Identifying Monetary Policy in a Small Open Economy Under Flexible Exchange Rates

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Abstract: Previous empirical study on the effects of monetary policy shocks in small open economies has produced exchange rate responses that are inconsistent with existing open economy macroeconomic theory. We argue that a careful identification of monetary policy in an explicit open economy setting is required. Using Canada as a case study, we specify and estimate a vector-autoregressive model that focuses on the identification of contemporaneous monetary policy, and we obtain tightly estimated results overall. The resulting dynamic responses to the identified monetary policy shock as well as to a foreign shock are consistent with traditional open economy analyses and highlight the importance of the exchange rate as a transmission mechanism.

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1. Introduction

Under flexible exchange rates, the effects of domestic monetary policy shocks on the small open economy, as well as policy responses to various home and foreign shocks, are often thought to revolve around interest rate and exchange rate effects. The common feature is that in the short run, an unanticipated fall in the money supply increases the nominal interest rate (the liquidity or interest rate effect) and appreciates the value of domestic currency (the exchange rate effect). Although policy discussion frequently proceeds as though these effects were well documented, empirical evidence has actually remained uncertain. The evidence from large structural econometric models summarized by Dornbusch and Giovannini (1990) [e.g. Frankel (1987) and Edison and Tryon (1988)] is subject to the criticisms raised by Sims (1980). He questioned the credibility of the many identifying restrictions employed in such models, and suggested the use of impulse responses from reduced-form vector autoregressions (VARs) for policy analysis. But identification, the ability to attribute the response of a certain variable to an economically interpretable shock, has remained a problem.

In a recent paper, Bernanke and Blinder (1992) argue that federal funds rate innovations are in some respects a better indicator of monetary policy shocks in the United States than are innovations in monetary aggregates. This argument, however, is challenged by Gordon and Leeper (1994) who find that innovations either in funds rates or in monetary aggregates produce some dynamic responses that are at odds with what is generally expected for the effects of monetary policy shocks. Otherwise, for the U.S., estimated responses of other variables such as output and exchange rates to statistical innovations in interest rates, or in monetary aggregates, have usually been consistent with traditional monetary analyses [Sims (1992a), Eichenbaum and Evans (1993), Grilli and Roubini (1993), and Christiano, Eichenbaum and Evans (1994)]. This makes sense for the United States because the U.S. economy is large and relatively closed. It can thus probably be modeled with relatively little attention to foreign variables without much loss of generality.[1] Compared to most countries in the world, movements in interest rates in the U.S. are the least likely to reflect foreign shocks, and the reaction of the money supply to foreign shocks could be relatively small. Moreover, in closed economy models [e.g., Christiano and Eichenbaum (1992)], the monetary policy transmission mechanism is often viewed as operating primarily through interest rate (liquidity) effects, and not exchange rate effects.[2]

These conditions for identifying monetary policy shocks and interpreting their effects are much less likely to be valid in the context of smaller and more *open* economies than the U.S. Therefore, it is not surprising that empirical evidence for such countries has often consisted of puzzling exchange rate responses to interest rate innovations interpreted as "monetary policy shocks": positive interest rate innovations lead to a significant depreciation of domestic currency and other unexpected effects [Sims (1992a) and Grilli and Roubini (1993)]. Either monetary policy influences these economies in different ways than usually expected, or monetary policy has not been successfully identified.

In this paper, we offer new empirical evidence on these issues by using a systems method of estimation for the identification of Canadian monetary policy within a comprehensive VAR model. We argue that the identification of monetary policy in an open economy requires the estimation of a proper policy reaction function which is distinguishable from private sector responses to both policy actions and changes in foreign variables. We also take the small open economy framework seriously and treat foreign variables as exogenous. Within this framework, we assess the transmission mechanisms for monetary policy shocks, the effects and relative importance of these shocks and other domestic and foreign shocks, the transmission channels of foreign shocks, and the possible ability of the monetary authority to react to foreign shocks.

[1]Papell (1989) treats the U.S. economy as a small open economy in his simultaneous equations model, but does not report any impulse responses to monetary policy shocks.
[2]Bernanke and Blinder (1988) also accentuate the role of "credit" channels.

The next section briefly discusses the analysis of the exchange rate effect in addition to the liquidity effect in existing open economy models, how such an analysis is an important characteristic for recent empirical studies of the identification of monetary policy shocks, and the monetary policy response to foreign shocks under flexible exchange rates. Section 3 describes the data set used in this paper. Section 4 documents the anomalous results of using a VAR model with simple Choleski normalization to identify Canadian monetary policy, and outlines our general strategy of addressing these unsatisfactory findings.

Section 5 is primarily concerned with the specification of our model, the identifying assumptions, the estimated model parameters, and the resulting dynamic responses to a negative money supply shock and to a foreign shock. In particular, our chief findings are that an unanticipated fall in home money supply raises both the nominal (and real) Canadian interest rate and the nominal (and real) value of Canadian currency; there is no exchange rate or interest rate puzzle. In contrast to strong interest rate effects in recent studies of monetary policy in the relatively large and closed economy of the U.S. [e.g., Gordon and Leeper (1994)], we find that the Canadian interest rate response is weak while the exchange rate effect is strong.[3] Our identified contractionary monetary policy shocks also produce a short-run J-curve effect in the trade balance, a short-run decrease in output, and a negative response in the price level. These results therefore provide, for a small open economy, plausible-looking effects from exogenous monetary policy shocks. Moreover, the dynamic responses to foreign shocks that we observe are consistent with monetary policy intervention that has been influential in the face of these external shocks.

2. Background and Overview

The anticipation of empirical interest rate (liquidity) and exchange rate effects from money supply shocks derives from many open economy models. In

[3]The importance of the empirical liquidity effect for identifying monetary policy in econometric models applied to a relatively large closed economy has been well addressed by Leeper and Gordon (1992) and the references therein.

generalizations of the Mundell-Fleming model [Turnovsky (1981), Marston (1985), Dornbusch and Giovannini (1990), Krugman (1993), and McCallum (1994)], unanticipated shifts in the money supply can have effects on the home country's output and prices.[4] With fixed wages and static exchange rate expectations, a negative money supply shock appreciates home currency in both nominal and real terms, but leaves the interest rate unchanged under uncovered interest rate parity. Thus, the monetary transmission mechanism occurs primarily through an "exchange rate effect" and its depressing effect on the trade balance, rather than through an "interest rate effect" as in closed economy models.[5] In extensions with rational expectations, short-run labor contracts and long-run full employment, the real interest rate rises because of expected deflation, restoring the interest rate along with the exchange rate as a transmission mechanism. In the Dornbusch (1976, 1980) overshooting model, a monetary contraction immediately increases the interest rate from the "liquidity effect," and appreciates home currency to maintain uncovered interest parity in the short-run before other variables can adjust. But overshooting or liquidity effects need not occur if output responds simultaneously in the model [Turnovsky (1981)] or if the domestic monetary authorities respond quickly to changes in variables such as exchange rates [McCallum (1994)].

Monetary intertemporal optimization models for the open economy also contain exchange rate and interest rate effects. In Ho's (1993) model with flexible prices, a monetary contraction leads to an increase in the nominal interest rate and for some parameter values an appreciation of home currency. The exchange rate effect can be also found in Obstfeld (1981). In Svensson and van Wijnbergen (1989), nominal interest rates are independent of monetary expansion but exchange rate effects and real interest rate effects play essential roles in intratemporal (between countries) and intertemporal substitution.

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[4]The original papers that are widely cited are Mundell (1963) and Fleming (1962).

[5]Other avenues for the effects of an appreciated home currency on the home economy in modified Mundell-Fleming models are the Laursen-Metzler effect and the real wealth effect [Laursen and Metzler (1950), Marston (1985)].

Regarding foreign shocks, both in traditional (Mundell-Fleming) models with rational expectations [Turnovsky (1981) and Marston (1985)] and in intertemporal optimization models [Stockman and Svensson (1987), Svensson and van Wijnbergen (1989), and Ho (1993)], a foreign disturbance can affect the home economy through the price channel, the output channel and the interest rate channel. In the simplest Mundell-Fleming models with static expectations, foreign price and output disturbances can be offset by exchange rate changes which keep the trade balance constant. But, more generally, the effect on home output is ambiguous, in part depending on the extent to which the disturbance is not expected to be permanent [Turnovsky (1981)]. Also, in addition to trade balance effects, exchange rate changes affect import prices and thus the overall domestic price level, money demand, and the labor market [Dornbusch and Krugman (1976), Turnovsky (1981), and Marston (1985)]. Meanwhile, a fall in the foreign interest rate (possibly from foreign monetary expansion), although reducing the home interest rate, tends to depress the home economy on balance because it appreciates home currency and worsens the trade balance. But in contrast to this Mundell-Fleming result, in Svensson and van Wijnbergen (1989) intertemporal substitution in favor of current goods (including home goods) from the fall in real interest rates can cause a net expansionary effect at home [see also Ho (1993)]. These possibilities leave a role for stabilizing domestic monetary policy.

As noted in the introduction, recent VAR empirical work on these issues has provided some mixed evidence concerning the exchange rate effect and other effects of monetary policy shocks. Sims (1992a) analyzes five major industrial countries (not including Canada) in six-variable VARs and assumes that the home interest rate innovations indicate monetary policy shocks. The variables in his model also include the exchange rate, a world commodity price, and home money, price, and output. While some impulse responses from the Choleski decomposition seem reasonable, he notes several puzzles. For several countries, positive interest rate innovations are associated with persistent *increases* in home price (particularly for France and Japan), and *depreciation* of home currency (for France and Germany). Also using the Choleski decomposition for their identification, Eichenbaum and Evans (1993) find no such puzzles for the U.S. in the floating rate period. Positive U.S. money innovations are associated with U.S. interest rate reductions and U.S. dollar depreciation with respect to five other major industrial countries (Canada is not on their list). They also find that positive U.S. interest rate innovations are associated with the appreciation of U.S. currency as generally expected. The effects of foreign interest rate innovations on the foreign countries themselves as well as on the U.S., however, are not reported. Grilli and Roubini (1993) use a very similar procedure to analyze the G-7 countries. But they observe that, except for the U.S., positive home interest rate innovations are associated with home currency *depreciation* in all other G-7 countries (the "exchange rate puzzle"). Racette and Raynauld (1992) analyze the Canadian case with several Canadian monetary aggregates, Canadian output, price, and interest rates, and a broader list of foreign variables including U.S. output, price, and interest rates, and two types of international commodity prices. Their identification employs the idea of identified VAR approaches beyond the Choleski decomposition. They also report the "exchange rate puzzle" whereby their identified contractionary monetary policy shocks depreciate the Canadian dollar.[6] These findings suggest that monetary policy has not been successfully identified for countries other than the U.S.[7]

This paper implements the following strategy to address these empirical puzzles for the relatively small open economy, using Canada as a case study. To distinguish unanticipated monetary policy disturbances from the reactions of the monetary authority to changes in various variables, we use an identified VAR approach in which we specify a monetary policy function explicitly for the impact period, rather than relying solely on reduced form

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[6]Previous papers applying VAR techniques to Canada include Choudhri (1983), Burbridge and Harrison (1985), Backus (1986), and Ambler (1989). These papers have not focused on the identification of monetary policy, our prime objective in this paper. Duguay (1994) responds to the unsatisfactory features of traditional large econometric models by utilizing single-equation approaches.

[7]McCallum (1994) writes: the implication that contractionary monetary policy shocks tend to devalue the domestic currency "is inconsistent not only with existing models but also with views that have been held by actual policy makers for many decades — indeed, for over a century (p.121)."

equations. This follows suggestions by Sims (1992a), Leeper and Gordon (1992), Sims (1994), and Pagan and Robertson (1994). Thus, we apply to the open economy the same general strategy that Gordon and Leeper (1994) and Sims and Zha (1994a) use to eliminate interest rate and price response puzzles sometimes found for the relatively closed U.S. economy [Leeper and Gordon (1992)]. We argue that the monetary authority reacts to contemporaneous changes in variables such as exchange rates and interest rates and that these financial variables also interact simultaneously in financial markets.

Since monetary policy in a small open economy is likely to respond to changes in a variety of foreign variables, contemporaneously and with lags, we include a broad set of foreign variables in addition to the home variables. This allows us to control for and assess shocks from a variety of sources. We also explicitly include trade flows in order to examine this traditional avenue for the transmission of domestic money supply shocks and foreign shocks in the open economy.

We use Canada as a case study because the United States essentially serves the role of rest-of-the-world to Canada and because Canada is relatively small and open to the United States. This simplifies the specification of foreign variables, and, given limited space, allows us to focus on the careful identification of monetary policy in a small open economy setting. We also argue that shocks from Canada have a negligible effect on the U.S., so that U.S. variables may be treated as exogenous from Canada's point of view.[8] We leave the application to other open economies to future research.

3. Data

Our data run monthly from 1974 through 1993. Though Canada's float began during 1970, our estimation period avoids the unsettled period for the U.S. dollar that preceded generalized floating in 1973, and avoids the oil price

[8]The idea of using block exogeneity in empirical study of small open economies is not new. It is used by Genberg, Salemi, and Swoboda (1987) in their analysis of Switzerland, and by Racette and Raynauld (1992) for Canada.

shock of 1973. For the "home" (Canadian) variables, we include the exchange rate (the U.S. dollar price of the Canadian dollar, Exc), the money supply (M1), the short-term treasury bill rate (R), the consumer price index (P), industrial production (y), and bilateral exports (Tx) and imports (Tm) with the U.S. The "foreign" variables are U.S. industrial production (y^*), the U.S. consumer price index (P^*), U.S. federal funds rates (R^*), and the world commodity export price (Wxp^*). All the variables are logarithmic except for interest rates which are expressed in percent. Export and import values have been deflated by the Canadian consumer price index and are thus conceptually in terms of Canadian goods units. We also include a complete set of seasonal dummies in each equation estimated throughout this paper. Further details on the data are in the Data Appendix.

4. A VAR Model with Choleski Decomposition

To confirm that the frequently used Choleski normalization with a Wold causal chain is insufficient for interpreting the effects of Canadian monetary policy, we first briefly consider the results of using this technique for identification.[9] We estimate the eleven-variable VAR with Choleski ordering of (y^*, P^*, R^*, Wxp^*, Tm, Tx, y, P, R, M1, Exc).[10] The idea of this ordering is that U.S. variables do not instantly respond to the variables in the Canadian economy, but Canadian variables may react to contemporaneous changes in U.S. variables.[11] Figure 1 displays several impulse responses of interest. The first column shows the responses of R^*, R and Exc to a one standard deviation disturbance in R^*, and the second column the responses to an innovation in R. The error bands around impulse responses in this figure are

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[9]Gordon and Leeper (1994) perform a similar experiment for their U.S. application.

[10]Throughout this paper we use a lag length of 12 months in estimation and a time horizon of four years for impulse responses. This makes our work comparable to published work that often chooses a one-year lag length for practical reasons. There is, of course, a trade-off between lag length and parsimony in estimating a fairly large VAR model. In the 11-variable VAR here, for example, a lag length of two years (24 months) would leave us with no degrees of freedom for estimation and inference.

[11]For convenience, in this paper we call y^*, P^*, R^* and Wxp^* "U.S. variables", and the rest of the variables "Canadian variables".

computed using the Bayesian Monte Carlo procedure available in the time-series software package RATS. Throughout this paper we follow a common practice in the literature and let the upper and lower lines of error bands around each estimated response function be one standard deviation above and below the mean of the Monte Carlo simulated responses.[12]

If we interpret the interest rate innovations as monetary policy shocks, the first column implies the usual exchange rate effect: contractionary policy shocks (higher interest rates in the U.S.) increase the value of the U.S. dollar. This therefore accords with similar findings for U.S. interest rate innovations in Sims (1992a), Eichenbaum and Evans (1993), and Grilli and Roubini (1993). The second column, however, reveals a different story for Canadian shocks: the Canadian dollar depreciates considerably during the first year following a positive Canadian interest rate innovation. In the full set of impulse responses not displayed in this paper, moreover, we can also observe that a positive innovation in Canadian money never decreases the Canadian interest rate (liquidity puzzle) and has little effect on the exchange rate; with some different orderings, it appreciates the Canadian dollar (exchange rate puzzle).[13]

These inconsistent results do not disappear when we reorder the Choleski normalizations among Canadian variables, or among U.S. variables, or between these two sets of variables. We are therefore led to believe that Choleski ordering is insufficient to isolate Canadian monetary policy shocks. The fact that positive Canadian interest rate innovations appear to devalue the Canadian currency may actually reflect the endogenous responses of Canadian interest rates to positive U.S. interest rate shocks, obscuring the

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[12]There are several reasons for using one-standard-deviation bands. First, it will make our work comparable with others. Second, one-standard-deviation bands are likely to correspond better to percentile bands because the location of low probability percentiles in tails is likely to be subject to large Monte-Carlo sampling error [Sims and Zha (1994b)]. Third, one-standard deviation bands effectively inform us of two-thirds of the likelihood concerning the pattern of estimated responses.

[13]Complete sets of the impulse responses related to this paper are available upon request.

identification of Canadian monetary policy. To resolve these anomalies, we now move to the treatment of Canada as a small open economy, and attempt to identify Canadian monetary policy explicitly.

5. An Identified VAR Model with Block Exogeneity

5.1. Specification and Estimation Issues

Let us now consider an alternative empirical model for Canada. We argue for economically reasonable identifying restrictions, with the primary aim of achieving the correct identification for monetary policy. We also test our identifying restrictions statistically.

Our overall specification follows the idea of traditional identified VAR approaches. As in Bernanke (1986), Blanchard and Watson (1986), Sims (1986), Blanchard (1989), Gali (1992), and Gordon and Leeper (1994), some of our restrictions rely on those implied by static simultaneous-equation theoretical models such as some extended Mundell-Fleming models.[14] We specify and estimate, however, the monetary policy reaction function in an explicit open economy setting. We note that the objective of our structural identification method is primarily to specify economically meaningful simultaneous interactions among variables, rather than a complete set of equations. There are no restrictions on lagged relationships or dynamic structures; they are left to be determined by the data. If the shocks have been correctly identified, the interpretation of the resulting impulse response functions then becomes much clearer.

The imposition of block exogeneity noted in the second section seems a reasonable way to help identify foreign shocks from the point of view of the small open economy. We are interested only in their impact on such an economy, and not in any interaction among themselves. The assumption seems reasonable for Canada. The Canadian economy is quite open, with exports recently equal to about 25 percent of its GDP. About 75 percent of Canada's

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[14]In their U.S. application, Sims and Zha (1994a) have made some progress in using dynamic, general equilibrium analyses to justify their identification.

exports go to the U.S. Meanwhile, the Canadian economy is only about one-tenth the size of the U.S. economy. With U.S. exports only 10 percent of its GDP and with only 20 percent of these to Canada, it seems reasonable to assume that U.S. economic events are little affected by Canada. Canada thus seems to fit the small-country case of macroeconomics, with the U.S. as a close proxy for the "rest-of-the-world."

Let us begin with a general specification. Assume the structural system is of a linear, stochastic dynamic form (omitting constant and other deterministic terms):

$$A(L)y(t) = \varepsilon(t) \ , \tag{1}$$

where $y(t)$ is an $m\times1$ vector of observations, $A(L)$ is an $m\times m$ matrix polynomial in the lag operator L with non-negative powers and $\varepsilon(t)$ is an $m\times1$ vector of structural disturbances or shocks with

$$y(t) = \begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} \ , \ A(L) = \begin{pmatrix} A_{11}(L) & A_{12}(L) \\ 0 & A_{22}(L) \end{pmatrix} \ , \ \varepsilon(t) = \begin{pmatrix} \varepsilon_1(t) \\ \varepsilon_2(t) \end{pmatrix} \ . \tag{2}$$

The dimension of $A_{11}(L)$ is $m_1\times m_1$, $A_{12}(L)$ $m_1\times m_2$, $A_{22}(L)$ $m_2\times m_2$, $y_1(t)$ $m_1\times1$, $y_2(t)$ $m_2\times1$, $\varepsilon_1(t)$ $m_1\times1$, and $\varepsilon_2(t)$ $m_2\times1$ where $m_1+m_2 = m$. We assume that the coefficient matrix of L^0, A_0, is non-singular and that $\varepsilon(t)$ is uncorrelated with past $y(t-s)$ for $s > 0$, and

$$E[\varepsilon(t)\varepsilon(t)'|y(t-s),\ s>0] = I,\ E[\varepsilon(t)|y(t-s),\ s>0] = 0 \ .$$

The restriction $A_{21}(L) = 0$, the "block exogeneity" restriction, implies that the second block $y_2(t)$ is exogenous to the first block $y_1(t)$ both contemporaneously and for lagged values of the variables. The concept of block exogeneity is identical to Granger causal priority defined in Sims (1980), except that Sims discussed it in the context of reduced form VARs. To see this, we write the reduced form of (1) as

$$B(L)y(t) = u(t) \ , \tag{3}$$

where $B_0 = I$, $B(L) = A_0^{-1}A(L)$, and $u(t) = A_0^{-1}\varepsilon(t)$. Since $B_{22}(L) = 0$, $y_2(t)$ is Granger causally prior to $y_1(t)$ in the strict sense of Sims (1980).

For our Canadian economy model, we let y_1 = (Exc, M1, R, P, y, Tx, Tm)' and $y_2 = (y^*, P^*, R^*, Wxp^*)'$. We first evaluate how important Canadian trade is to the U.S. We use (3) to test if y_2 is Granger causally prior to bilateral trade flows Tx and Tm alone, i.e., Canadian trade. The number of restrictions on the second block is thus 96. The likelihood ratio test is used here.[15] The chi-squared statistic $\chi^2(96)$ is 108.03, implying the null is acceptable at the 19% level of significance. Since Canadian trade is highly correlated with other Canadian variables, we expect that y_2 is strongly Granger causally prior to the entire first block y_1. Indeed the chi-squared statistic $\chi^2(336)$ = 258.61 where 336 is the number of restrictions on the second block of (3). The null hypothesis is therefore acceptable at the significance level of 0.999.

The gist of our analysis is to extend the general methodology developed by Bernanke (1986), Blanchard and Watson (1986), and Sims (1986) to our model of the small open economy. The block exogeneity restriction follows naturally from small open economy models, and enables us to estimate the non-Canadian block separately. This considerably reduces the number of parameters needed to estimate the Canadian block. As we will see below, the non-Canadian* parameters are tightly estimated. To avoid potentially unreasonable restrictions, we do not attempt to identify the behavior in the non-Canadian block, y_2, but simply keep its reduced form VAR with normalization in the lower-triangularized order of y^*, P^*, R^*, and Wxp^*. We do not impose other restrictions on the coefficients of lagged variables but simply let the data reveal the patterns of responses and transmissions.

Table 1 presents our overidentified system of contemporaneous variables for the Canadian economy.[16] As indicated in the table, our identification can

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[15]All the tests throughout this paper are of likelihood-principle based inference [Zellner (1971), pp. 292-302]. They inform the reader of the shape of the likelihood. From a Bayesian point of view the interpretation of test results does not depend on whether our model system has unit roots; thus the system allows for possible cointegration of variables (for detailed arguments, see Sims (1992b) and Phillips (1994)].

[16]One should note that the contemporaneous restrictions describe the relationships not merely between reduced form innovations but between the

be characterized by three categories: a money market, an information market, and a production sector. In the money market, the money demand equation is analogous to what is implied by static simultaneous-equation models.[17] The functional form of $M - P = y - \alpha R$ is often suggested in traditional monetary analyses [e.g., Blanchard and Fischer (1989), p.513; Woodford (1994), p.105]. It can be also derived from some money-in-utility models [McCallum (1989), pp.35-42].[18] Meanwhile, in a representative agent's rational expectations model such as Leeper and Sims (1994), shocks to money demand can in principle be correlated with changes in transactions technology (e.g., teller machine introduction). The responses of other variables such as output and price to money demand shocks may not, therefore, conform to what typical Keynesian models predict.

The identification of the contemporaneous monetary policy equation (money supply) is based on the information likely to be available to the monetary authority within the month. During this period, the monetary authority (here, the Bank of Canada) certainly has immediate access to information on the exchange rate (Exc), interest rates (R and R^*), the money supply (M1, from the reports of chartered banks), and commodity prices (Wxp^*). But it would be unable to observe the data on output, the general price level and trade flows.[19] This description of possible policy behaviour also distinguishes the

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levels of variables as well. This can be easily seen through equations (1) and (3).

[17]An alternative to using static simultaneous-equation theory as a guide is to impose the estimated cointegrated relation for money demand [Stock and Watson (1993)] to long run restrictions as in King, Plosser, Stock and Watson (1991). One could also consider the possibility of currency substitution. We leave these issues to future research.

[18]On the other hand, cash-in-advance models often imply that $M - P = y$ in the current period [e.g., Lucas (1982) and Stockman and Svensson (1987)].

[19]This situation contrasts with the implications of using the Choleski normalization to identify Canadian monetary policy. In our empirical application of the Choleski normalization in Section 4, if "R" innovations are interpreted as monetary policy shocks, it implies that policy does not respond to the contemporaneous changes in the exchange rates (because "Exc" is ordered after "R"). For a small open economy, however, the monetary authority is likely to respond quickly to both home and foreign interest rate changes as well as exchange rate changes [McCallum (1994)].

Bank of Canada reaction function from the one likely for the U.S. monetary authority (the Federal Reserve), because the Federal Reserve is unlikely to react to changes in Canadian interest rates and money stock. Finally, we emphasize that this specification does not prevent the Bank of Canada from reacting to all the variables including output and price over subsequent months in our VAR specification.[20]

The information market equation includes all 11 contemporaneous variables. Similar to the information equation in Sims and Zha (1994a) that reflects the commodity market, ours captures the feature that in efficient foreign exchange markets exchange rates can possibly respond within the month to all relevant information in both the U.S. and Canadian economy. This equation is important in our identification of monetary policy because the data on exchange rates reflect indirectly other sources of information that may not be available within the month.

Finally, we specify a production sector comprised of the variables Tm, Tx, y and P. The arrival and departure of imports and exports may be contemporaneously related to overall output and some instantaneous price setting in Canada. But we exclude the contemporaneous U.S. variables and the other financial variables including the exchange rate from the sector. These variables are probably related to production only through lags, reflecting trade contracts and advance production planning. Again, all these exclusion restrictions are only within the month and there are no restrictions on lagged variables. We do not attempt to identify each individual equation within this sector but simply normalize equations in the order of Tm, Tx, y and P.

Because of the block exogeneity restriction, the method for ML estimation and inference used in standard identified VAR models [Sims (1986) and Gordon

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[20]The identification used by Racette and Raynauld (1992) allows the Bank of Canada to react contemporaneously to several variables including the GDP deflator, U.S. GNP and U.S. GNP deflator, but not to the exchange rate. This seems somewhat implausible because the GDP deflator, U.S. GNP and U.S. GNP deflator are not available to the Bank within the month, while the exchange rate, which is of probable interest to the Bank, is available daily. This unsatisfactory aspect of their identification may help explain their empirical puzzles.

and Leeper (1994)] cannot be applied directly. If there were no restrictions imposed on the submatrix A_{012} in the contemporaneous coefficient matrix A_0, one would still be able to apply the conventional procedure directly to, say, the equations in the first block [Genberg, Salemi, and Swoboda (1987), and Racette and Raynauld (1992)]. But when some elements in A_{012} are restricted as in our model, such a procedure becomes inefficient in general. This is mainly because the direct, simple mapping from the covariance matrix of reduced form innovations to the matrix of structural contemporaneous coefficients breaks down and the ML estimation for contemporaneous coefficients will now depend on the coefficients of lagged variables as well. As a consequence, the Bayesian method of computing error bands for impulse response functions suggested by Sims and Zha (1994b) is modified to take account of these features [following Zha (1994)]. In our model, the ML estimation and inference for the second block can be easily computed by using the conventional procedure for Choleski normalization. As for the ML estimation of the first block and resulting error bands for impulse responses, we use the algorithm outlined in Technical Appendix B [from Zha (1994)], taking into account the dependence of ML estimates on both the covariance matrix of reduced form residuals and the coefficients of lagged variables.

5.2. Results for Contemporaneous Coefficients

Table 2 reports the maximum likelihood (ML) estimates of coefficients and the corresponding standard errors in our overidentified model. We do not display the estimated coefficients for the production sector because we do not have separate structural interpretations for each individual equation within the subsystem block. The ML estimation is invariant to the normalization of each equation and, unlike the conventional presentation, our reported estimates are not normalized so that one can examine the precision of all the individual estimates as well as their correlations.

In Table 2, we first note that the estimated money demand and money supply equations have reasonable economic interpretations. The contemporaneous interest elasticity of money demand is negative, as expected, and it is statistically significant. In the money supply function, the (home) interest elasticity of money supply is also positive. This is consistent with a policy reaction for the current period where the central bank increases the money supply to offset high interest rates, as in Poole's (1970) framework for the closed economy where money demand fluctuations dominate. The elasticity of money supply with respect to the exchange rate is also positive, consistent with the Bank of Canada increasing the money supply to offset currency appreciation (leaning against the wind). These estimates are statistically significant at the level of 0.01 or better. The estimated coefficient of Wxp^*, significant at the 0.05 level, suggests that the Bank of Canada also responds quickly to information on potential inflationary pressure: the money supply is reduced when world commodity prices rise. The positive sign of the coefficient on R^* in money supply is probably not what we would expect of the Bank of Canada's reaction to the rise of the foreign interest rate, but the estimate is insignificant. This does not preclude the Bank of Canada from responding in some sense to changes in the foreign interest rate, because the individual hypotheses do not take account of any information about the other parameters. If a rise in the foreign interest rate causes an immediate decline in the Canadian dollar, the Bank may respond through its exchange rate reaction. Consistent with this, multiple correlation among the parameters of R^*, R, M and Exc could make it difficult to distinguish a response to independent changes in foreign interest rates. Indeed, the correlation between the parameter values for R^* and R is -0.55, for R and M 0.42, and for M and Exc 0.81.

In the information equation, the coefficients of the exchange rate, the home money supply, imports, exports and the foreign price level are all statistically significant at the level of less than 0.01. They are also correlated with each other (for example, the bivariate correlation between coefficients is -0.50 for Tm and Tx, -0.41 for Tm and Exc, and -0.86 for M and Exc). The coefficients on P and y are significant at about the 0.05 level. All these results are consistent with a quick response of the exchange rate to these variables.

The coefficients on R, y^*, R^* and Wxp^* are statistically insignificant individually, but these conclusions may be affected by multiple correlation among themselves or by correlation with other parameters. For example, the estimated bivariate correlation between the coefficients of R and Exc is 0.75. Our inference is based on likelihood principle, and thus it is also important to explore the overall shape of likelihood. We apply a Wald test to the hypothesis that the coefficients of Exc, R, y^*, R^* and Wxp^* are jointly zero. The hypothesis is rejected at the significance level of 3.82E-09.[21]

5.3. Testing Sample Stability and Identifying Restrictions

Our sample period includes the period following the Bank of Canada announcement in January 1988 that price stability would be its goal. It would be interesting to see if our model results are robust with the period 1988:1 - 1993:12. Unfortunately, in our model with exogeneity, the subsample period 1974:1 - 1987:12 gives us a meager 4 degrees of freedom and the period 1988:1 - 1993:12 no degrees of freedom at all. With overidentifying restrictions on contemporaneous coefficients, the model solution simply does not converge for the period 1974 - 1987. We can, however, examine the sample stability of 74:1-93:12 vs 74:1-87:12 for our reduced form model with block exogeneity. We use both the Akaike and the Schwartz criteria.[22] The Akaike criterion compares the chi-squared statistic with the number of restrictions multiplied by 2 while the Schwartz criterion compares it with the number of restrictions multiplied by the the logarithm of the sample size. In our case, the chi-squared statistic is 972.23, the Akaike number is 2496, and the Schwartz number 6302.22. Since both numbers are much larger than the chi-squared statistic, the sample stability is thus acceptable by either of these criteria.

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[21]Even though "Exc" is significant individually at the level of 8.1E-06, the fact that the significance level of the joint test is much less than 8.1E-06 reflects the correlation among these parameter values. In general, however, statistical significance of individual parameter values does not guarantee the same conclusion for a joint hypothesis test.

[22]Sims and Zha (1994a) use a similar application of these criteria for testing sample stability in their model. We prefer the Schwartz criterion because it has an asymptotic Bayesian justification [Schwartz (1978)].

So far we have not discussed any test on the identifying restrictions in our model. This is because the usual likelihood ratio (LR) test for block exogeneity in reduced form VAR models cannot be directly used and neither can we directly use the conventional LR test for overidentifying restrictions on the contemporaneous coefficient matrix A_0 without taking account of block exogeneity. A correct procedure must involve a joint test for overall restrictions: both the block exogeneity restriction and other identifying restrictions on A_0. As long as all restrictions are treated as a restricted subset (defined by the null hypothesis) of the complete (unrestricted) parameter space, it turns out that the standard LR test procedure can be used. Specifically, suppose that the null hypothesis is true, then $2(L_u - L_R) \xrightarrow{d} \chi^2(J)$ where the degrees of freedom J equal the number of hypotheses, L_u is the log-likelihood function for the unrestricted ML estimator and L_R the log-likelihood function for the restricted ML estimator. In our model, we have 28 overidentifying restrictions on A_0; and the number of restrictions of block exogeneity on A_s $(s \geq 1)$ is 336. Thus $J = 364$. The chi-squared statistic $\chi^2(364) = 346.13$, implying that the null is acceptable at the significance level of 0.74.

5.4. Interpreting the Effects of Monetary Policy From the Data

Let us first focus on the dynamic responses of Canadian variables to a negative Canadian money supply shock given in Figure 2.[23] The sharp decline in the money supply is accompanied by an immediate and significant appreciation of the Canadian dollar that lasts about twelve months — the exchange rate effect. The nominal home interest rate rises briefly by a small (but statistically significant) amount; its deviation from the zero line is then statistically insignificant for most of the remaining four-year time horizon. We also calculate the real exchange rate, and a real interest rate using the forecasted three-month inflation rate responses. These show that the real

[23]The error bands in this figure and subsequent graphics are computed using the Bayesian procedure described in Zha (1994). The computation is based on 5000 Monte Carlo draws of which only 82 draws are discarded in order to keep the diagonal elements of drawn A_0 positive. This takes about 21 hours on a 486/50 PC for our 11-variable model.

values move very similarly to the nominal ones. Consequently, we have no puzzle here about the relationships among a money supply shock, interest rate responses, and exchange rate response.

Let us look at the responses of other variables in Figure 2. First, we note that the monetary contraction seems relatively persistent (except for some tempering toward the end of the first year). The price level responds gradually and negatively (except for a slight positive response in the second month), though the response is not strongly significant, implying that policy shocks have weak effect on price. Output shows a significant but relatively small decline for about six months.

These results are consistent with the predictions of traditional small open economy analyses. It appears that, in the early months, it is the money supply contraction and real interest rate increase that adversely affect the economy. Meanwhile, in response to the currency appreciation, exports fall, imports fall then rise, and the real (*in domestic goods units*) trade balance improves then worsens. We therefore see a classic J-curve effect, so that by the time the trade balance worsens, the result is mostly to depress price. Toward the end of the time horizon, the money supply and price level are lower but less statistically significant, the real exchange rate change has been eliminated, and the remaining variables are back to their original levels (as indicated by the insignificance of estimated response functions). Thus, both the short-run and relatively longer-horizon responses seem plausible for the small open economy.

We can briefly discuss some implications for uncovered interest parity (UIP). In the typical, theoretical small open economy model of McCallum (1994), he argues that endogenous monetary policy reaction may be the main explanation for the puzzling empirical findings regarding uncovered interest parity despite the fact that the UIP relation may be valid. It is not hard to see from his model that a contractionary one-standard-deviation monetary policy shock (in the absence of the other shocks in his model) appreciates the domestic currency contemporaneously but has no effect on the differential between home and foreign interest rates. As a result, the value of domestic currency will stay at the initial impact level for subsequent periods while the interest rate differential remains zero. We note that his simplified monetary policy equation does not contain variables such as money supply, but we can allow policy disturbances in his equation to follow, say, a second-order autoregressive process rather than white noise in an attempt to capture the possible influence on policy of lagged money supply. Then with the same parameter values he uses and some specifications of the second-order autoregressive process, one can generate the following dynamic responses of exchange rates and interest rates to a contractionary policy shock: the interest rate differential rises initially by a small amount and then gradually declines to the original level while the domestic currency appreciates considerably at impact and then falls at a faster speed towards the original level. This pattern is quite similar to what we observe in Figure 2, except the estimated responses of the interest rate differential ($R-R^*$) in our empirical model becomes statistically insignificant very shortly after the shock though the point estimates tend to stay positive. Notice that the responses of R in Figure 2 are also those of $R-R^*$ because the foreign interest rate is held constant through the exogeneity restriction.

We also calculate the response path of $Z \equiv R-R^*+(Exc^f - Exc)$ following a negative money supply shock, where Exc^f is the forecasted three-month exchange rate response ahead of Exc. If market participants see the exchange rate effect of policy shocks as we do from our econometric model, the uncovered interest parity relation implies that the responses of Z to a contractionary monetary policy shock should be zero. The dynamic responses of Z are plotted in Figure 2. They show somewhat significant deviations from zero for only 4 months in the entire four-year horizon, and these few deviations do not appear to be very strong (in the sense of two standard deviations).

We now turn our attention to Figure 3, which gives the dynamic responses to a foreign shock emanating from the y^* equation (referred to as "y^*" shocks). The responses to the y^* shock seem to provide evidence on the possible extent and efficacy of policy reaction by the Bank of Canada. The y^* shock reflects a sharp, though not permanent, U.S. output rise coupled with a steady rise in the U.S. price level and a higher nominal U.S. interest rate. In Canada, we see in the short-run a falling Canadian dollar, a falling money supply, a higher nominal interest rate, lower output, and possible slight trade balance improvement (primarily between the 12th and 18th month) in spite of higher import value. The interest rate increase (in most months) and the Canadian dollar depreciation are real ones.

In Mundell-Fleming models with rational expectations and sticky prices, one expects that with no action by the Bank of Canada, and holding the nominal U.S. interest rate constant, a temporary rise in U.S. output (or price) would tend to increase Canadian output and price while appreciating the Canadian dollar. In particular, with the foreign expansion temporary, the appreciation of home currency would also be temporary, leading to expected subsequent depreciation. This requires a higher nominal home interest rate under uncovered interest parity, implying higher domestic real income (and output) to maintain money market equilibrium. And this occurs through increased foreign demand for home goods.[24] If nominal U.S. interest rates rise as well (as in Figure 3), this would tend to depreciate the Canadian dollar, improving Canada's trade balance and stimulating domestic income.[25] A falling Canadian dollar may also have a direct positive impact on Canadian prices in the short-run [Dornbusch and Krugman (1976) and Turnovsky (1981)].

In view of these possibilities, it appears that the impact of the foreign interest rate increase dominates in affecting the exchange rate, because the Canadian dollar falls. The fact that the Canadian money supply declines significantly (Figure 3) is then consistent with a Bank of Canada attempt to temper the fall in the Canadian dollar, and inflationary pressure from the

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[24]In Turnovsky's (1981) short-run dynamic model, home price and output response to a temporary foreign price increase can be ambiguous to the extent that the exchange rate affects the overall domestic price level. Home currency appreciates by less than the amount of the foreign price increase. Only if the increase is expected to be permanent is there perfect insulation against a foreign price increase.

[25]As noted previously, in Svensson and van Wijnbergen's (1989) model, a foreign interest rate rise could have a negative effect on home output through the intertemporal substitution.

U.S.. With the statistically insignificant trade balance increase, this contractionary policy response to the foreign shock is consistent with the gradual decline in Canadian output we observe in Figure 3 within the first 16 months.[26]

Table 3 reports the variance decompositions for Canadian output from various shocks. Since we do not identify individual shocks for the production sector and for the foreign (U.S.) economy, we display the decomposition only according to these two subsystems referred to as "production" and "foreign". In Table 3, "MD" stands for money demand, "MS" money supply, and "Information" the information market equation. Among domestic shocks, shocks emanating from the production sector (containing four equations) and shocks from the information sector (consisting of only one equation) are the primary source of output fluctuations, when compared with monetary policy shocks. External shocks become the dominant source of domestic output fluctuations after 12 months.[27] Monetary policy shocks have relatively little impact on Canadian output, especially after 12 months.[28] These findings accord with conclusions reached earlier based on the impulse responses. The evidence that unanticipated monetary policy disturbances have no major effect on output by no means implies that monetary policy itself is ineffective. On the contrary, the dynamic responses to external shocks in our model seem to suggest that endogenous monetary policy responses can be influential.

6. Conclusion

The effects of unpredicted monetary policy disturbances in the open economy have remained an unsettled empirical issue in recent VAR analyses.

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[26] In his rational expectations models, McCallum (1989, pp.221-228) shows that the systematic (endogenous) response of monetary policy can be in general effective in affecting output, contrary to the prediction in Sargent and Wallace's (1975) model. Previous empirical evidence on this can be found in, e.g., Mishkin (1982).

[27] Genberg, Salemi and Swoboda (1987) conclude in their empirical analysis of Switzerland that foreign shocks are more important than domestic ones in explaining domestic output fluctuations.

[28] This evidence is consistent with the findings of Sims and Zha (1994a). It seems robust across countries in a recent study of Kim (1994).

Though credible results have been observed for innovations identified as monetary shocks for the United States, for many other economies the responses of exchange rates and other variables have often been puzzling. We believe this is generally the consequence of applying identification assumptions which, though reasonable for the United States, are not suitable for most other countries because they are relatively small and open compared to the United States. Our work suggests that identification for contemporaneous money supply behavior and other private behavior that takes into account various features of the small open economy is a promising way to eliminate the puzzles of existing work. Meanwhile, behavior at all subsequent lags remains unconstrained in estimation, to avoid the "incredible" restrictions criticized by Sims (1980). We also suggest that, for a small open economy such as Canada, foreign variables be treated as exogenous. The assumption of block exogeneity in the presence of the contemporaneous structural restrictions is economically sensible and helps identify foreign shocks from the viewpoint of the small open economy.

Using Canada as a case study, we estimate a reasonable contemporaneous money supply function. The resulting identified contractionary monetary policy shocks cause a small and brief increase in the Canadian interest rate, and a larger and longer-lasting appreciation of Canadian currency. The estimated dynamic responses of other Canadian variables are also consistent with the general view of existing monetary analyses under flexible exchange rates: the trade balance shows a J-curve effect, the domestic price level tends to fall, and output falls temporarily. Next, our impulse responses to a foreign shock are consistent with a plausible view of domestic monetary policy response. In particular, the money supply is reduced in response to domestic currency depreciation that accompanies higher foreign interest rates. Overall, our evidence supports the view that the exchange rate is an important channel for the transmission of domestic monetary policy shocks and foreign shocks in open economies. We hope these results will provide a useful background for further study on policy issues in open economies.

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Table 1 Structural System of Contemporaneous Variables

Money Demand and Supply Equations
$d_1(\mathrm{M1}-\mathrm{P}) - d_1 y + a_1 \mathrm{R} = \varepsilon_d$ $d_2\mathrm{R} + a_2\mathrm{M1} + a_3\mathrm{Exc} + a_4\mathrm{R}^* + a_5\mathrm{Wxp}^* = \varepsilon_s$
Information Market
$d_3\mathrm{Exc} + a_6\mathrm{M1} + a_7\mathrm{R} + a_8\mathrm{P} + a_9 y + a_{10}\mathrm{Tx} + a_{11}\mathrm{Tm}$ $+ a_{12}y^* + a_{13}\mathrm{P}^* + a_{14}\mathrm{R}^* + a_{15}\mathrm{Wxp}^* = \varepsilon_i$
Production Sector
This subsystem is normalized in the lower-triangularized order of Tm, Tx, y and P.

Table 2 Estimated Contemporaneous Coefficients

Money Demand	$21.06(M1-P) - 21.06y + 2.75R = \varepsilon_d$
(stand. error)	(9.79) (9.79) (0.13)
Money Supply	$1.53R - 113.55M1 + 163.63Exc + 0.16R^* - 10.87Wxp^* = \varepsilon_s$
(stand. error)	(0.29) (20.90) (21.57) (0.23) (5.48)
Information (stand. error)	$133.98Exc + 133.50M1 + 0.77R - 79.50P - 19.26y + 40.98Tx$ (30.02) (20.93) (0.46) (43.52) (10.09) (6.99) $- 19.40Tm + 29.73y^* - 230.45P^* - 0.35R^* - 1.08Wxp^* = \varepsilon_i$ (7.45) (21.43) (61.79) (0.26) (5.74)

Table 3 Decomposition of Forecast Variance for Output*

Months	Information	MD	MS	Production	Foreign
1	0.00	0.00	0.00	100.00	0.00
6	2.89	0.75	2.75	40.29	53.31
12	4.07	0.47	1.00	20.30	74.33
18	3.06	0.37	0,67	16.70	79.19
24	4.27	0.31	0.74	22.17	72.51
36	5.76	0.22	0.64	18.98	74.41
48	4.08	0.31	0.61	20.82	74.17

*Initial responses take place at month 1.

Data Appendix

The monthly data from 1974 to 1993 used in the paper are described in detail here. They are extracted from two sources: Statistics Canada's CANSIM data base and IMF's *International Financial Statistics* (IFS) data base. The identifier for each series is given in parenthesis.

Exc: the U.S. dollar price of Canadian currency (US$/C$) (IFS, 156..AH.ZF...);

M1: Canada monetary aggregate M1, seasonally adjusted (CANSIM, B1627);

R: Canada three-month Treasury bill rate (IFS, 15660C..ZF...);

P: Canada consumer price index (IFS, 15664...ZF...);

y: Canada industrial production, seasonally adjusted (IFS, 15666..CZF...);

Tx: total Canada exports to the U.S., in thousands of Canadian dollars (CANSIM, D418423)

Tm: total Canada imports from the U.S. (CANSIM, D458126); the series before 1980:1 is created by running a regression of the series D458126 on the series D445105 and then using the estimates to splice D458126 and D445105;

y^*: U.S. industrial production, seasonally adjusted (IFS, 11166..CZF...);

P^*: U.S. consumer price index (IFS, 11164...ZF...);

R^*: U.S. federal funds rate (IFS, 11160B..ZF...);

Wxp^*: world total exports commodity price index (IFS, 00176AXDZF...).

Figure 1 Dynamic Responses For the Model with Choleski Decomposition

Response of	Innovation to R^* equation	Innovation to R equation
R^*		
R		
Exc		

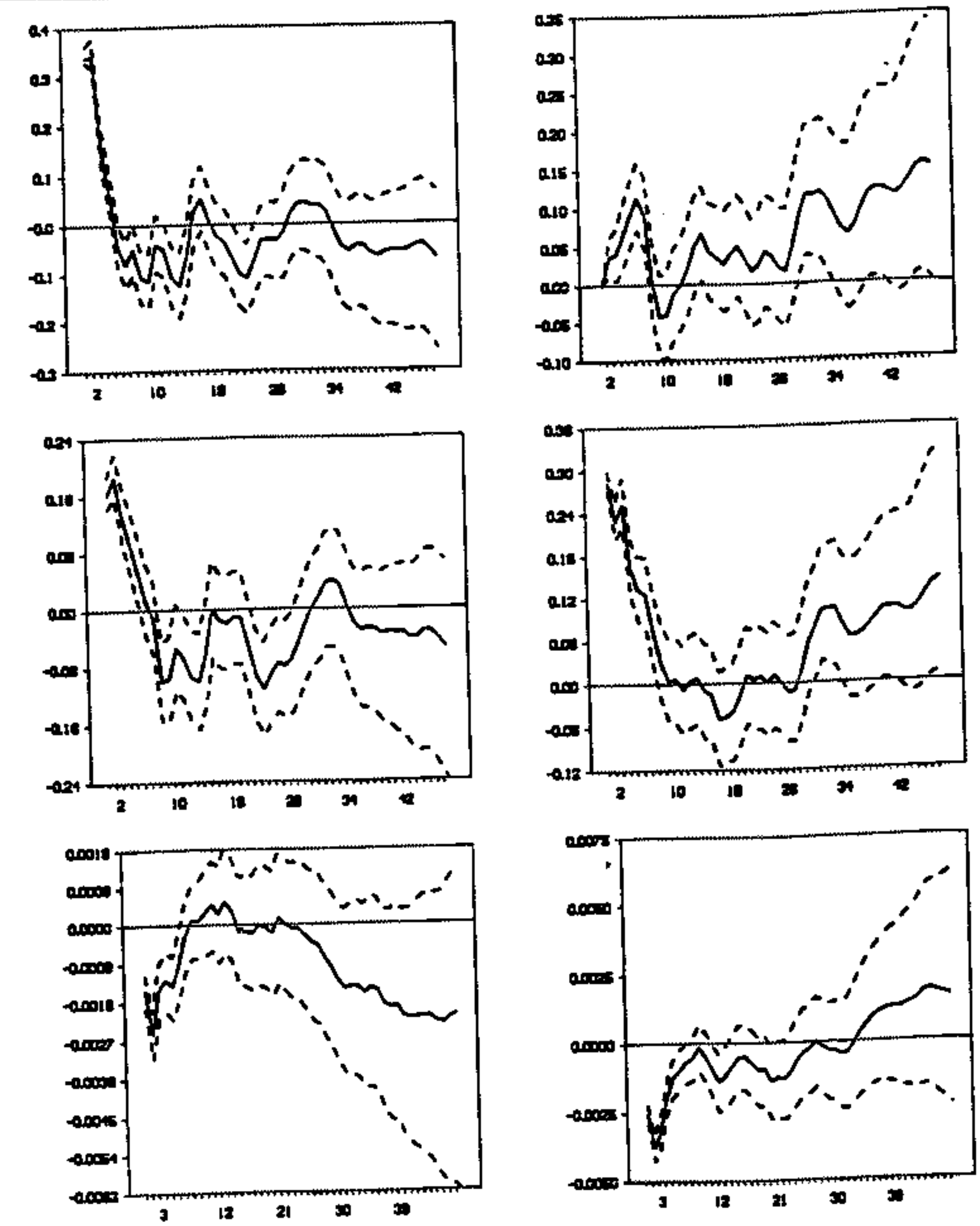

Figure 2 Dynamic Responses to Monetary Policy Shock

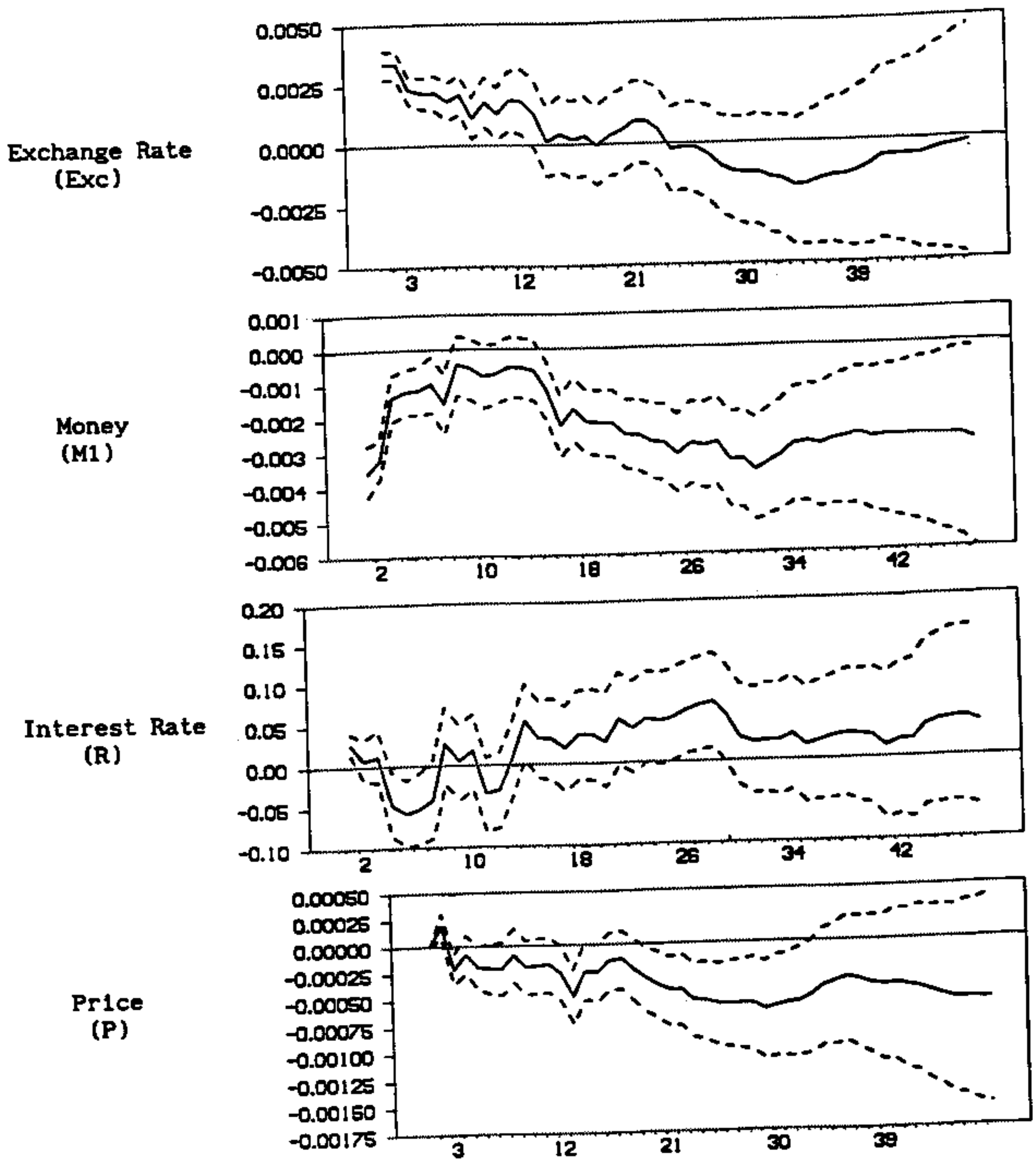

Figure 2 (Continued)

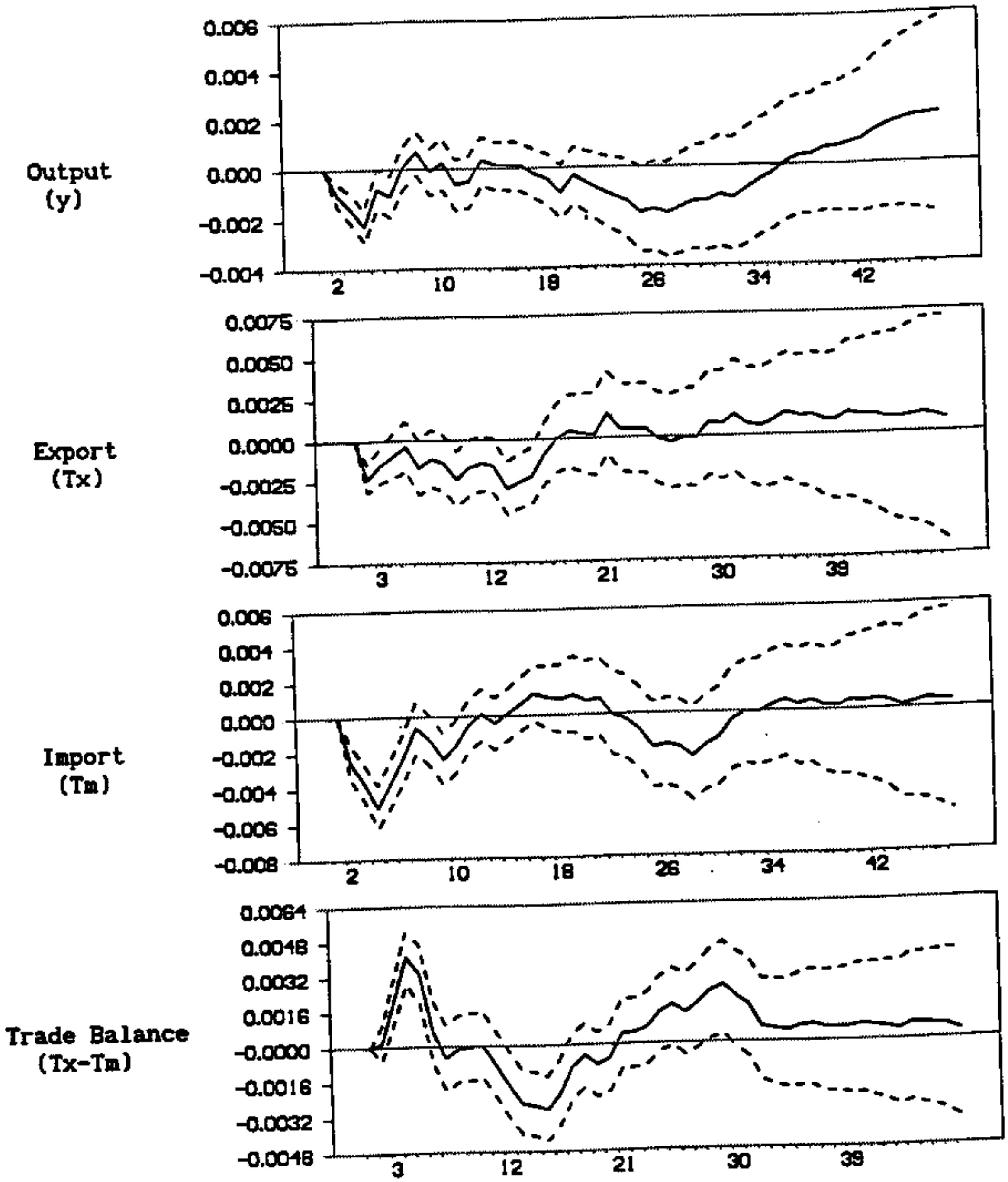

Figure 2 (Continued)

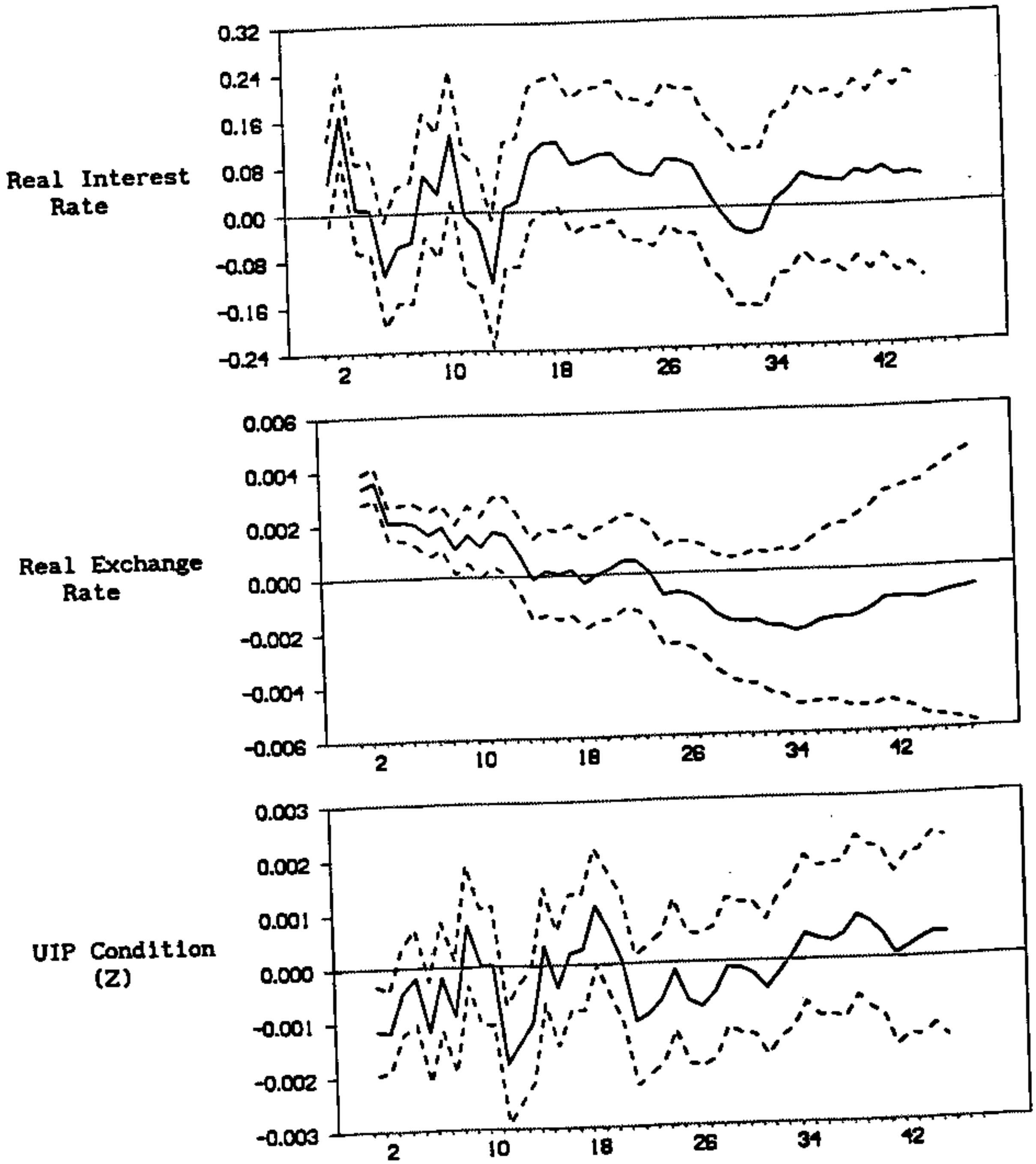

Figure 3 Dynamic Responses to Foreign Shock

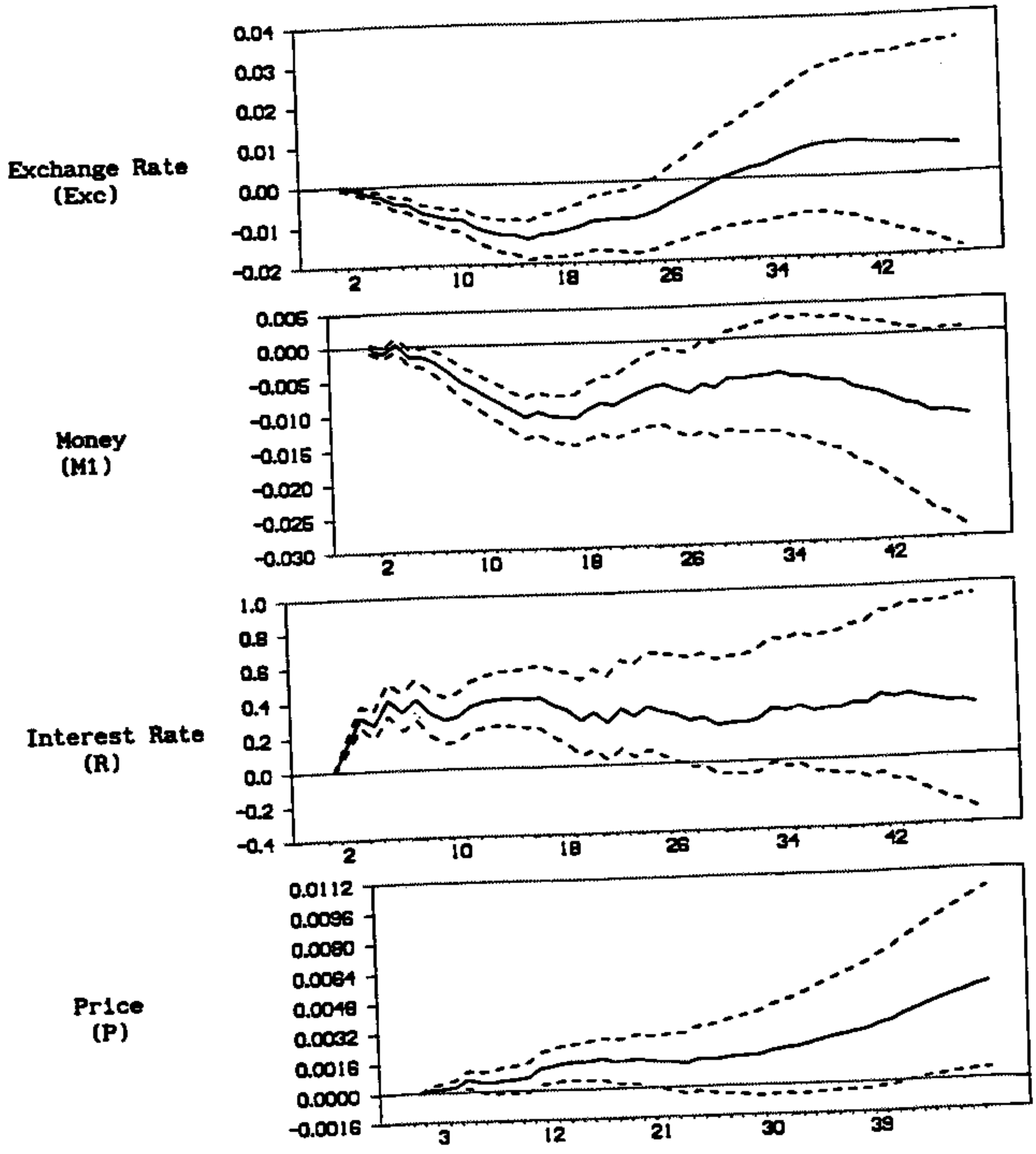

Figure 3 (Continued)

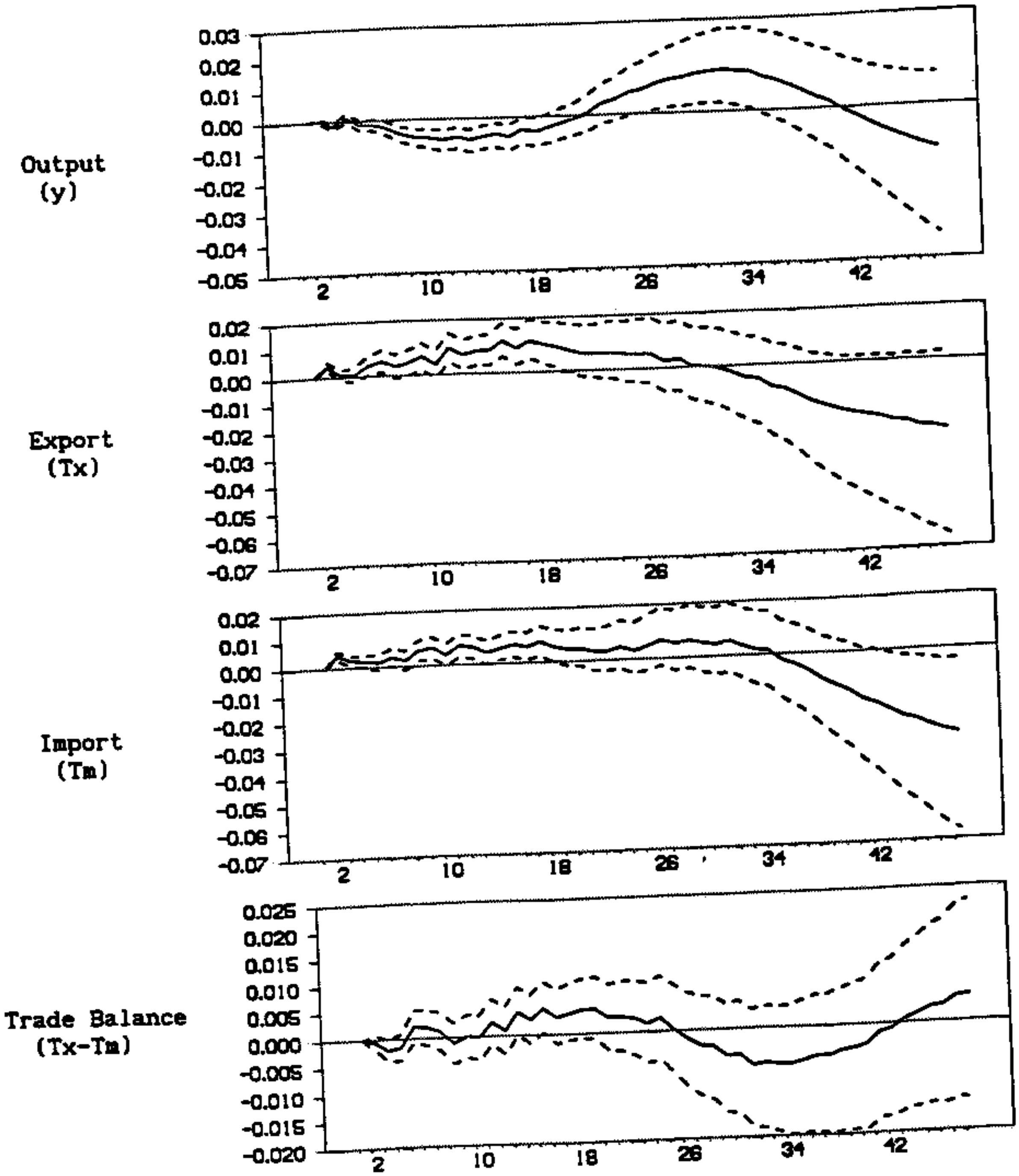

Figure 3 (Continued)

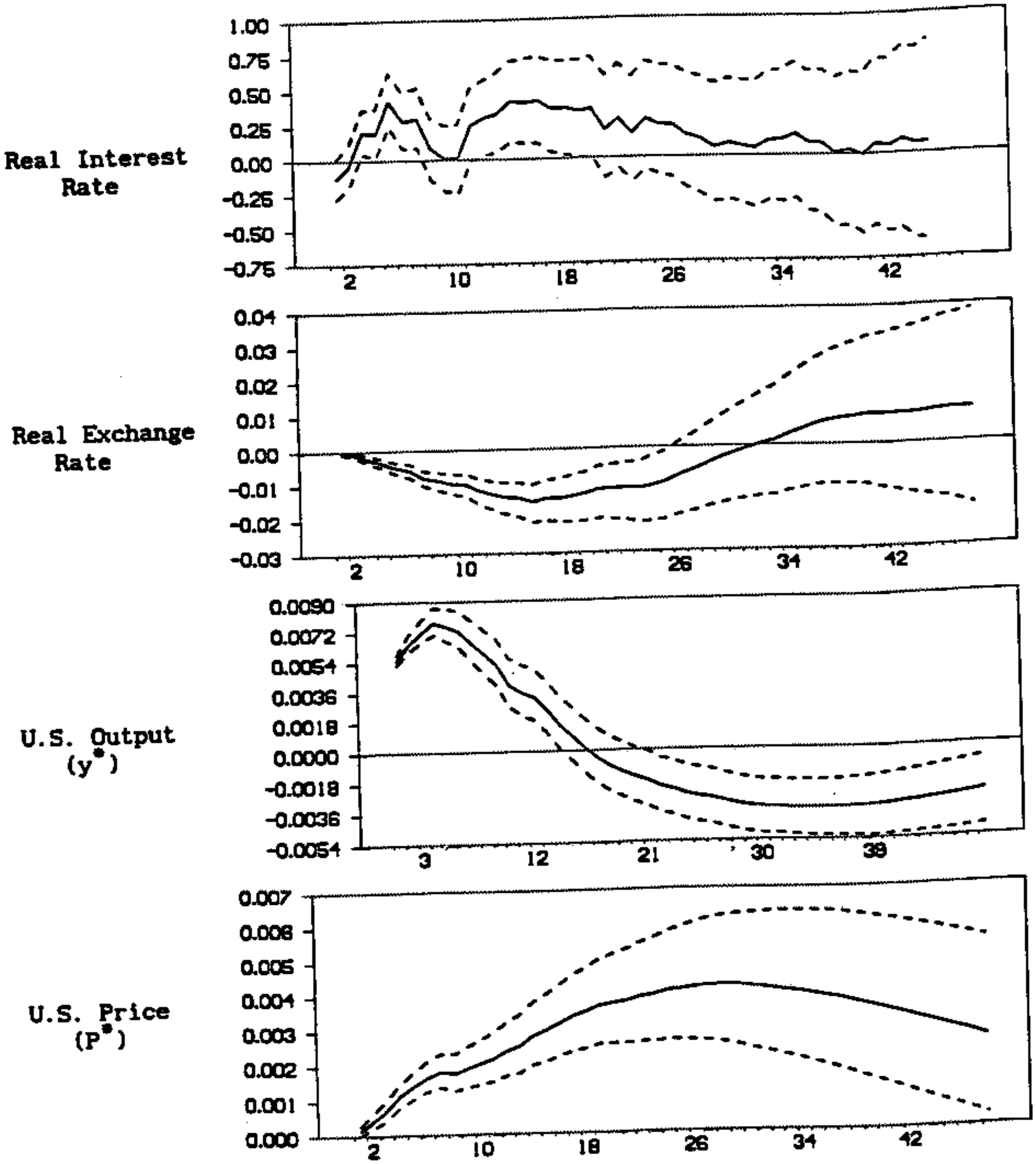

Figure 3 (Continued)