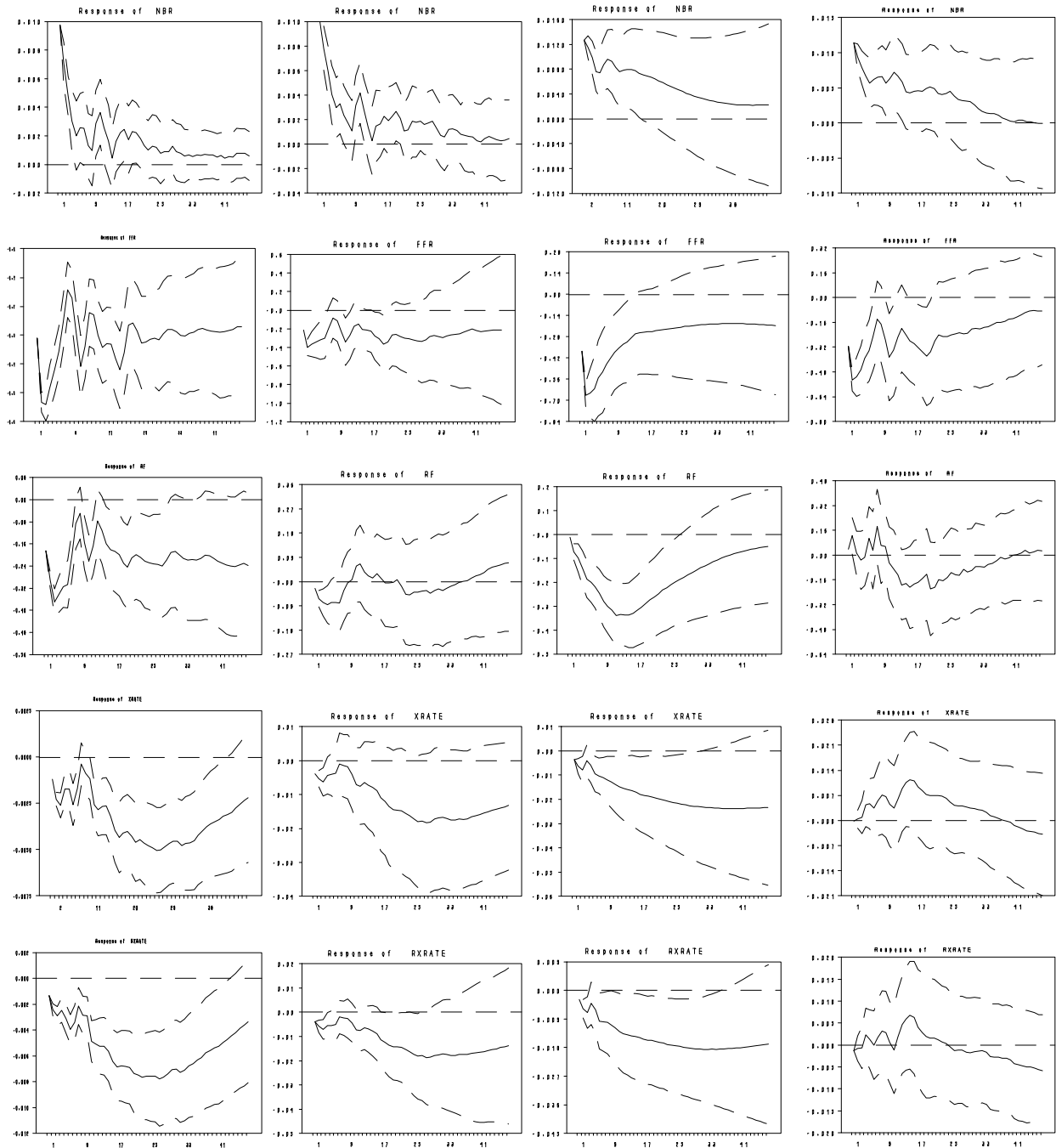
Figure 2b. Estimated impulse response to foreign monetary policy shocks under the fully recursive identification scheme.



**Notes:** Columns 1 to 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation foreign monetary policy shock. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar.

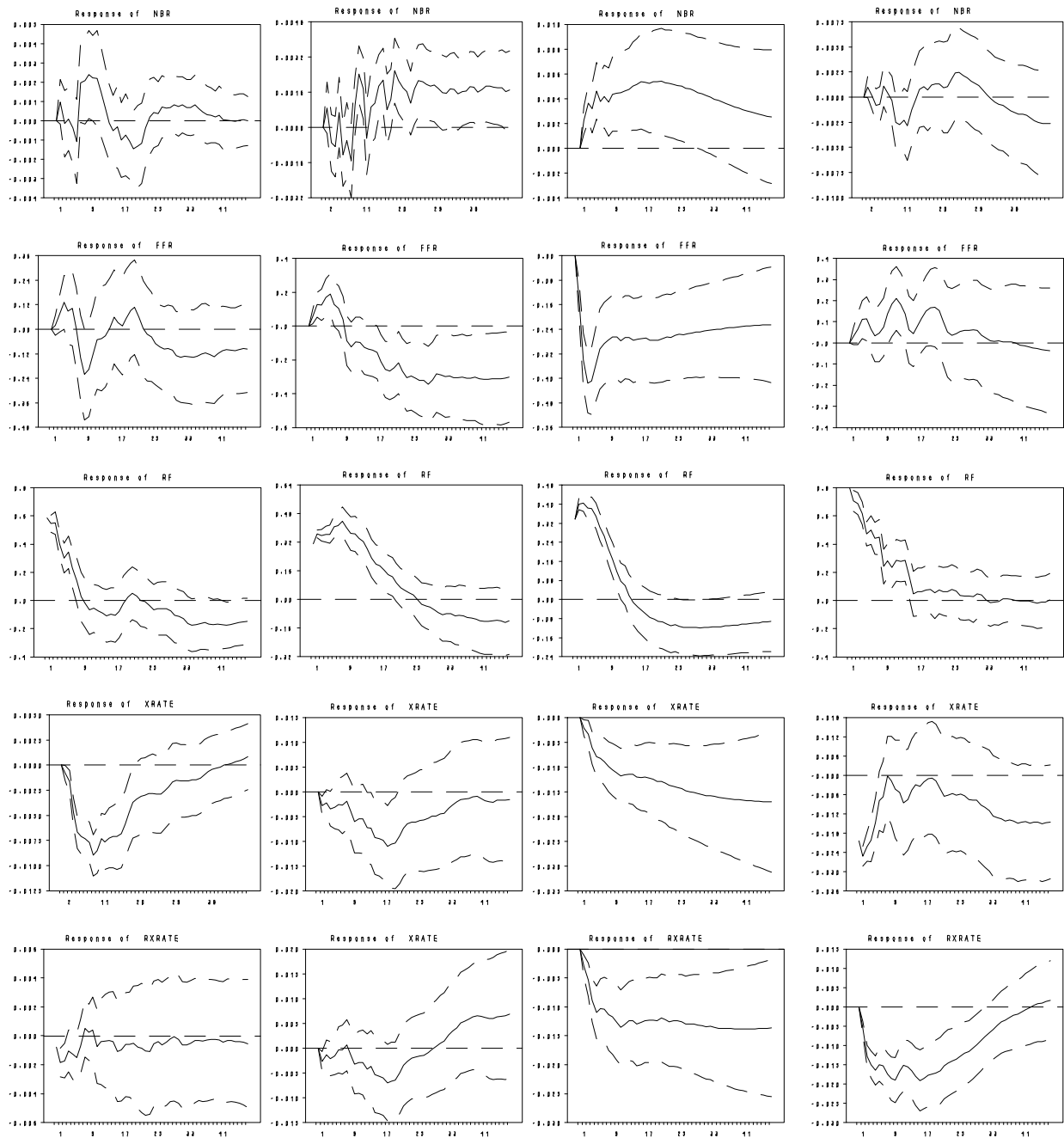


Figure 3a. Estimated impulse responses to US Monetary Policy Shocks; given the semi-recursive identification scheme.



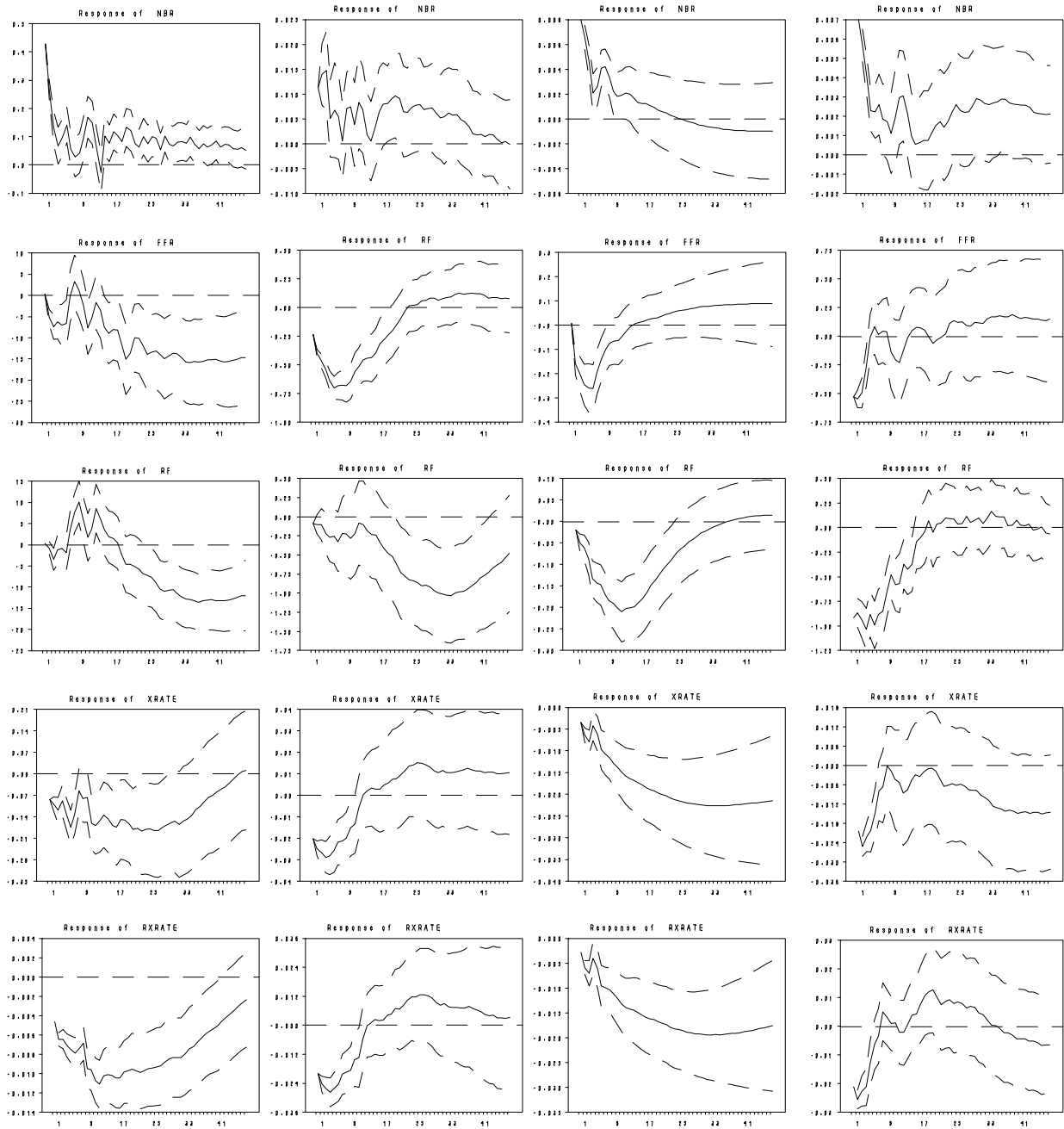
**Notes:** Columns 1 to 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation US monetary policy shock. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar.

Figure 3b. Estimated impulse responses to foreign monetary policy shocks; given the semi-recursive identification scheme.



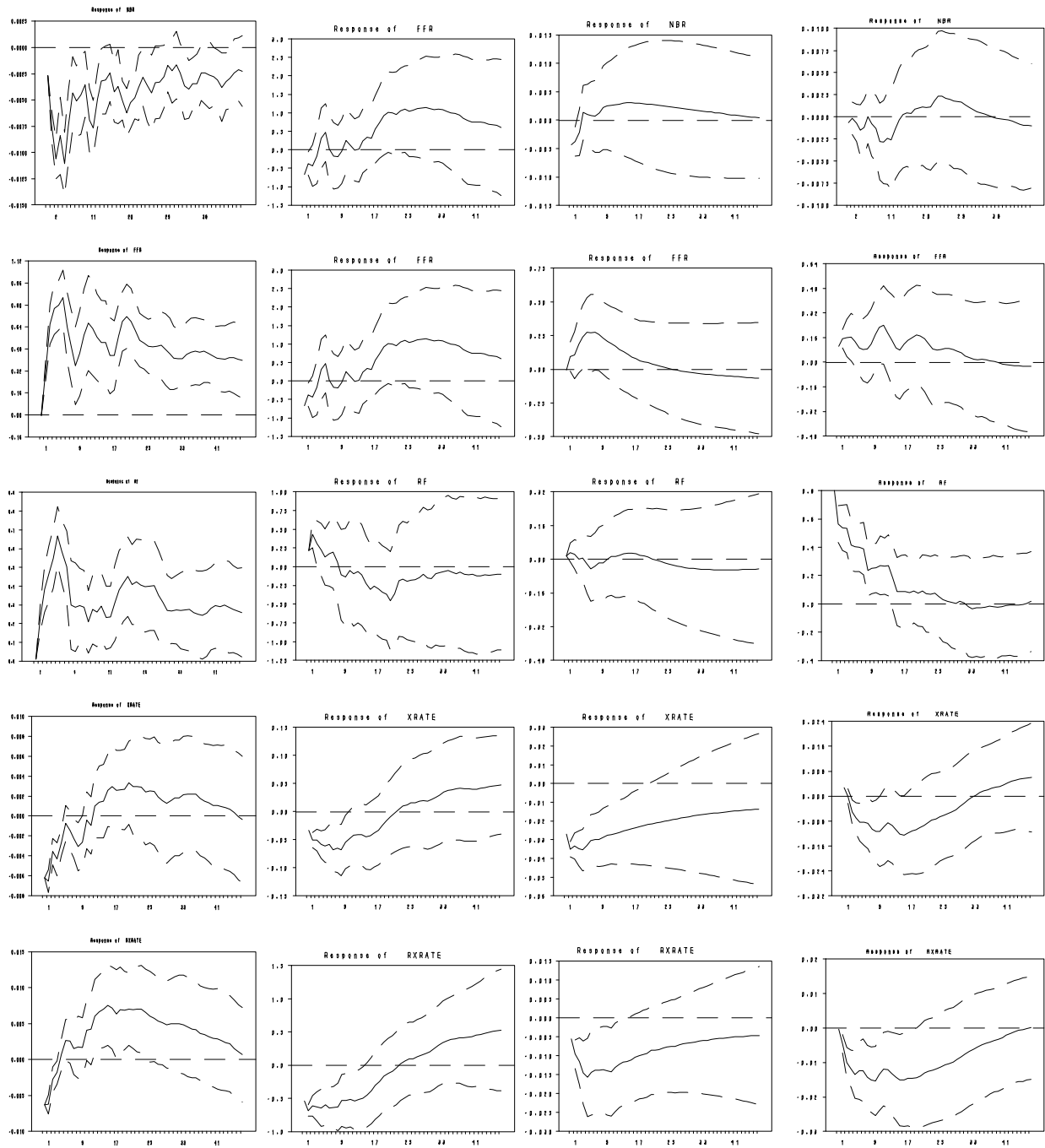
**Notes:** Columns 1 to 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation foreign monetary policy shock. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar.

Figure 4a. Estimated impulse responses to US Monetary policy shock; given the structural identification scheme.



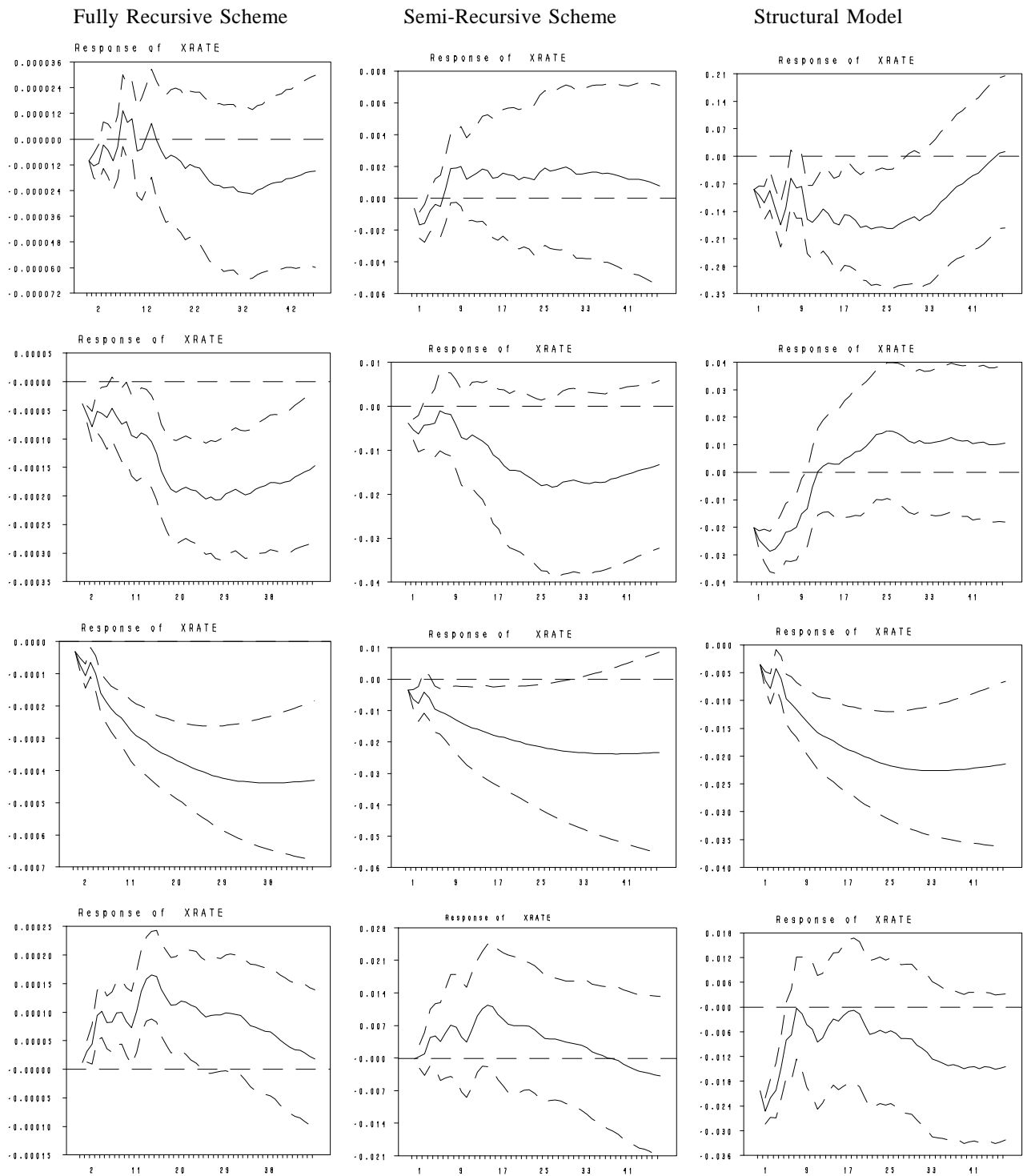
**Notes:** Columns 1 to 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation US monetary policy shock. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar.

Figure 4b. Estimated impulse responses to foreign policy shocks; given the structural identification scheme.



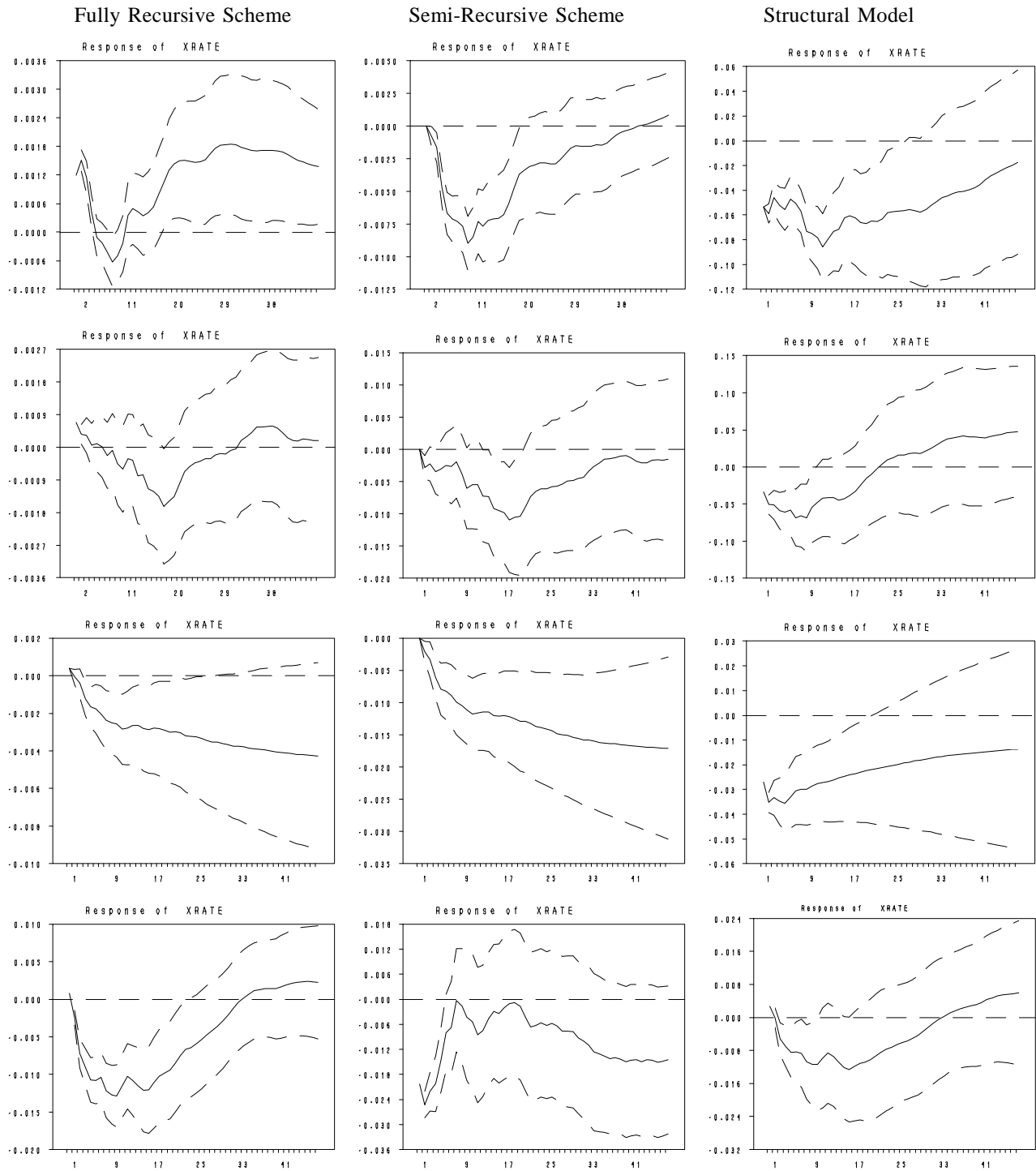
**Notes:** Columns 1 to 4 show the estimated responses obtained using Canadian, German, Japanese and British data respectively. The rows 1 through 5 depict the estimated response of the US nonborrowed reserves, US federal funds rate, the foreign short term interest rate, the nominal exchange rate, and the real exchange rate respectively to a one-standard-deviation foreign monetary policy shock. The nominal exchange rate is measured as the domestic currency price of a unit of the US dollar.

Figure 5a. Monetary policy identification schemes and estimated exchange rate responses to US Monetary Policy Shock.



**Notes:** The rows refer to the estimated responses of the nominal exchange rate to a one standard deviation foreign monetary policy shock obtained using Canadian, German, Japanese and British data respectively. The columns correspond to the various identification schemes used in estimating the responses.

Figure 5b. Monetary policy identification schemes and estimated exchange rate responses to respective foreign monetary policy shocks.



**Notes:** The rows refer to the estimated responses of the nominal exchange rate to a one standard deviation foreign monetary policy shock obtained using Canadian, German, Japanese and British data respectively. The columns correspond to the various identification schemes used in estimating the responses.