Identifying Monetary Policy in Open Economies

by

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Abstract

This thesis estimates the effects of monetary policy shocks by employing vector auto regressions (VAR). I argue that to the extent the central bank and the private sector have information not reflected in the VAR, the measurement of policy innovations is contaminated. These incorrectly estimated policy shocks then generate misleading results about the effects of monetary policy. This thesis first attempts to figure out the variables indeed observed by central banks to make monetary policy decisions and then formulates the monetary policy reaction function by using those variables. Having identified more realistic monetary policy functions in VAR models, I conclude that most of the previous puzzling results about the effect of monetary policy shocks might be due to incorrectly identifying the monetary policy reaction function.

Co-Authorship

Chapter 2 of this thesis was co-authored with Robert Lucas in the Department of Economics, University of Saskatchewan. A version of chapter two was published in the *Canadian Journal of Economics*.

Dedication

To

Mike Abbott,

Shahid El Bukhari,

Asadul Hossain,

Hafizur Rahman, and

Sharif Khan

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Chapter 1

Introduction

This thesis identifies monetary policy shocks employing vector autoregressions (VAR) for open economies, using Canada and the UK as case studies. The main argument is that if the information set in the monetary policy reaction function in a VAR model is different from that of a central bank, then the policy reaction function is incorrectly identified. The incorrect policy function then yields mis-measured policy shocks, which in turn generates misleading results. First I examine the macroeconomic variables a central bank considers to make monetary policy decisions and then I formulate monetary policy functions by using those variables. Having identified the monetary policy function by incorporating the set of variables actually observed by the central bank, this thesis concludes that most of the previous puzzling results about the effects of monetary policy shocks might be due to incorrectly identifying the policy reaction function.

Sims (1980) suggested the use of impulse responses from the VAR model for policy analysis. Subsequently, a great deal of VAR literature has been developed to better estimate the impulse responses of various macroeconomic variables due to monetary policy shocks (see Christiano, Eichenbaum and Evans (1999) for details). Bernanke and Blinder (1992) argued that innovations in the federal funds rate, identified in a recursive approach, are in some respects better measures of monetary policy shocks than are innovations in monetary aggregates for the US. This argument was challenged by Gordon and Leeper (1994). Using innovations both in the federal funds rate and monetary aggregates in a recursive approach, they found dynamic responses that are at odds with what we expect from monetary policy shocks. Identifying contractionary policy shocks with innovations in the ratio of non-borrowed reserves to total reserves in a recursive VAR model, Eichenbaum and Evans (1995) reported a persistent appreciation of the US dollar for a prolonged period of time. Using the same policy instrument in a recursive VAR approach for the US, Strongin (1995) found a strong liquidity effect but an insignificant effect on the price level due to monetary policy shocks.

Sims (1992) pointed out that innovations in any type of monetary aggregates may not correctly represent changes in monetary policy, since they might reflect some other shocks in the economy, such as the money demand shocks. Therefore he suggested using innovations in short-term interest rates as policy shocks. But using short-term interest rates as policy instruments in a recursive approach for G-7 countries, Grilli and Roubini (1995) found that home currencies depreciate in response to innovations in home interest rates for every country except the US.

Cushman and Zha (1997) argued that the recursive approach of monetary policy identification might make sense for the US, since it is a large and relatively closed economy and the movement of US monetary policy due to foreign shocks is relatively small. In addition, in closed economy models, such as those used by Christiano and Eichenbaum (1992) and Kim (1999), the monetary policy transmission mechanism operates primarily through the interest rate, not the exchange rate. Therefore, the conditions of recursive identification that are somewhat valid for the US are very unlikely to be valid for smaller and more open economies, since central banks of small open economies contemporaneously respond to movements in exchange rates and other foreign variables.

In an attempt to identify monetary policy more realistically, Sims and Zha (1995) proposed a structural VAR model for the relatively closed US economy. Cushman and Zha (1997) and Kim and Roubini (2000), among others, extended this structural model for more open economies. The gist of the structural approach is that, rather than relying solely on the recursive Choleski technique, it allows simultaneous interactions among the policy variable and other macroeconomic variables of the model within the month. Faust and Rogers (2003) also incorporated these standard assumptions in their VAR model. On the other hand, Bernanke, Boivin, and Eliasz (2004) used a factor-augmented VAR model that allows the monetary policy variable to interact with a large set of variables simultaneously.

In chapter two of the thesis, I argue that since any key objective of a central bank is to maintain a stable inflation rate, and the central bank affects inflation only with a lag, expectations about future inflation must be crucial inputs to a central bank's policy decisions. Therefore, an econometrician also needs to incorporate inflationary expectations in the monetary policy function in order to estimate the policy shock correctly. In chapter two, I identify the monetary policy reaction function using inflation expectations as contemporaneous inputs. I calculate inflationary expectations by decomposing the nominal interest rate into the expected inflation rate and the *ex ante* real interest rate, using the Blanchard-Quah VAR model.

By identifying the monetary policy function in a recursive VAR model for Canada, I find that monetary policy significantly reacts to inflation expectations as well as affects inflation expectations. The estimated results of chapter two suggest that a contractionary monetary policy shock increases the real interest rate and lowers the expected inflation rate, findings which are consistent with what we expect from a contractionary policy shocks. The contractionary policy shock, however, depreciates the home currency which is a puzzling result, widely known as the exchange rate puzzle in the literature.

While the use of inflation expectations is a step forward towards correctly identifying the monetary policy function, the recursive VAR approach cannot capture any simultaneous interactions among the variables used in the model. Therefore, in chapter three I identify monetary policy shocks employing a structural VAR model that allows the policy variable and the other variables in the model to interact with each other contemporaneously. I also develop the structural VAR model in an open-economy context and assume that the central bank responds to a number of foreign variables, in addition to domestic variables, in deciding the monetary policy. Finally, in order to obtain accurate statistical inference, I employ a Bayesian Gibbs sampling method to estimate the posterior distribution of the model parameters.

When I apply this structural VAR model to the Bank of Canada, I find that monetary policy shocks transmit to real output through both the interest rate and exchange rate channels. I also find that the higher return in Canadian currency, induced by a contractionary policy shock, is offset by the gradual depreciation of the Canadian dollar after an impact appreciation. The estimated results also suggest that the Bank of Canada significantly responds to the US variables including the federal funds rate.

While chapter two improves the policy identification by including inflation forecasts, and chapter three increases the precision of the model identification by deploying a structural VAR model, chapter four identifies a forward-looking monetary policy function by using a number of macroeconomic forecasts in a structural VAR model. Since I use both forecasted and actual macroeconomic variables in this structural model, I call it a forecast-augmented VAR (FVAR) model. This FVAR model developed in chapter four gives us the opportunity to examine whether the central bank responds to the two types of variables differently. In addition, since the macroeconomic forecasts are based on many other variables that the central bank and the private sector might observe, the identified policy function spans a bigger information set, without estimating a larger model. Finally, since the standard structural VAR model is a special case of the FVAR model, by estimating both models, we can understand the contributions to identifying the forward-looking monetary policy of using forecasted variables.

When I apply the FVAR model developed in chapter four to the Bank of England, I find that forecasted variables play a greater role than realized variables in the monetary policy function. I also find that a contractionary policy shock almost instantaneously increases the market interest rate as well as the forecast of the market interest rate. This policy shock also appreciates both the British pound and the forecast of the pound on impact. On the other hand, while the contractionary policy shock lowers the expected inflation rate almost immediately, the shock does not have a significant effect on the actual inflation rate until the beginning of the second year after the shock.

When I estimate the standard model nested in the forecast-augmented model, I find that there is a remarkable change in the impulse responses of the realized inflation rate and the exchange rate: due to a contractionary monetary policy shock, the realized inflation rate increases and the British pound keeps appreciating for about six months after the shock. To examine which aspect of the forecast-augmented model absent from the standard model causes these puzzling responses, I put the forecasted variables into the standard model one after another. I find that the incorporation of the inflation forecast into the standard VAR reverses the puzzling response of the inflation rate, and the inclusion of both the market interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate.

Chapter 2

Real and Nominal Effects of Monetary Policy Shocks

2.1 Introduction

Early attempts to estimate the macroeconomic effects of monetary policy shocks utilizing recursive VAR methods encountered puzzling dynamic responses identified as the liquidity, price, and exchange rate puzzles. Through the work of Sims and Zha (1995), Cushman and Zha (1997) and Kim and Roubini (2000), among others, we now understand that these puzzles result from an inadequate identification of exogenous policy shocks. To resolve these puzzles, these authors employ a structural VAR approach with contemporaneous restrictions in order to identify the policy rea ction function and thereby obtain measures of policy shocks that are orthogonal to the other variables in the model.

In a different resolution of the aforementioned puzzles, Kahn, Kandel and Sarig (2002), hereafter KKS, focus directly on the role of inflationary expectations. They argue that without a direct measure of inflationary expectations, one cannot distinguish between central banks interaction for a good real with interest rates and its interactions with inflationary expectations. Using an Israeli data set of real interest rates and inflationary expectations calculated from the market prices of indexed and nominal bonds and employing a fully recursive VAR model, they find that a negative monetary policy shock, identified as an innovation in the overnight rate of the Bank of Israel, raises one-year real interest rates, lowers inflationary expectations and appreciates the Israeli currency, responses which are absent from the aforementioned puzzles. They also find that the monetary policy impacts are mainly concentrated on short-term real rates.

In this chapter of the thesis I propose to apply the KSS methodology to Canadian data. Unfortunately, due to an incomplete set of maturities of indexed bonds I cannot calculate inflationary expectations from bond market prices as KKS do. Following the example of St-Amant (1995) and Gottschalk (2001) for U.S. and Euro-area data, I estimate inflationary expectations and *ex ante* real interest rates using the structural VAR method proposed by Blanchard and Quah (1989) with the identifying restrictions that real interest rate innovations have temporary effects while inflationary expectations innovations have permanent effects on nominal interest rates.

Using the estimated *ex ante* real interest rates and inflationary expectations, I then estimate the separate reactions of *ex ante* real interest rates and inflationary expectations to monetary policy shocks. I also examine how both short-term and longer-term real interest rates react to monetary policy shocks. In addition, to provide a diagnostic check of my model, I augment the basic model to include some non-financial variables that may also impact the policy process, for the exclusion of these variables may give misleading results if they are related systematically to central bank actions. The additional variables in the augmented model are the exchange rate, industrial output, and the unemployment rate.

The estimated results show that a positive monetary policy shock to M1 (currency and all chequable deposits in chartered banks) temporarily lowers the *ex ante* real interest rate and raises inflationary expectations. I find that the impact of a monetary policy shock is smaller on longer-term interest rates than on the one-year rate. I also find that a positive monetary shock increases industrial output, depreciates the Canadian currency, and marginally increases the unemployment rate, although these responses are not statistically significant.

Using the overnight target rate as the monetary policy instrument, I find that a negative monetary policy shock temporarily lowers inflationary expectations and increases the *ex ante* one-year real interest rate but does not have a statistically significant effect on the second and the third year *ex ante* real forward rates. I also find that this policy shock decreases output, increases the unemployment rate and depreciates the Canadian currency. The estimated results using the overnight target rate as the monetary policy instrument are more consistent with the predictions of macroecomic theories than those generated with M1 as the policy instrument.

The remainder of this chapter is organized as follows: Section 2.2 briefly outlines the application of the Blanchard-Quah structural VAR method, section 2.3 provides the data sources, section 2.4 reports on the suitability of the data for the Blanchard-Quah method, section 2.5 provides the framework for identifying monetary policy shocks, section 2.6 presents the estimation results, and section 2.7 draws conclusions.

2.2 Nominal Interest Rate Decomposition

I apply the structural VAR method developed by Blanchard and Quah (1989) to decompose the Canadian one-year, two-year and three-year nominal interest rates into the expected inflation and the *ex ante* real interest rate components following the example of St-Amant (1996) and Gottschalk (2001). The starting point is the Fisher equation that states that the nominal interest rate is the sum of the *ex ante* real interest rate and the expected inflation rate:

$$i_{t,k} = r_{t,k} + \pi^e_{t,k}, \tag{2.1}$$

where $i_{t,k}$ is the nominal interest at time t on a bond with k periods untill maturity, $r_{t,k}$ is the corresponding *ex ante* real rate, and $\pi^e_{t,k}$ denotes inflationary expectations for the time from t to $t + k$. The inflation-forecast error, $\varepsilon_{t,k}$, is defined as the difference between the actual inflation rate, $\pi_{t,k}$, and the expected inflation rate, $\pi^e_{t,k}$:

$$\varepsilon_{t,k} = \pi_{t,k} - \pi^e_{t,k}. \tag{2.2}$$

Substituting the inflation-forecast-error equation (2.2) into the Fisher equation (2.1), we obtain:

$$i_{t,k} - \pi_{t,k} = r_{t,k} - \varepsilon_{t,k}. \tag{2.3}$$

Therefore, the *ex post* real rate, $i_{t,k} - \pi_{t,k}$, is the difference between the *ex ante* real rate and the inflation forecast error. Under the assumptions that both the nominal interest rate and the inflation rate are integrated of order one and they are co-integrated, and that the inflation forecast error is integrated of order zero, assumptions I test and confirm in Section 2.4, the *ex ante* real rate must be stationary.

Gottschalk (2001) emphasizes three implications that follow from these assumptions. First, if the nominal interest rate is non-stationary, this variable can be decomposed into a non-stationary component comprised of changes in the nominal interest rate with a permanent character and a stationary component comprised of the transitory fluctuations in the interest rate. Second, if the nominal interest rate and the actual inflation rate are co-integrated, it implies that both variables share the common stochastic trend, and this stochastic trend is the source of the non-stationary of both variables. Further, if the *ex ante* real interest rate is stationary, the nominal trend has no long-run effect on this variable. Third, if the nominal interest rate and the actual inflation rate are co-integrated (1,-1) and the inflation forecast error is integrated of order zero, this implies that changes in inflationary expectations are the source of these permanent movements in the nominal interest rate.

Therefore, the permanent movements of the nominal interest rate obtained by using the Blanchard-Quah method will be nothing other than these inflationary expectations. Since the permanent component of the nominal interest rate corresponds to inflationary expectations, the stationary component must be the *ex ante* real interest rate. Using the identifying restrictions that shocks to the *ex ante* real rate have only a transitory effect on the nominal interest rate while shocks to inflationary expectations induce a permanent change in the nominal interest rate, I can estimate inflationary expectations and the *ex ante* real rate of interest.

2.3 Canadian Monthly Data

The data run monthly from January 1980 to December 2002. All the data are collected from the Statistics Canada's CANSIM database. The variables are: m, the logarithm of money supply (M1) (Cansim, V37199); i_o, the overnight target rate (Cansim, V114039); i_1, the one-year treasury-bill rate (Cansim, V122533); i_2, the two-year treasury-bill rate (Cansim, V122538); i_3, the three-year treasury-bill rate (Cansim, V122539); π, the annualized monthly inflation rate calculated from the consumer price index (Cansim, V737311); s, the logarithm of the nominal exchange rate expressed in units of Canadian dollar for one unit of the US dollar (Cansim, V37426); y, industrial production (Cansim, V2044332); and u, the unemployment rate (Cansim, V2062815).

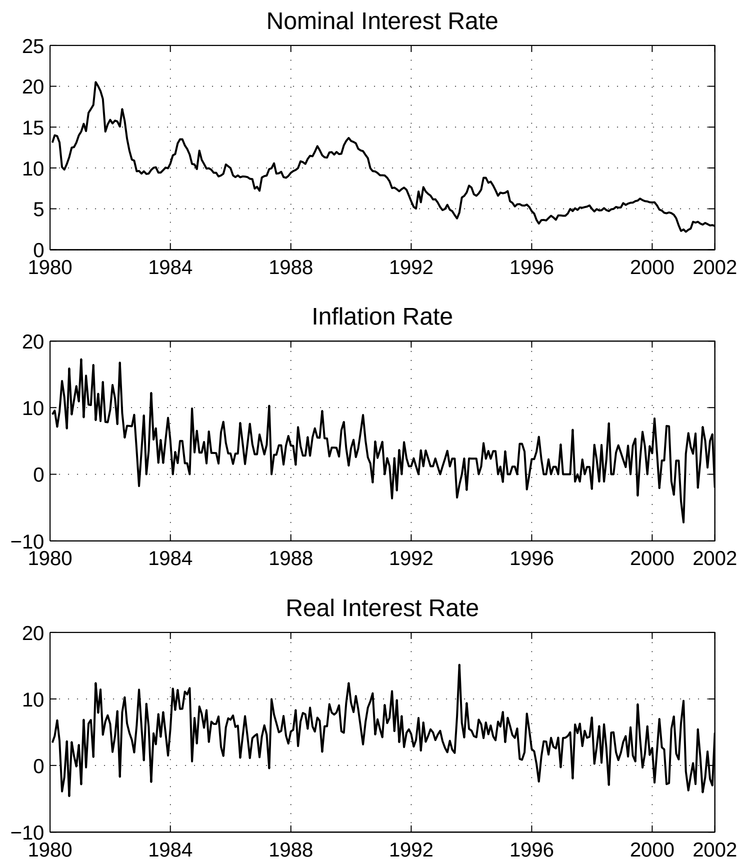
2.4 Inflationary Expectations and the *Ex ante* Real Interest Rate

Our required assumptions are that the nominal interest rate of three different maturities and the inflation rate are both integrated of order one and the real rate is integrated of order zero, assumptions that imply that that the nominal interest rate and inflation rate are co-integrated (1,-1). To investigate the stationary properties of these variables, I first graph them in figure 2.1 and then graph their autocorrelation functions in figure 2.2.

Figure 2.1 appears to support the hypothesis that the nominal interest rate and the inflation rate are integrated of order one and the real interest rate is integrated of order zero. The autocorrelation functions in figure 2.2 also support these hypotheses. For the nominal interest rate and the inflation rate, the autocorrelation coefficient starts with a high value and it approaches zero as the lag increases. In contrast, the autocorrelation function for the real interest rate does not exhibit decay of this magnitude.

Next I use the Augmented Dickey Fuller test (ADF) test to test our hypothesis about the stationarity properties of these variables. The results of the unit-root tests are reported in table 2.1. Table 2.1 demonstrates that the ADF test cannot reject the null hypothesis of unit root for the inflation rate at a ten percent level of significance and the unit root of the first difference of the inflation rate is rejected at a one percent level of significance. Therefore, I conclude that the inflation rate is integrated of order one. Table 2.1 also indicates that the ADF test cannot reject the null hypothesis of a unit root for the nominal interest rates of all maturities at the ten percent level of significance

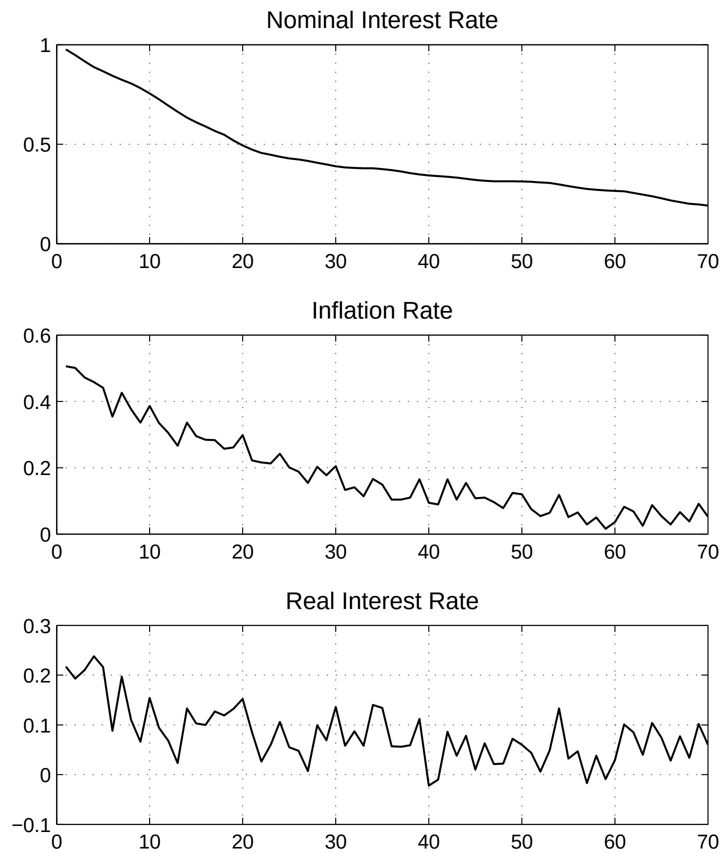
Figure 2.1: Nominal Interest Rate, Inflation Rate, and One-year Real Rate



Note: The horizontal axis measures the time horizon in years and the vertical axis measures values of the variables in percentage points.

and the hypothesis of a unit root of their first differences is rejected at a one percent level of significance. These results support the hypothesis that nominal interest rates of all maturities are integrated of order one. Finally the ADF test also rejects the null hypothesis of a unit root for the *ex post* real interest rates of all maturities at a one percent level of significance. From these finding I conclude that nominal interest rates and the inflation rate are co-integrated (1,-1).

Figure 2.2: Autocorrelation Functions



Note: The horizontal axis measures the lag (in months) and the vertical axis measures the coefficients of the autocorrelation function.

One might notice that the lag length of all the variables in Table 2.1 is close to twelve. This might indicate the possibility of a seasonal root at lag twelve. However, when I perform the lag length test allowing for a seasonal root at different lags including lag twelve, the conclusion does not change.

The next step is to utilize the Blanchard-Quah (1989) method to estimate the time series of expectational error and real interest rate shocks that will be employed to

Table 2.1: Unit-root Tests

Variable	ADF Test Statistic	Variable	ADF Test Statistic
Inflation Rate(π)	-1.968 (c,13)	2-year Nominal Rate	0.8877 (c,13)
$\triangle$ Inflation Rate	-6.835 (c,12)	$\triangle$ Nominal Rate	4.802 (c,12)
Inflation Forecast Error	3.678 (0,3)	2-year Real Rate	-4.150 (c,4)
1-year Nominal Rate	1.432 (c,13)	3-year Nominal Rate	0.893 (c,13)
$\triangle$ Nominal Rate	4.675 (c,12)	$\triangle$ Nominal Rate	4.978 (c,12)
1-year Real Rate	-3.679 (c,6)	3-year Real Rate	-4.268 (c,4)

Note: $\triangle$ indicates the first-difference operator. The bracket indicates the inclusion of a constant and lag length. Lag lengths are chosen by the Ng-Perron (1995) recursive procedure. These unit-root tests were done without using trends.

calculate the time series of the *ex ante* real interest rate and inflationary expectations. I define i_t^d as the first difference of the nominal interest rate. Now if we ignore the intercept terms, the bivariate moving average representation of i_t^d and r_t can be written in the following form:

$$i_t^d = \sum_{k=0}^{\infty} c_{11}(k)\varepsilon_{\pi t-k} + \sum_{k=0}^{\infty} c_{12}(k)\varepsilon_{rt-k}, \tag{2.4}$$

$$r_t = \sum_{k=0}^{\infty} c_{21}(k)\varepsilon_{\pi t-k} + \sum_{k=0}^{\infty} c_{22}(k)\varepsilon_{rt-k}. \tag{2.5}$$

Using matrix notation, in a more compact form, we can rewrite these equations as follows:

$$\begin{pmatrix} i_t^d \\ r_t \end{pmatrix} = \begin{pmatrix} C_{11}(L) & C_{12}(L) \\ C_{21}(L) & C_{22}(L) \end{pmatrix} + \begin{pmatrix} \varepsilon_{\pi t} \\ \varepsilon_{rt} \end{pmatrix}. \tag{2.6}$$

where the $C_{ij}(L)$ are polynomials in the lag operator L such that the individual coefficients of $C_{ij}(L)$ are denoted by $c_{ij}(k)$. For example, the second coefficient of $C_{12}(L)$ is $c_{12}(2)$ and the third coefficient $C_{21}(L)$ is $c_{21}(3)$. As mentioned earlier, the key to decomposing the nominal interest rate, i_t, into its trend and irregular component is to assume that *ex ante* real interest rate shocks, ε_{rt}, have only a temporary effect on the nominal interest rate, i_t. If the nominal interest rate and the inflation rate are co-integrated, and the real interest rate is stationary, that means changes in inflationary expectations are the source of the permanent movements of the nominal interest rate while the real interest rate movements have no permanent effects on the nominal interest rate. Since the real interest rate shocks have no permanent effects on the nominal interest rate, the cumulated effects of these shocks on the nominal interest rate is zero. Thus the coefficients in the nominal interest rate equation (2.4) must be such that:

$$\sum_{k=0}^{\infty} c_{12}(k)\varepsilon_{rt-k} = 0. \tag{2.7}$$

I estimate three different VAR models for the three different nominal interest rates (first differenced) and corresponding real interest rates. The lag length for each model was ten which was determined on the basis of the Akaike information criterion. The two key outputs of VAR estimation that are of interest are the variance decompositions and impulse response functions. The decomposition of variance presented in table 2.2 allows us to measure the relative importance of inflationary expectations and the *ex ante* real interest rate shocks that underlie nominal interest rate fluctuations over different time horizons. It is evident from table 2.2 that the proportion of the variance of nominal interest rates of all maturities explained by *ex ante* real interest rate shocks approaches zero in the long run which is a result of the restriction that *ex ante* real interest rate shocks have no permanent effect on the nominal interest rate. As in St. Amant (1996), both types of shocks have been important sources of nominal interest rate fluctuations.

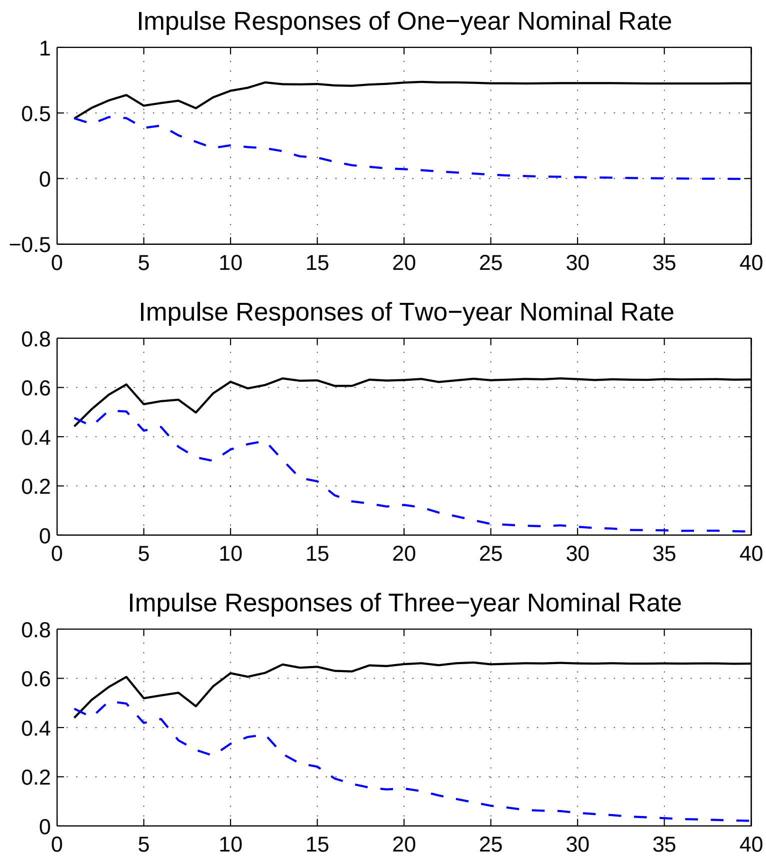
Table 2.2: Variance Decomposition of Nominal Interest Rates (in percentage points)

	One-year Rate		Two-year Rate		Three-year Rate	
Horizon	Inflationary Expectations	Ex ante Real Rate	Inflationary Expectations	Ex ante Real Rate	Inflationary Expectations	Ex ante Real Rate
1	50.9	49.1	46.0	54.0	50.1	49.9
6	63.5	36.5	56.7	43.3	58.5	41.5
12	73.6	26.4	63.7	36.3	63.1	36.9
24	80.05	17.95	74.5	25.5	69.1	30.1
48	85.9	14.1	81.1	18.9	75.9	24.1
96	87.5	12.5	84.5	15.5	78.4	21.6
Infinity	100	0	100	0	100	0

Next I present the impulse responses of nominal interest rates to the structural shocks in figure 2.3 wherein the horizontal axis measures the number of months and the vertical axis measures the proportion, in percentage points, of the movements of the nominal interest rate due to inflationary and real interest rate shocks. The solid line shows the response of the nominal interest rate due to inflationary expectation shocks and the dashed line shows the response due to *ex ante* real interest rate shocks. Recall that although the long-run responses are constrained, the short-run dynamics are not constrained. As in Gottschalk (2001) and St-Amant (1996), the majority of the effect of an *ex ante* real interest rate shock disappears within two years.

To review, I first estimate the effects of *ex ante* real rate and inflationary expecta-

Figure 2.3: Impulse Responses of Nominal Interest Rates



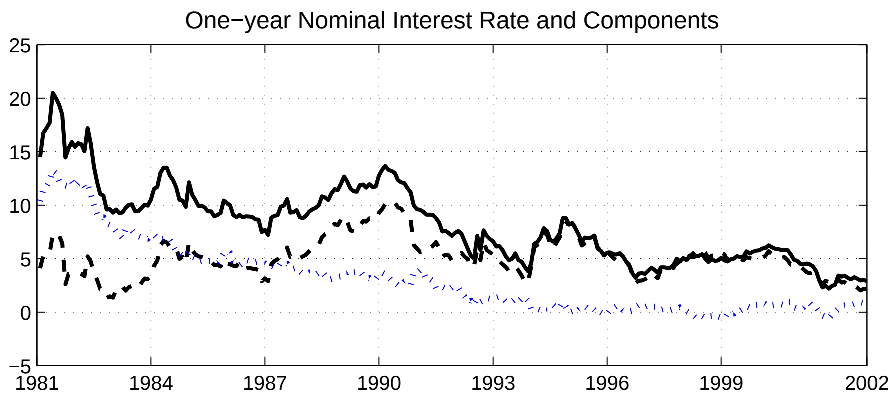
Note: The solid lines show the response of the nominal interest rates due to inflationary expectation shocks and the dashed lines show the response due to *ex ante* real interest rate shocks. The horizontal axis measures the number of months and the vertical axis measures the proportion (in percentage points) of the movements of the nominal interest rates due shocks.

tions shocks on nominal interest rates. Summing the effects of these structural shocks yields the stationary and permanent components of nominal interest rates. An estimate of *ex ante* real interest rates is then obtained by adding the stationary components to the mean of the difference between the observed nominal interest rate and the contemporaneous rate of inflation. Then the measure of inflationary expectations is calculated by subtracting the estimated *ex ante* real interest rate from the nominal interest rate.

The estimated *ex ante* real interest rates and inflationary expectations for one, two and three years along with the corresponding nominal interest rates are depicted in figure 2.4, figure 2.5, and figure 2.6 respectively. The actual inflation rate and the expected inflation rate of one-year horizon are reported in figure 2.7. It is apparent from figure 2.7 that expected inflation is less volatile than the realized inflation rate and that expectations lag the turning points of actual inflation. The solid lines represent nominal interest rates, the heavy dashed lines represent the *ex ante* real interest rates, and the light dashed lines represent inflationary expectations.

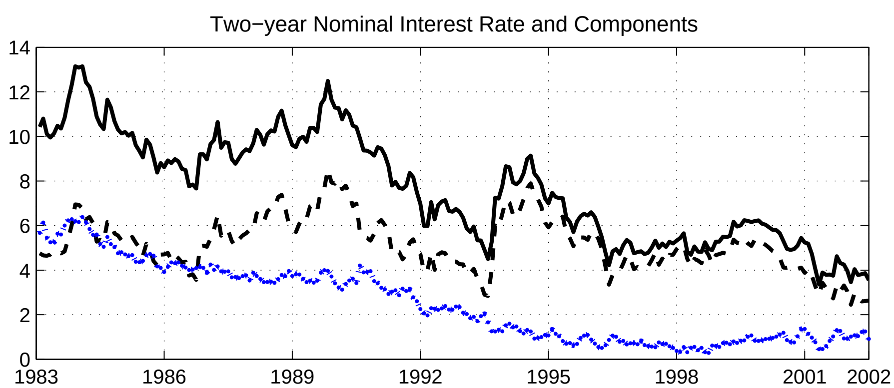
Finally, recall that I assume that the inflation forecast errors are integrated of order zero. As reported in Table 2.1, the ADF test statistic supported this hypothesis at the one percent level of significance.

Figure 2.4: One-year Nominal Interest Rates and Components



Note: The solid line represents nominal interest rate of one-year maturity, the heavy dashed line represents the *ex ante* real interest rates of one-year maturity, and the light dashed line represents inflationary expectations of one-year maturity.

Figure 2.5: Two-year Nominal Interest Rates and Components

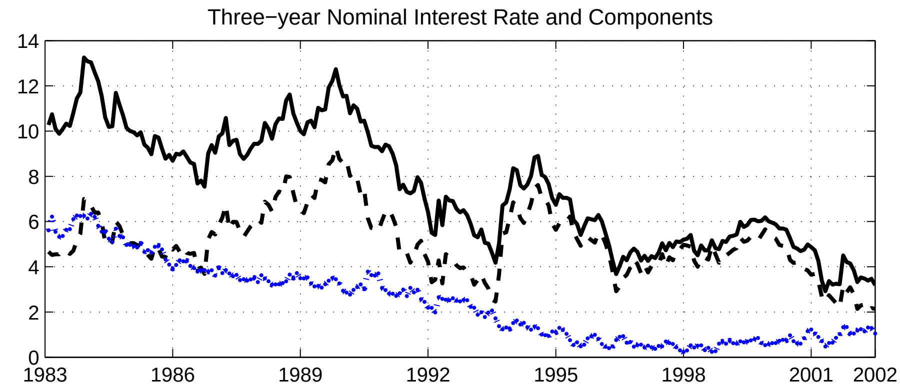


Note: The solid line represents nominal interest rate of two-year maturity, the heavy dashed line represents the *ex ante* real interest rates, and the light dashed line represents inflationary expectations of the same maturity.

2.5 The Identification of Monetary Policy Shocks

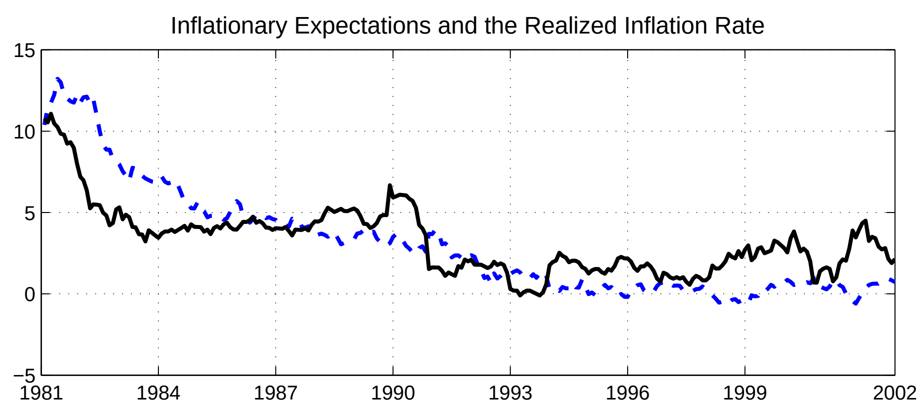
I employ a fully recursive VAR model to estimate the effects of monetary policy shocks on various macroeconomic variables. The first step is to identify policy shocks

Figure 2.6: Three-year Nominal Interest Rates and Components



Note: The solid line represents nominal interest rate of three-year maturity, the heavy dashed line represents the *ex ante* real interest rates, and the light dashed line represents inflationary expectations of the same maturity.

Figure 2.7: Inflationary Expectations and the Realized Inflation Rate



Note: The solid line shows the realized inflation rate and the dashed line represents the expected inflation rate of one-year horizon.

that are orthogonal to the other shocks in the model. To do this, I follow the approach of KKS to categorize all the variables in our model into three broad types.

The first type of variable (Type I variable) is the monetary policy instrument. I use money stock, m, and the overnight target rate, i_o, as alternative monetary policy instruments. The second type of variable (Type II variable) is a contemporaneous input to the monetary policy rule, that is, a variable the central bank observes when setting its policy. To facilitate a comparison with KKS, in the basic model I include only one variable, the measure of inflationary expectations, π^e, as the contemporaneous input to the policy process. The third type of variable (Type III variable) in the basic model is a variable that responds to the change in policy. Since conventional theory treats the *ex ante* real interest rate as the channel through which changes in policy are transmitted to policy targets, I use three alternative interest rates: the one-year *ex ante* real interest rate, r_1, the two-year forward *ex ante* real interest rate, f_2, and the three-year forward *ex ante* real interest rate, f_3, as Type III variables. The use of the forward rates in years two and three is motivated by a concern for double counting that is inherent in the use of yields to maturity. If r_1 and r_2 are the one-year and the two-year *ex ante* real interest rates, and f_2 is the *ex ante* real forward rate of year two, the relationship between them is $f_2 = \frac{(1+r_2)^2}{(1+r_1)} - 1$. Similarly, $f_3 = \frac{(1+r_3)^2}{(1+r_2)} - 1$, where r_3 the three-year *ex ante* real interest rate, and f_3 is the *ex ante* real forward rate of year three. In the augmented model, however, I include three other variables, the exchange rate, s, output, y, and the unemployment rate, u, as Type III variables.

Therefore our basic model includes three different variables: $[\pi^e, m/i_o, r]$. I assume that the central bank's feedback rule is a linear function of contemporaneous values of Type II variables (inflationary expectations) and lagged values of all types of variables in the economy. That means that time t's change of monetary policy of the

Bank of Canada is the sum of the following three things:

(a) the response of the Bank of Canada's policy to changes up to time $t-1$ in all variables in the model (that is, lagged values of Type I, Type II, and Type III variables),

(b) the response of the Bank of Canada's policy to time t changes in the non-policy Type II variable (inflationary expectations in the basic model), and

(c) the monetary policy shock.

Therefore, a monetary policy shock at time t is orthogonal to: changes in all variables in the model observed up to time $t-1$, and contemporaneous changes in the Type II non-policy variable (inflationary expectations). So, by construction, a time t monetary policy shock of the Bank of Canada affects contemporaneous values of Type III variables (that is, the *ex ante* real interest rates of different maturities in the basic model) as well as all variables in the later periods.

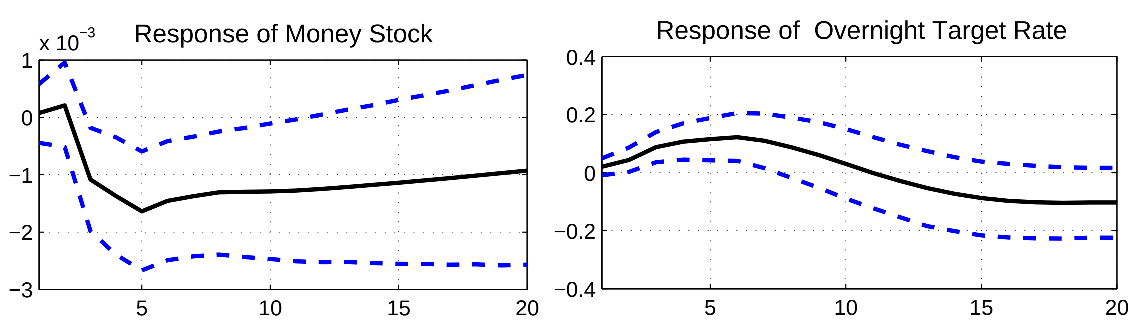
2.6 Estimation

First I estimate the basic three-variable model and report the impulse responses. Then I augment the basic model by including non-financial variables into the model. The overall results of the basic model are robust to the incorporation of the non-financial variables.

2.6.1 The Basic Model

The basic model was estimated using a lag length of three, which was determined on the basis of the Akaike information criterion. First I report the impulse response of the money stock m and the overnight rate, i_o, to a positive one-standard-deviation shock to inflationary expectations in figure 2.8. Under the current inflation-targeting regime, I anticipate that the central bank's response to a rise in inflationary expectations is to tighten the money supply and I observe this response in figure 2.8. The solid lines are point estimates and the dashed lines are one-standard-deviation error bands. We observe from the figure that due to a positive shock in inflationary expectations the stock of money decreases (though it slightly increases in the first month) and the overnight target rate increases. I interpret these responses as support for my view that my measure of inflationary expectations is an input to the policy process.

Figure 2.8: Impulse Responses of the Policy Variables



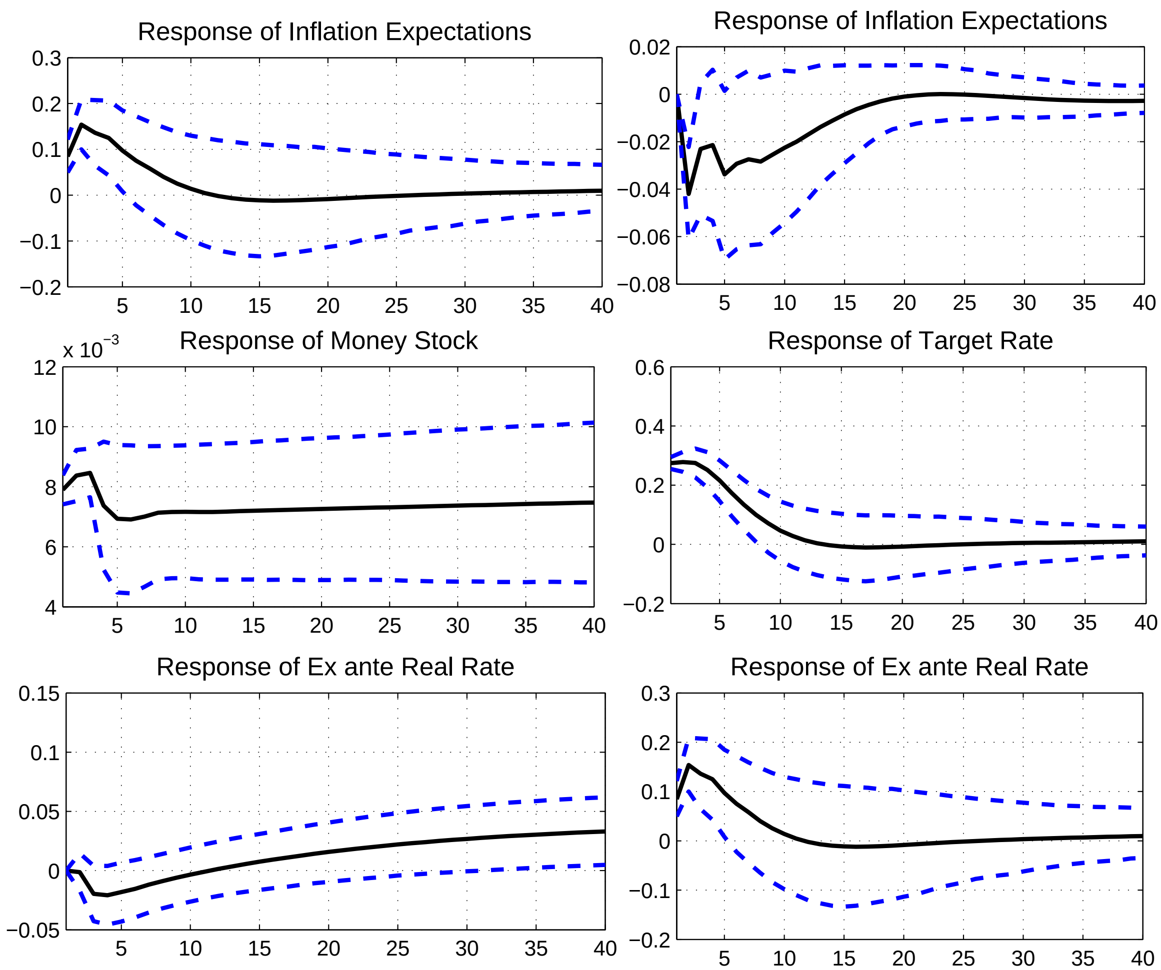
Note: The solid lines are point estimates and the dashed lines are one-standard-deviation error bands.

I begin with the money stock as the policy instrument to facilitate comparisons with previous research. In the first column of figure 2.9 I report the response of inflationary expectations and the one-year *ex ante* real interest rates to a one standard deviation policy shock to money. I expect innovations in the money supply will increase inflationary expectations and reduce *ex ante* real interest rates, although the degree of impact on a particular interest rate should vary depending on the maturity of the rate. Observe from figure 2.9 that inflationary expectations increase by 15 basis points (statistically significant for six months) and the one-year *ex ante* real interest rate decreases, although the effect on the *ex ante* real interest rate is statistically insignificant.

It is instructive to compare these results with previous research. Using the money stock as the policy instrument, KKS find for Israeli data that the effect on inflationary expectations is statistically insignificant while the effect on the one-year *ex ante* real interest rate is statistically significant for about eight months. In contrast, using a structural VAR model with contemporaneous restrictions and the money stock as the monetary policy instrument, Cushman and Zha (1997) find for Canadian data that a negative monetary policy shock raises the real interest rate but the effect is small and statistically insignificant.

In 1994 the Bank of Canada adopted a target band and target rate for the overnight rate on loans among banks and other financial intermediaries as its principal policy instrument. The target band of 50 basis points is designed to allow for small and presumably temporary adjustments of the overnight rate to market developments while adjustments in the target rate are reserved for implementation of changes in the stance

Figure 2.9: Impulse Responses of the Basic Models



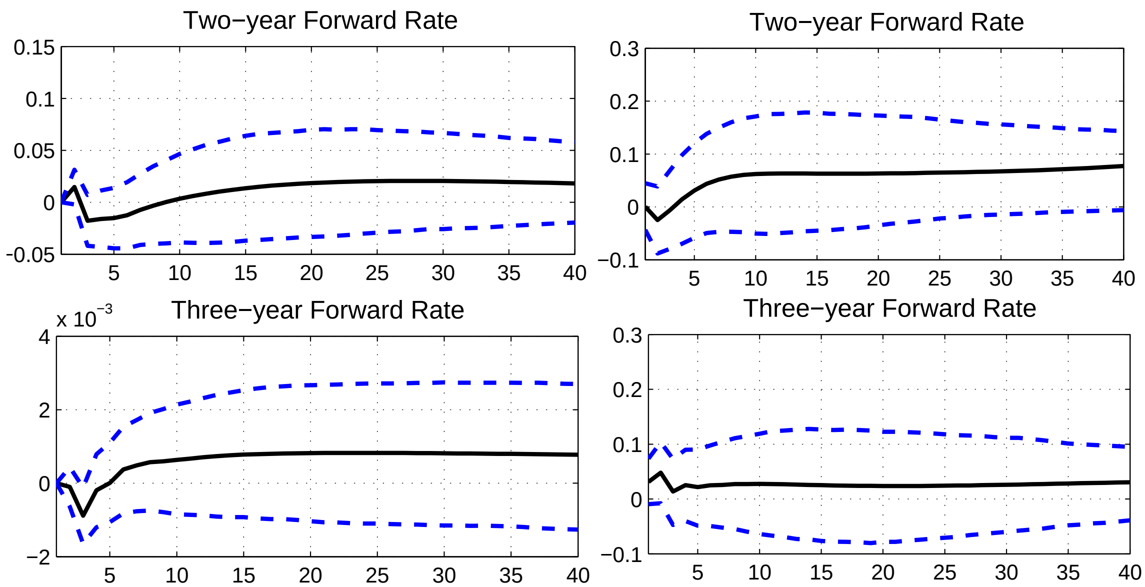
Note: The left panel shows the impulse responses of the basic model due shock to m and the right panel shows the impulse responses due to shock to i_o. The solid lines are point estimates and the dashed lines are one-standard-deviation error bands.

of policy. Only if the overnight rate threatens to break through the upper or lower band will the Bank intervene in the overnight market.

Since the target rate is under the sole control of the Bank of Canada, it follows that innovations in this rate should be a more precise measure of monetary policy shocks than innovations in a monetary aggregate. I re-estimate the basic VAR model using the overnight target rate as the monetary policy instrument from 1994 to 2002 and the impulse responses are reported in the second column of figure 2.9. A negative monetary policy shock introduced by increasing the overnight target rate by 28 basis points (a one standard deviation shock) lowers inflationary expectations by 5 basis points and raises the *ex ante* one-year real interest rate by 15 basis points and these effects are statistically significant for three and five months, respectively. A comparison with the results using the money stock suggests that a shock to the overnight target rate has a more immediate and signficant impact on the real interest rate than a shock to a monetary aggregate and this difference is likely because the interest rate shock does not require a response of chartered bank deposits for its impact.

Although the Bank of Canada's policy impacts real interest rates at the short end of the maturity spectrum, I expect it may also impact real interest rates at longer horizons. Following KKS I use two-year *ex ante* forward real interest rate (f_2) and three-year *ex ante* forward real interest rate (f_3) to estimate the longer-term impact of monetary shocks and I report the estimated impulse responses of these forward real interest rates in figure 2.10. We observe from the figure that, for both the money supply and the target rate as policy instruments, the effects of monetary policy shocks are insignificant on longer-term interest rates. These results are similar to that found by Edelberg and Marshall (1996) and KKS.

Figure 2.10: Impulse Responses of the Forward Real Interest Rates



Note: The left panel shows the impulse responses due shock to m and the right panel shows the impulse responses due to shock to i_o. The solid lines are point estimates and the dashed lines are one-standard-deviation error bands.

2.6.2 The Augmented Model

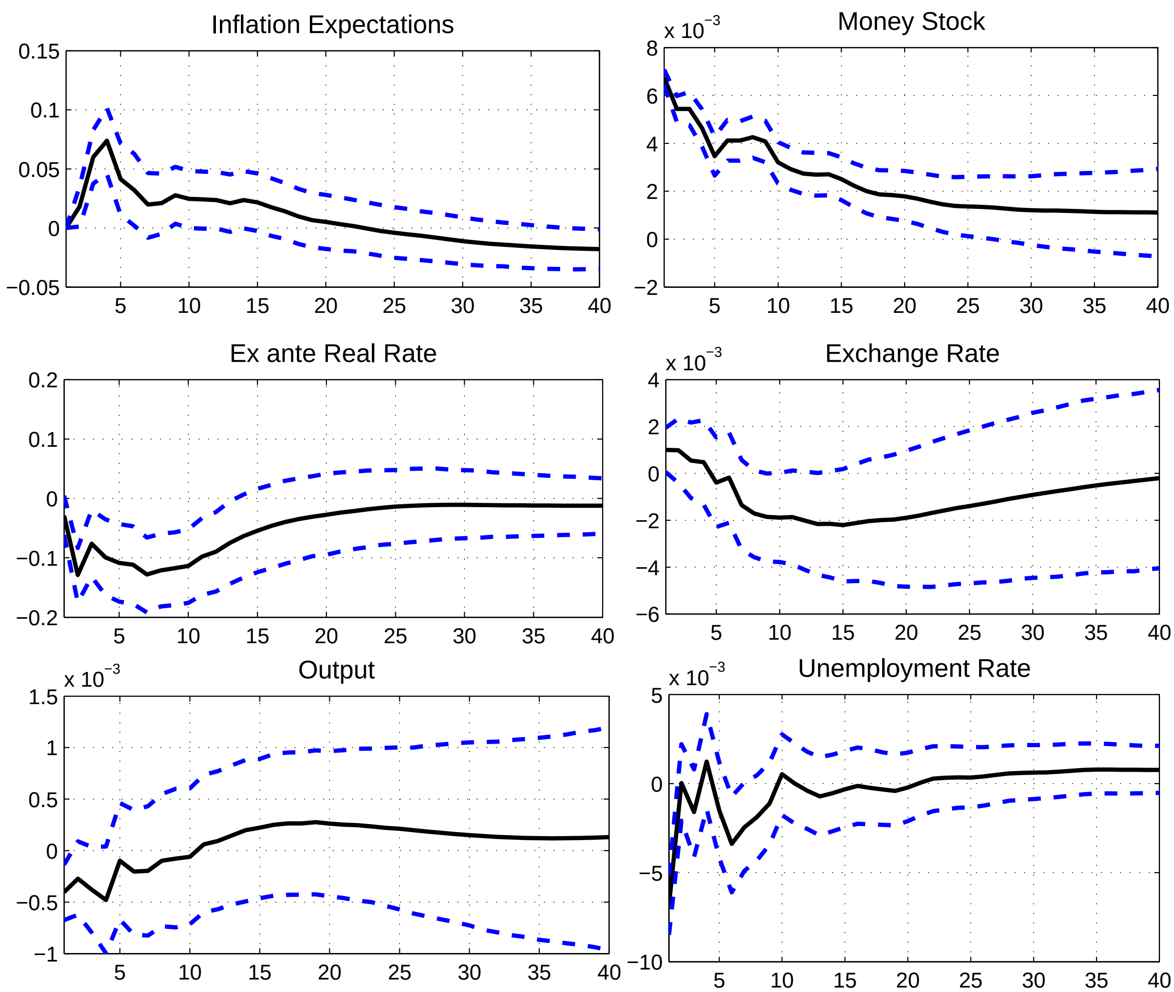
I now augment the basic VAR model by incorporating some additional variables that may impact real interest rates and inflationary expectations. If these variables are correlated with the monetary policy of the Bank of Canada, their omission may lead us to erroneously attribute the impact of these variables to Bank policy. Cushman and Zha (1997), for example, identify the exchange rate as an important channel of the monetary transmission mechanism. Additionally, in the semi-annual *Monetary Policy Report*, the Bank places significant emphasis on its estimates of the real output gap. Therefore, in the augmented model I include the exchange rate, output, and the unemployment rate.

In the the augmented model I continue to use inflationary expectations as the only Type II variable and specify the *ex ante* real interest rate, the exchange rate, industrial output and the unemployment rate as Type III variables with the following order: $[\pi^e, m, r_1, s, y, u]$. The estimated impulse responses of this augmented model are reported in figure 2.11. In the augmented model inflationary expectations increase by 8 basis points following a positive monetary policy shock and this response remains statistically significant for six months. The *ex ante* real interest rate also decreases by 12 basis points and the decrease remains significant for fifteen months. In addition, the shock appreciates the Canadian dollar (although it depreciates for the first four months), increases industrial output (although it decreases for first ten months), and has an insignificant, noisy effect on the unemployment rate. KKS also found an insignificant effect for the unemployment rate.

The impulse responses for the exchange rate, output, and the unemployment rate are not what one would expect. This may reflect the fact that a monetary aggregate is likely to be influenced by sources other than the central bank and this will reduce the precision of estimates of monetary policy shocks in a recursive setting. Accordingly, I also investigate the overnight target rate as an alternative measure of the monetary policy instrument in the augmented model.

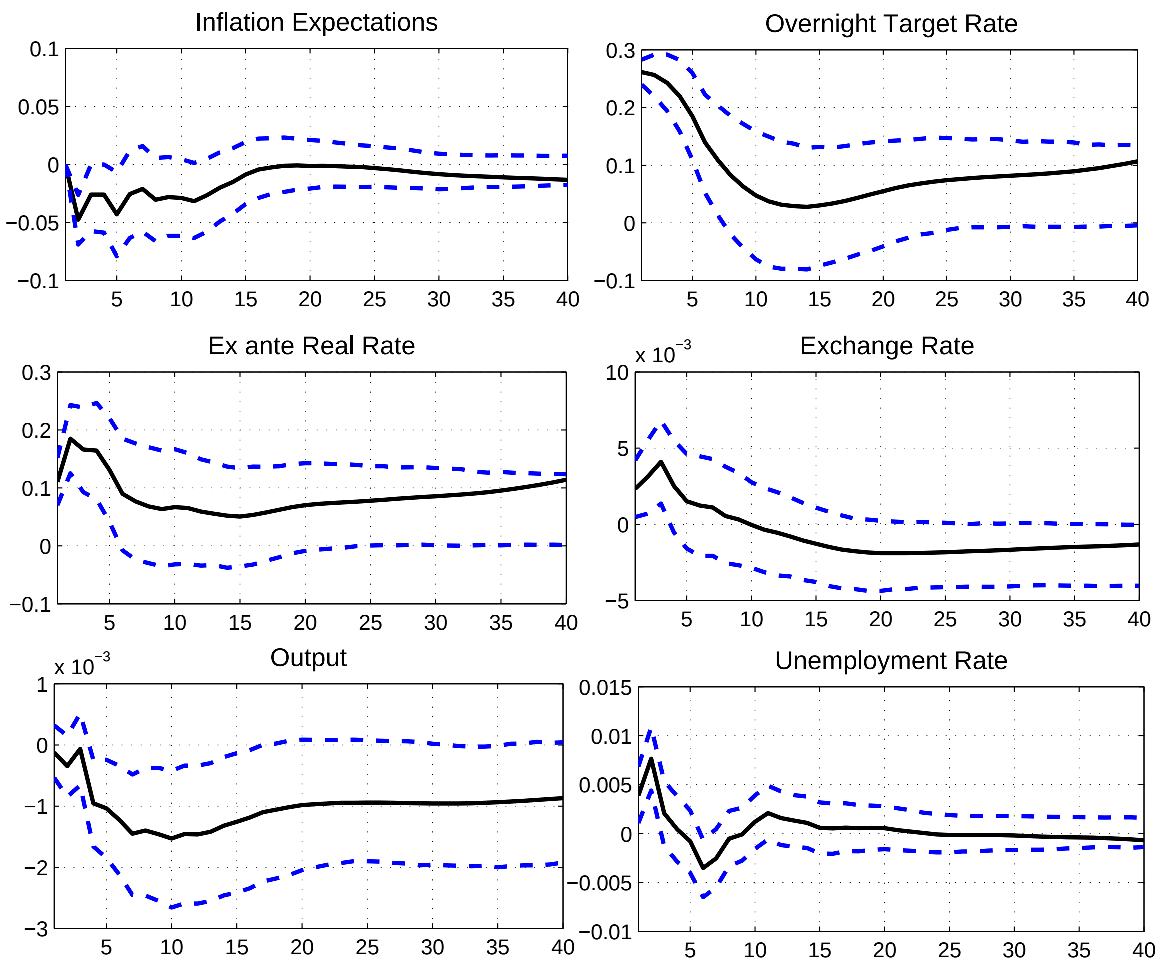
The impulse responses of the augmented model with the overnight target rate are reported in figure 2.12. I find that a 28 basis point increase in the overnight target rate lowers inflationary expectations by 5 basis points and raises the *ex ante* real inter-

Figure 2.11: Impulse Responses of the Augmented Model using Money



est rate by 18 basis points and these responses are significant for five and six months respectively. In addition, the exchange rate depreciates (the exchange rate puzzle), industrial output decreases (significant for about two years), and the unemployment rate increases (statistically insignificant). Comparing the responses of the augmented model with those from the model with the money stock as the policy instrument, we find no reversal in the movement of the exchange rate but a more significant response of industrial output.

Figure 2.12: Impulse Responses of the Augmented Model using Overnight Rate



2.7 Conclusion

I estimated the impact of monetary policy on various real and nominal macroeconomic variables. The approach of decomposing the nominal interest rate into the *ex ante* real interest rate and inflationary expectations using the Blanchard-Quah identification makes it possible to separately examine the reactions of these variables to monetary policy shocks. Employing inflationary expectations as inputs to the monetary policy reaction function, I obtain results that are more consistent with the predictions of economic theories using the overnight target rate rather than a monetary aggregate as the policy instrument. I suggest this result likely follows because, unlike money, the overnight target rate cannot be influenced by private sector behavior except through the channel of an endogenous policy response of the central bank to changing economic conditions.

My results differ from Cushman and Zha (1997) in one important respect. They find that the transmission mechanism from monetary policy shocks to real output is through the exchange rate. While I obtain this effect as well, I also find a significant role for the real interest rate channel. That is, I estimate that a 28 basis point increase in the overnight target rate raises the one-year *ex ante* real interest rate by 18 basis points and this response is significant for four months.

While this chapter has the appealing feature that it includes market-based measures of inflationary expectations in the monetary policy reaction function, the two-step VAR procedure employed to identify monetary policy shocks is a disadvantage. Another shortcoming of this chapter is the recursive VAR model that cannot allow contemporaneous interactions among the variables used in the model. The next two chapters explore two alternative ways to address these problems. In chapter three, I develop a structural VAR (SVAR) model to allow simultaneous interactions among the variables and use a proxy variable for inflationary expectations instead of using a direct measure. On the other hand, in chapter four, I augment the SVAR model, developed in chapter three, by including a set of forecasted variables in order to make the policy identification more realistic. In the forecast-augmented VAR model I assume that the central bank observes forecasts of a number of other macroeconomic variables, in addition to inflation forecasts.

Chapter 3

Monetary Transmission Mechanism in a Small Open Economy: A Bayesian Structural VAR Approach

3.1 Introduction

This chapter identifies monetary policy shocks employing a Bayesian structural VAR model for a small open economy, using Canada as a case study. To identify the monetary policy function, I follow the general procedure of Cushman and Zha (1997) and Kim and Roubini (2000), but change it in a number of respects. First, unlike these authors, I do not use money in the basic model and therefore do not define a money demand function or a money supply function. Instead, I use the overnight target rate as the policy instrument, which is what the Bank of Canada actually uses to conduct monetary policy. The estimation of the basic model without money also gives me the opportunity to check the robustness of the impulse responses and to study the role of money, after estimating an extended model that incorporates money. Second, in order to increase the precision of the model identification, I allow the policy variable and financial variables of the model to interacts simultaneously with each other and with a number of other homes and foreign a number of other home and foreign variables within the month. Finally, since the over-identified structural VAR model developed in this chapter entails simultaneous interactions, in order to obtain accurate statistical inference I employ a Bayesian Gibbs sampling method to estimate the posterior distribution of the model parameters.

As explained in chapter two, it is difficult to measure changes in monetary policy by shocks to money supply or market interest rates, since these shocks might reflect some other shocks in the economy. In contrast, unlike money and market interest rates, the overnight target rate is under the sole control of the Bank of Canada. Therefore, shocks to the target rate cannot be influenced by private-sector behaviour, except through the channel of an endogenous policy response of the central bank to changing economic conditions. Since the structural VAR model developed in this chapter explicitly identifies the policy reaction function as a function of all key home and foreign variables, I am able to estimate policy innovations to the overnight target rate that are orthogonal to these variables.

I assume that the Bank of Canada contemporaneously reacts to some foreign variables, such as the federal funds rate and the world export commodity price index, in addition to the domestic nominal market interest rate and the exchange rate. I use the world export commodity price index as a proxy for inflationary expectations. While in chapter two I use a direct measure of inflationary expectations, in chapter three I use a proxy for inflationary expectations, the export commodity price index. Cushman and Zha (1997) also assumed that this price index contains information about future inflation.

I allow the nominal interest rate to react contemporaneously to the financial variables of the model, assuming that financial variables interact instantaneously with each other. I also assume that an efficient foreign-exchange market has all the relevant information within the month and let the exchange rate react to all variables in the model contemporaneously. The use of the structural VAR approach, as opposed to the recursive VAR approach, enables me to capture these economically meaningful cross-directional relationships among variables. Following Cushman and Zha (1997) and Zha (1999), I treat the foreign variables as exogenous from Canada's point of view in order to maintain the small-open-economy assumption strictly.

This identification approach involves a great deal of simultaneity among the contemporaneous variables. Therefore, the shape of the posterior density of the model parameters tends to be so non-Gaussian that the widely used importance sampling technique of obtaining finite-sample inferences from the posterior distribution becomes inefficient. In order to obtain accurate statistical inferences from the parameter estimates and subsequent forecasts, I estimate the model employing Waggoner and Zha's (2003) Bayesian Gibbs sampling method that incorporates prior information into the VAR following Sims and Zha (1998). The other advantage of this method is that it can be efficiently used for this over-identified structural VAR model that has a restricted covariance matrix of the reduced-form residuals as well as restrictions on the lagged coefficients.

When I apply this model to Canadian data, I find that the monetary policy shock transmits to real output through both the interest rate and exchange rate channels, as opposed to Cushman and Zha (1997), who found that the transmission operates through the exchange rate only. I also find that the higher return in Canadian currency, induced by the contractionary policy shock, is offset by the gradual depreciation of the Canadian dollar after an impact appreciation. This result differs from that of Eichenbaum and Evans (1995), who, in a recursive VAR model, found that the higher return in home currency is further magnified by a persistent appreciation of the exchange rate. This chapter finds that the Bank of Canada responds to any home and foreign variables that embody information about future inflation. This reaction of the Bank is consistent with its inflation-targeting policy. I also find that US federal funds rate shocks have significant effects on Canadian macroeconomic variables, and external shocks are an important source of Canadian output fluctuations.

Since some previous studies, such as those by Gordon and Leeper (1994) and chapter two of this thesis, used money as the policy instrument, I investigate the role of money by incorporating the monetary aggregate, $M1$, now identified as a money demand function, into the basic model. When I re-estimate this model, I find that the impulse responses of all variables in the extended model remain unchanged from the basic model. The key finding of this extended model, however, is that the impulse response of $M1$ does not exactly follow the impulse response of the target rate. In particular, I find that the contractionary policy shock of increasing the target rate peaks almost immediately, while, following the same shock, the money stock keeps declining, the highest impact of which is not realized until the end of the second year. This imprecise response of the money stock casts further doubt on the rationalization of using money as the policy instrument and justifies the use of the overnight target rate. This result also supports the conclusion in chapter two that the overnight target rate is a better measure of the monetary policy instrument.

The remainder of the chapter is organized as follows: section 2.2 presents the context of the research, section 2.3 provides the data sources, section 2.4 describes the structural VAR model that identifies the exogenous monetary policy shock, section 2.5 presents the results, and section 2.6 draws conclusions.

3.2 Research Context

Both Cushman and Zha (1997) and Kim and Roubini (2000) identified a money demand function and a money supply function in their structural VAR models and treated the money supply equation as the reaction function of the monetary authority. While both studies developed structural models in an open-economy context, Cushman and Zha (1997)'s model incorporated the small-open-economy assumption strictly by treating the foreign block of variables as exogenous in the model. In addition, Cushman and Zha (1997) realistically allowed the policy reaction function to react to the Fed policy contemporaneously and conditioned the reaction function to more foreign variables.

Although Cushman and Zha's (1997) model is more realistic than other existing structural models for a small open economy, there is room to build a better model for Canada under evolving circumstances. As mentioned in chapter two, in 1994, the Bank of Canada adopted a target band and a target rate for the overnight rate on loans among banks and other financial institutions, which the Bank calls its main monetary policy instrument. Since the Bank of Canada controls the overnight target rate, innovations in this rate should be a more precise measure of monetary policy shocks.

Therefore, I build a structural VAR model using the target rate as the policy instrument. In addition, since some previous studies used different measures of monetary aggregates as policy instruments, it would be a useful exercise to build the basic model without money, so that, by extending the model to incorporate money, we can examine the robustness of the impulse responses and study the role of money. Another important dimension of improving existing structural VAR models is allowing more simultaneous interactions among the policy variable and the financial variables of the model. Since the information about financial variables is available to the monetary authority instantaneously, and since financial variables react to the policy variable and also react to each other contemporaneously, allowing simultaneous interactions among them will increase the precision of the model identification.

Having identified a monetary policy by incorporating these economically meaningful identifying assumptions into the structural VAR model, how much can we rely on its impulse response functions as measures of the dynamic responses of the macroeconomic variables? In response to the skepticism expressed by Chari, Kehoe, and McGrattan (2005) regarding the ability of the structural VAR model to document empirical phenomena, Christiano, Eichenbaum, and Vigfusson (2006) demonstrated that, if the relevant short-run identifying restrictions are justified, the structural VAR procedures reliably recover and identify the dynamic effects of shocks to the economy. In a recent paper, Fernández-Villaverde, Rubio-Ramírez, Sargent, and Watson (2007) also demonstrated that, if the variables chosen by the econometricians are accurate and if the identifying restrictions are precise, then the impulse responses of the VAR model do a good job of portraying the dynamic behaviour of the macroeconomic variables due to shocks.

3.3 Canadian Monthly Data

The data run monthly from 1994 to 2007. Over the years, the Bank of Canada has shifted the way it conducts monetary policy. Since 1994, the Bank has been using the target for the overnight rate as its key monetary policy instrument. Therefore, I choose to run the sample from 1994 to 2007. All the data are collected from Statistics Canada's CANSIM database and the International Monetary Fund's *International Financial Statistics* (IFS). The variables are: i_0, the overnight target rate (Cansim, V122514); i, the three-month Treasury bills rate (Cansim V122529); s, the logarithm of the nominal exchange rate in units of Canadian currency for one unit of US dollar (Cansim, B3400); π, the annualized monthly inflation rate calculated from the consumer price index (Cansim, V737311); y, the logarithm of the gross domestic product (GDP) (Cansim, V41881478); m, the logarithm of the monetary aggregate, $M1$ (Cansim, V37199); i^*, the US federal funds rate (IFS, 11164B..ZF..); y^*, the logarithm of the US gross domestic product (GDP) (IFS, 11166..CZF..); π^*, the annualized monthly US inflation rate calculated from the US consumer price index (IFS, 11164..ZF..); and wxp^*, the logarithm of the world total export commodity price index (IFS, 06174..DZF..).

3.4 A Structural VAR Model with Block Exogeneity

In the first subsection, I develop the structural VAR model to identify the monetary policy of the Bank of Canada, and in the second subsection, I describe the Bayesian Gibbs sampling method of estimating the model.

3.4.1 Identification of Monetary Policy

Omitting constant terms, the standard structural system can be written in the following linear and stochastic dynamic form:

$$Ax_t = \sum_{l=1}^{p} B_l x_{t-l} + \varepsilon_t, \tag{3.1}$$

where x_t is an $n \times 1$ column vector of endogenous variables at time t, A and B_l are $n \times n$ parameter matrices, ε_t is an $n \times 1$ column vector of structural disturbances, p is the lag length, and $t = 1, ..., T$, where T is the sample size. The parameters of the individual equations in the structural VAR model (3.1) correspond to the rows of A and B_l. I assume that the structural disturbances have a Gaussian distribution with $E(\varepsilon_t \mid x_1, ..., x_{t-1}) = 0$ and $E(\varepsilon_t \varepsilon_t' \mid x_1, ..., x_{t-1}) = I$.

In the model, x comprises two blocks of variables—the Canadian block, x_1:$[i_0, i, s, y, \pi]$ and the non-Canadian block, x_2:$[y^*, \pi^*, i^*, wxp^*]$, where the variables in each block have been defined in the previous section. For the sake of clarity, I rewrite the structural system (3.1) in the following matrix notation:

$$Ax_t = Fz_t + \varepsilon_t, \tag{3.2}$$

where $z_t = [x_{t-1}....x_{t-p}]'$ and $F = [B_1....B_p]$. Here z_t is the $np \times 1$ column vector of all lagged variables and F is the $n \times np$ matrix of all lagged coefficients.

For the precision of the model identification, it is important to treat the relationship between the Canadian and the non-Canadian blocks of variables appropriately. Canada's economy is about one-tenth of the size of the US economy, and about 75 percent of Canada's exports go to the US, while only about 20 percent of US exports come to Canada. Therefore, it seems economically appealing to treat the foreign block of variables as exogenous. Zha (1999) demonstrated that failing to impose such exogeneity restrictions results in misleading conclusions. Incorporating the exogeneity assumption, the structural model (3.2) can be rewritten as follows:

$$\begin{pmatrix} A_{11} & A_{12} \\ 0 & A_{22} \end{pmatrix} \begin{pmatrix} x_{1t} \\ x_{2t} \end{pmatrix} = \begin{pmatrix} F_{11} & F_{12} \\ 0 & F_{22} \end{pmatrix} \begin{pmatrix} z_{1t} \\ z_{2t} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}. \tag{3.3}$$

The restriction that $A_{21} = 0$ follows from the assumption that the Canadian block of variables does not enter into the non-Canadian block contemporaneously, and the restriction that $F_{21} = 0$ follows from the assumption that it does not enter into the non-Canadian block in lag. It is worth noting that this concept of block exogeneity is similar to Granger causal priority defined by Sims (1980) in the context of the reduced-form VAR. The reduced-form version of the structural model (3.2) can be written as follows:

$$x_t = Ez_t + e_t, \tag{3.4}$$

where $E = A^{-1}F$ and $e_t = A^{-1}\varepsilon_t$. The block-exogeneity restrictions in the reduced-form model (3.4) is $E_{22} = 0$, which implies that z_{2t} is Granger causally prior to x_{1t} in the sense of Sims (1980).

I perform the likelihood ratio test to examine if the non-Canadian block is Granger causally prior to the Canadian block. With a lag length of eight, which is determined on the basis of the likelihood ratio test and the Akaike information criterion, the Chi-squared statistic is $\chi^2(160) = 160.612$, where 160 is the total number of restrictions on the non-Canadian block. This value of the Chi-squared statistic implies that the null hypothesis is not rejected at a standard significance level. Therefore, any structural identification for small open economies that treats both the home and the foreign blocks of variables as endogenous, such as that of Kim and Roubini (2000), is likely to produce imprecise estimates resulting in misleading forecasts.

Let Σ be the variance-covariance matrix of the reduced-form residuals, e_t. Since the structural disturbances, ε_t, and the regression residuals, e_t, are related by $\varepsilon_t = Ae_t$, we can derive that $\Sigma = (AA')^{-1}$. To show the identifying restrictions on the contemporaneous-coefficients matrix A, I display the relationship between the reduced-form residuals and the structural shocks in the system of equations (3.5). These restrictions do not merely describe the relationships between the residuals and the structural shocks, but they also describe the contemporaneous relationships among the levels of these variables. I do not impose any restrictions on the lagged coefficients except the block-exogeneity restrictions on the foreign block of variables, as shown in the structural model (3.3).

$$\begin{pmatrix} \varepsilon_{i_0} \\ \varepsilon_i \\ \varepsilon_s \\ \varepsilon_y \\ \varepsilon_\pi \\ \varepsilon_{y^*} \\ \varepsilon_{\pi^*} \\ \varepsilon_{i^*} \\ \varepsilon_{wxp^*} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & 0 & 0 & a_{18} & a_{19} \\ a_{21} & a_{22} & a_{23} & 0 & 0 & 0 & 0 & a_{28} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} & a_{37} & a_{38} & a_{39} \\ 0 & 0 & 0 & a_{44} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{54} & a_{55} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{66} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{76} & a_{77} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{86} & a_{87} & a_{88} & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{96} & a_{97} & a_{98} & a_{99} \end{pmatrix} \begin{pmatrix} e_{i_0} \\ e_i \\ e_s \\ e_y \\ e_\pi \\ e_{y^*} \\ e_{\pi^*} \\ e_{i^*} \\ e_{wxp^*} \end{pmatrix} \tag{3.5}$$

As mentioned, there are two special features of the identification scheme. First, there is no money in the model, and I use the overnight target rate as the monetary policy instrument.[1] The contemporaneous identification of this policy equation is given by the first equation of the system of equations (3.5), where I condition the overnight target rate as a function of the nominal market interest rate (i), the exchange rate (s), the federal funds rate (i^*), and the world export commodity price index (wxp^*). I assume that the Bank of Canada certainly has access to the information on these variables within the month. I use the world export commodity price index as a proxy for inflationary expectations. Since a key objective of the Bank is to maintain a stable inflation

[1] Before 1999, the target rate could be anywhere within the band, but since 1999 it has been set at the midpoint of the band. Before 2001, the target rate could be changed on any day, but since 2001 there have been eight fixed dates of the year on which the target rate can be changed. For the four months of the year when the Bank is not scheduled to meet to decide the target rate, I replace the target rate with the overnight rate.

rate, I assume that the Bank looks at some measures of inflationary expectations when it determines the monetary policy. On the other hand, the Bank of Canada would be unable to observe data on output and the general price level of both domestic and foreign countries within the month.

The second feature of this structural identification is the simultaneous interactions among the policy variable and the financial variables within the month. The second equation of the system of equations (3.5) is the nominal market interest rate equation, which I assume to be contemporaneously affected by the overnight target rate, the exchange rate, and the federal funds rate. The third equation is the exchange-rate equation. Since the exchange rate is a forward-looking asset price, following the information equation of Cushman and Zha (1997) and Kim and Roubini (2000), I assume that an efficient foreign exchange market is able to respond to all macroeconomic variables in the model within the month.

It may not seem plausible that the exchange rate responds to output and the inflation rate, since there is a lag in their publication. But when I empirically test for this response, I find that the contemporaneous coefficients on output and the inflation rate in the exchange rate equation are significantly different from zero. Perhaps this is due to the response of the foreign exchange market to leading indicators that are correlated with shocks to output and inflation but are not included in the model.

On the other hand, it may also seem unusual that the overnight target rate does not react to output and the inflation rate, while the exchange rate does. But again I test whether the coefficients on output and the inflation rate in the monetary policy equation are statistically different from zero. The estimated results suggest that these coefficients are both individually and jointly insignificant. Although the policy variable does not react to the inflation rate and output directly within the month, it does react to these variables indirectly through the exchange rate channel, since the policy variable reacts to the exchange rate contemporaneously.

The structural model identified this way allows the policy variable, the market interest rate, and the exchange rate to interact simultaneously with each other and with other important home and foreign variables within the month. Since the recursive approach, with any ordering of the variables, cannot capture this simultaneity, it may produce flawed monetary policy shocks, resulting in unreliable dynamic responses. Recursive identification approaches, such as those used by Eichenbaum and Evans (1995) and Kahn, Kandel, and Sarig (2002), assume that monetary policy does not react to the exchange rate contemporaneously, which is inconsistent with what the central bank actually does. Faust and Rogers (2003), among others, give a detailed description regarding how frequently the central bank adjusts its policy rate to changes in economic condition home and abroad. These recursive VAR studies, as well as some structural VAR studies such as those by Kim and Roubini (2000) and Kim (2005), also assume that non-US central banks do not respond to the Fed policy move until a month later. This assumption is particularly inappropriate for the Bank of Canada, which always seems to adjust the target rate on the fixed action date following any change in the federal funds rate.

Finally, I specify the production sector of the Canadian block, which comprises two variables: output (y) and the inflation rate (π). I assume that the financial variables of both Canadian and non-Canadian blocks do not affect real activities contemporaneously but with a lag. Although the exchange rate will eventually feed through to the domestic price level, evidence suggests that this pass-through effect is not instantaneous (See for example Engel (2002) and Burstein, Eichenbaum, and Rebelo (2002)). Also, firms do not change their output and price in response to changes in signals of financial variables or monetary policy within the month due to inertia, adjustment cost, and planning delays. Therefore, I normalize this subsystem in the lower-triangularized order of y and π. The estimated results, however, are robust to the reverse order of π and y. As shown in the system of equations (3.5), I also do not impose any structure on the foreign block of variables but follow Cushman and Zha (1997) to keep them in the lower-triangularized fashion of the order y^*, π^*, i^*, wxp^*. However, the qualitative results do not change when I estimate the model using other alternative orderings of the foreign variables. I do not impose any structural relationship among the foreign block of variables since the focus of the paper is not to identify the equations of the foreign variables.

3.4.2 A Bayesian Approach of Imposing Restrictions and Estimation

Two circumstances unfold from the identification scheme in the previous subsection. First, while a total of 45 zero restrictions on the contemporaneous-coefficient matrix, A, would exactly identify the model, I have imposed a total of 50 zero restrictions, which makes the covariance matrix of the reduced-form residuals, Σ, restricted. Second, the identifying restrictions involve simultaneous interactions among the target rate, the market interest rate, and the exchange rate. Due to this high degree of simultaneity, the shape of the posterior density for the model parameters tends to be non-Gaussian, making the widely used importance sampling method of obtaining finite-sample inferences inefficient, as noted by Leeper, Sims, and Zha (1996) and Zha (1999). Waggoner and Zha (2003) demonstrated how the use of the importance sampling method in a simultaneously interacted over-identified model results in misleading inferences. Therefore, I cannot use the existing importance sampling technique as did Cushman and Zha (1997) and Kim and Roubini (2000), although their identification approaches also had simultaneous interactions but to a lesser extent than my approach.

To circumvent the problem incurred due to the simultaneity involved in this over-identified structural VAR model, I estimate the model following the Bayesian Gibbs sampling method of Waggoner and Zha (2003), who incorporated prior information into the VAR as suggested by Sims and Zha (1998). The advantage of this approach is that it delivers accurate statistical inferences for models with a high degree of simultaneity among the contemporaneous variables, as well as for models with restricted variance-covariance matrices of the residuals and for models with restrictions on lagged coefficients.

As I mentioned before, the structural VAR model developed in this chapter is estimated using the Bayesian technique developed by Waggoner and Zha (2000), who followed Sims and Zha's (1998) methodology to introduce prior information into the VAR model. Since I exactly follow Sims and Zha (1998) to determine the prior distribution, I do not explain it in detail. Sims and Zha (1998) (p.960) provide details.

As in Sims and Zha (1998), the weight given to the prior information is governed by six hyperparameters: λ_0, λ_1, λ_3, λ_4, μ_5, μ_6. Here, λ_0 influences the tightness of beliefs regarding the coefficients in the contemporaneous-coefficient matrix. An increase in λ_0 allows the coefficients to have larger variance. The hyper parameter λ_1 controls how tightly the model conforms to the random walk prior, and increasing its value implies that the random walk prior will not be enforced strictly. λ_3 governs how much the coefficients in the lagged matrices can vary from one another. An increase in λ_3 allows the parameters contained in these lags to vary less around their conditional mean of zero. λ_4 affects the standard deviation of the constant in each equation, and an increase in λ_4 allows greater variance for the constant around the conditional mean of zero. μ_5 is the sum of coefficients that gives weight to the possibility that the model may be stated as a first difference model. Therefore, as μ_5 increases, the likelihood that the model can be expressed in first differences increases. Finally, μ_6 allows for the possibility that the variables are co-integrated.

To explain how the Gibbs sampling method can be applied to this structural VAR model, let a_i be the ith row of the contemporaneous-coefficient matrix, A, and f_i be the ith row of the lagged-coefficient matrix, F, defined in the structural equation (3.2), where $1 \leqslant i \leqslant n$. Let Q_i be any $n \times n$ matrix of rank q_i, and R_i be any $k \times k$ matrix of rank r_i. Therefore, the linear restrictions on the contemporaneous-coefficient matrix, A, and on the lagged-coefficient matrix, F, can be summarized, respectively, as follows:

$$Q_i a_i = 0, \quad i = 1, ...n, \tag{3.6}$$

$$R_i f_i = 0, \quad i = 1, ...n. \tag{3.7}$$

Assuming that there exist non-degenerate solutions to the above problems, I can define a $n \times q_i$ matrix U_i whose columns form an orthonormal basis for the null space of Q_i, and a $k \times r_i$ matrix V_i whose columns form an orthonormal basis for the null space of R_i. Therefore, a_i and f_i, which, respectively, are the rows of A and F, will satisfy the identifying restrictions (3.6) and (3.7) if and only if there exists a $q_i \times 1$ vector g_i and a $r_i \times 1$ vector h_i such that

$$a_i = U_i g_i, \tag{3.8}$$

$$f_i = V_i h_i. \tag{3.9}$$

The model then becomes much easier to handle by forming priors on the elements of g_i and h_i, since the original parameters of a_i and f_i can be easily recovered via the linear transformations through U_i and V_i. Waggoner and Zha (2003) demonstrated that, using this approach, simulations can be carried out on an equation-by-equation basis, which vastly reduces the computational burden of the problem. To obtain the finite-sample inferences of g_i and h_i, and their functions, that is, impulse responses, it is necessary to simulate the joint posterior distribution of g_i and h_i. To do this simulation, I follow Waggoner and Zha's (2003) two-step Gibbs sampling procedure.[2] First, I simulate draws of g_i from its marginal posterior distribution, and then, given each draw of g_i, I simulate h_i from the conditional posterior distribution of h_i. The second step is straightforward, since it requires draws from multivariate normal distributions. The first step, however, is less straightforward as the over-identifying restrictions on the contemporaneous-coefficient matrix, A, make the reduced-form covariance matrix, Σ, restricted.

3.5 Empirical Evidence of the Effects of Monetary Policy Shocks

The first step of estimation is to test the over-identifying restrictions imposed on the contemporaneous and the lagged coefficients. Following Cushman and Zha (1997), I perform a joint test of the contemporaneous and the lagged identifying restrictions. As long as all restrictions are treated as a restricted subset of the complete unrestricted parameter space, the likelihood ratio test can be applied to test the overall identifying restrictions. In the model, the contemporaneous-coefficient matrix, A, has

[2] For a detailed explanation of the algebra and the algorithm, see Waggoner and Zha (2003).

5 over-identifying restrictions, and with a lag-length of 8, the number of lagged restrictions on the non-Canadian block is 160. Therefore, with a total of 165 restrictions, the estimated Chi-squared statistic $\chi^2(165) = 176.543$ implies that the null is not rejected at a standard significance level.

As mentioned in subsection $3.4.1$, a greater degree of simultaneous interactions among the variables makes the structural approach developed in this chapter different from the existing approaches in the literature. Therefore, the estimated contemporaneous coefficients will be informative about the effectiveness of this approach. The estimated contemporaneous coefficients of the first three equations of the model are reported in table 3.1. Since the production sector and the foreign block of variables do not have any structural interpretations, those contemporaneous coefficients are not produced here. The significance of most of the contemporaneous coefficients and, in particular, the strong significance of the simultaneously interacted coefficients—a_{12}, a_{21}, a_{13}, a_{31}, a_{23}, a_{32}—indicates that both a recursive identification and a structural identification that does not allow the financial variables to interact with each other simultaneously would be erroneous.

In the monetary policy equation, the positive and significant coefficient of the market interest rate implies that the Bank of Canada tightens monetary policy if the current nominal market interest rate is low. The negative and significant coefficient of the exchange rate shows that, as a measure of leaning today against the wind, the Bank increases the overnight target rate to offset currency depreciation. These findings are

Table 3.1: Estimated Contemporaneous Coefficients

a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}
1.177	0.871	−9.328	0	0	0	0	−0.156	−1.629
(0.512)	(0.379)	(4.405)	–	–	–	–	(0.071)	(0.915)
a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}	a_{28}	a_{29}
−7.461	8.037	−7.423	0	0	0	0	−0.214	0
(3.594)	(3.489)	(3.467)	–	–	–	–	(0.104)	–
a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}	a_{38}	a_{39}
4.851	4.693	53.881	0.848	−53.164	75.719	−0.013	−1.333	57.568
(1.646)	(1.542)	(18.025)	(0.318)	(29.748)	(12.240)	(0.121)	(0.582)	(19.178)

Note: Entries correspond to rows 1 through 3 of the contemporaneous-coefficient matrix, A, defined in equation (3.5), and apply to shocks to i_0, i, and s respectively. Parentheses contain standard errors.

consistent with the inflation-targeting monetary policy of the Bank of Canada. Since both the lower market interest rate and the depreciation of the Canadian dollar are indications of future inflation, the Bank would want to tighten the monetary policy by raising the overnight target rate in order to reduce future inflation by influencing these variables. The negative and significant coefficient of the federal funds rate confirms the traditional belief that the Fed is the leader and the Bank of Canada is in part the follower. Although the coefficient of the world export commodity price index is not significant, its negative sign implies that the Bank undertakes a contractionary monetary policy when seeing a higher world export price.

All the contemporaneous coefficients of the market interest rate equation and the exchange-rate equation are statistically significant at less than the 0.05 level, except the coefficient of the US inflation rate on the exchange-rate equation. The significance of these coefficients validates the structural identification and the simultaneity I assumed among the target rate, the market interest rate, and the exchange rate. On the other hand, the significance of the coefficients of the exchange-rate equation with the non-financial variables, except the US inflation rate, justifies the assumption that an efficient exchange-rate market can contemporaneously respond to these variables within the month. Although this identification scheme does not allow the market interest rate to react directly to the non-financial variables within the month, it allows this rate to react indirectly to these variables via reacting to the exchange rate, which in turn reacts to all the variables. When I test whether the market interest rate directly responds to the non-financial variables, I find that the coefficients of these variables are both individually and jointly insignificant.

Before presenting impulse responses, it is worth discussing the theory underlying the open-economy monetary transmission mechanism. Following the pioneering work by Obstfeld and Rogoff (1995), a number of open-economy monetary transmission models, such as those by Chari, Kehoe, and McGrattan (2002), Corsetti and Pesenti (2001), Galí and Monacelli (2004), and Kollmann (2001), made contributions to the New Open Economy Macroeconomics literature. These models with stickiness in prices and wages imply that monetary policy operates through the interest rate and exchange rate channels. For example, following a contractionary monetary policy shock, the market interest rate rises, which causes an inflow of capital into the country from around the world, leading to an appreciation of domestic currency. The rise in the interest rate also increases the cost of borrowing and thus tends to dampen the demand for interest-sensitive consumption and investment expenditures. On the other hand, the appreciation of domestic currency increases prices of home products relative to foreign ones, leading to a decline in net exports. Therefore, the contractionary policy shock leads to a reduction in aggregate demand.

Over short periods of time, since output is determined by aggregate demand, the fall in aggregate demand causes a fall in aggregate output. With a given underlying growth rate of potential output, this reduction in actual output implies a negative output gap. While this negative output gap might continue for a while, eventually the economic slack leads to a fall in wages and prices of other inputs. Finally, this reduction in firms' costs of production leads to a reduction in the price of output, that is, to a low inflation rate in the economy. Therefore, theoretically, while the effects of the policy shock on interest rates and exchange rates are realized immediately, this effect on the level of output is realized with a lag, and on the price level with further a lag.

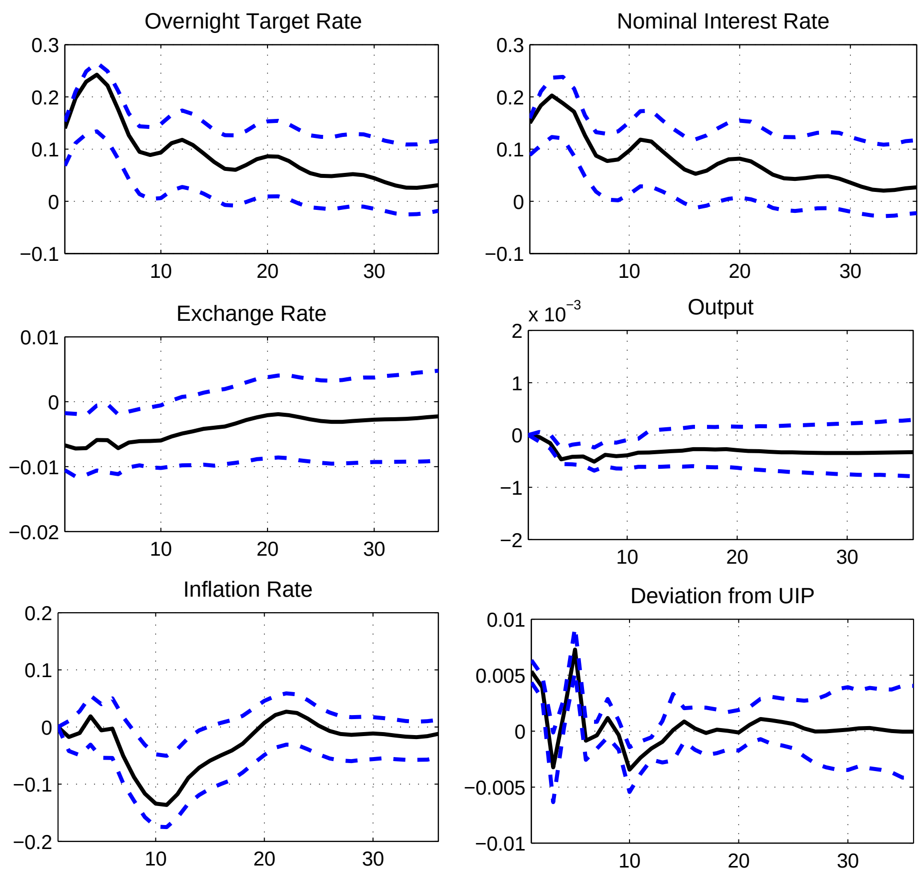
The estimated impulse responses of the macroeconomic variables are displayed in figure 3.1. The response horizon, in months, is given on the horizontal axis. The solid lines are the estimated impulse responses computed from the values of a_i and f_i, defined in subsection 3.4.2, at the peak of their posterior distributions. The upper and lower dashed lines are one-standard-error bands, derived using the Bayesian Gibbs sampling method of Waggoner and Zha (2003).[3]

[3] The error bands are computed from a set of 10000 draws. I gratefully acknowledge Tao Zha for helping me with the Matlab codes.

We observe from the figure that a one-standard-deviation contractionary monetary policy shock of increasing the overnight target rate by 25 basis points increases the nominal market interest rate by 20 basis points, which remains statistically significant for about a year. Following the same shock, the exchange rate appreciates on impact and gradually depreciates to its terminal value. Therefore, this reaction of the exchange rate is consistent with Dornbusch's prediction that following a policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment to the initial value. We also observe that due to this contractionary policy shock the output level falls with a lag of over half a year. Finally, this policy shock lowers the inflation rate by 15 basis points, the highest impact of which is realized with a lag of about one year and remains significant up to a year and a half after the shock was introduced. Therefore, while the market interest rate and the exchange rate respond to the policy shock immediately, output responds with a lag and the response of the inflation rate is further delayed. These impulse responses are consistent with the theoretical predictions of the dynamic responses of a contractionary monetary policy shock, both in terms of the direction and the timing of the responses.

At this point it is interesting to compare the findings of this chapter with other findings in the literature for Canada. Both Cushman and Zha (1997) and Kim and Roubini (2000) found that the exchange rate appreciates at the time of a contractionary monetary policy shock, but then gradually depreciates to the terminal value. However, Cushman and Zha (1997) did not find any significant effect on the nominal interest rate

Figure 3.1: Impulse Responses Due to Monetary Policy Shock



and concluded that the monetary policy transmission mechanism operates through the exchange rate, not the interest rate. They also found that the effect on the price level started to be significant after about two years, which remained significant up to the end of the third year.

The contractionary monetary policy shock in Kim and Roubini's (2000) approach produced the liquidity puzzle—a decrease in the nominal interest rate following a contractionary policy shock—for Canada and a few other G-7 countries. They also found that this policy shock had a statistically significant effect on the Canadian price level for more than four years. On the other hand, the contractionary monetary policy shock of raising the overnight target rate in a recursive identification approach by Bhuiyan and Lucas (2007) increased the real interest rate and lowered inflationary expectations. However, following this contractionary policy shock, the exchange rate depreciated, and there was no significant effect on output.

I believe that the superiority of the impulse responses generated in this chapter, in terms of matching with the theoretical predictions, is due to a more accurate identification of the structural model, which estimates a more precise measure of the exogenous monetary policy shock. In the structural model I realistically allow the target rate, the nominal interest rate, and the exchange rate to react to each other and to a number of other home and foreign variables within the month, which increases the precision of the model identification. On the other hand, since the overnight target rate cannot be influenced by other shocks in the economy, except through an endogenous policy response of the Bank to changes in the variables captured in the policy equation, innovations to this equation truly estimate exogenous policy shocks. In a recent paper, Carpenter and Demiralp (2008) made a similar argument to demonstrate the liquidity effect for the US. They showed that the liquidity puzzle or the time-insensitive liquidity effect is the result of the misspecification of the VAR model arising from the use of inappropriate variables.

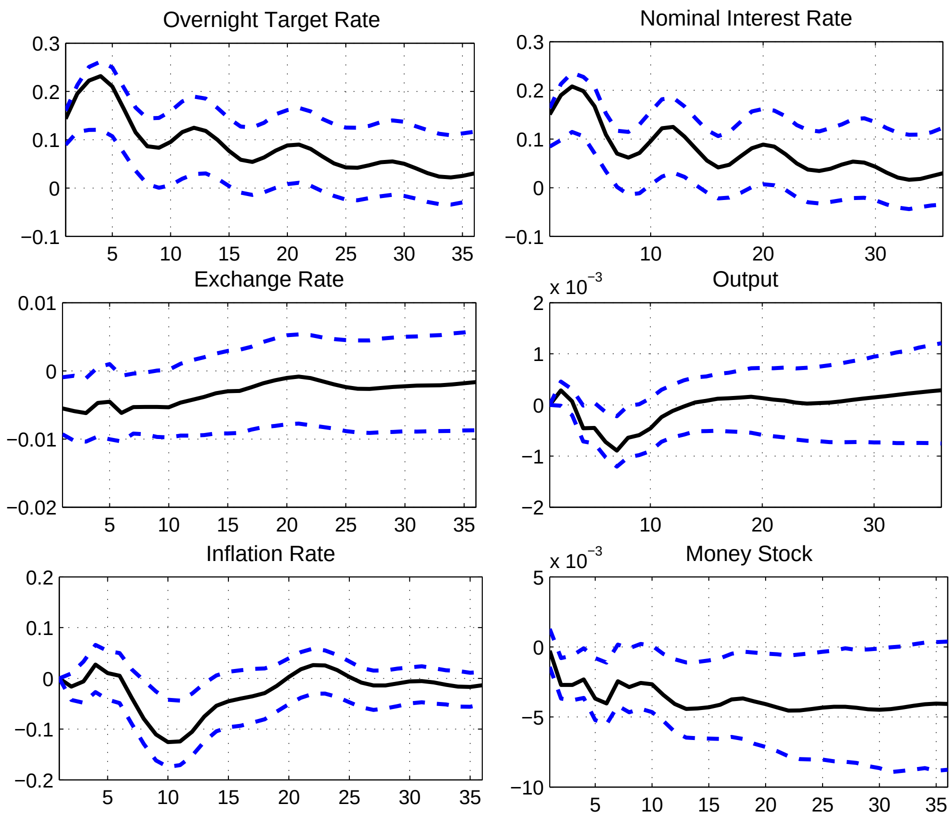
I check the robustness of the results by estimating the model using some other alternative identifications. I find that the recursive approach with various orderings of the variables generates some puzzles similar to those found in previous studies. For example, a recursive identification that does not allow the overnight target rate to contemporaneously respond to the exchange rate causes a depreciation of the Canadian dollar after a contractionary policy shock. On the other hand, when I use the market interest rate instead of the overnight target rate as the policy instrument, I find less significant impulse responses of all variables and an insignificant impulse response of the exchange rate. If I impose zero restrictions on output and inflation of both home and foreign countries, the exchange-rate effect becomes almost insignificant. Finally, although the omission of the world export price index does not generate a price puzzle, it causes an insignificant effect of policy changes on the price level.

Since uncovered interest rate parity (UIP) is directly related to the interest rate and the exchange rate, I also investigate whether the monetary policy shock induces a systematic departure from this parity. To explore this issue, I follow Eichenbaum and Evans (1995) to define ψ as the *ex post* difference in the return between investing in one-period Canadian assets and one-period US assets, that is, $\psi_t = i_t - i_t^* - 4(s_{t+3} - s_t)$. For a direct comparison with interest rates, which are already in annual terms, I multiply the exchange rate change by twelve. If the UIP condition holds and expectations are rational, the conditional expectation of this excess return should be zero. From the estimated impulse responses of the interest rate and the exchange rate, I compute the impulse response of this excess return due to the monetary policy shock as shown in the lower right block of figure 3.1. Figure 3.1 shows that there is no systematic evidence of excess returns due to the contractionary monetary policy shock; the excess returns are highly noisy and mostly insignificant.

This finding that the gradual depreciation of the exchange rate offsets the excess return from home country assets differs from that of Eichenbaum and Evans (1995). These authors, identifying contractionary monetary policy shocks with innovations in non-borrowed reserves in a recursive VAR model, found that the higher return in home currency is further magnified by a persistent appreciation of the exchange rate for a prolonged period of time. This result similar to that of Cushman and Zha (1997), who also reported an insignificant impulse response of the UIP deviation due to the policy shock. This empirical confirmation of the conditional UIP condition found in this chapter as well as in Cushman and Zha's (1997) study reflects the importance of identifying the monetary policy function in a small-open-economy context for Canada.

Next I extend the basic model by incorporating the monetary aggregate, $M1$. In the extended model, I still keep the overnight target rate as the policy instrument but include an informal money demand function, where money holding is a contemporaneous function of the nominal market interest rate, the inflation rate, and output. I also let the nominal interest rate and the exchange rate be contemporaneously affected by money. No other variables either affect money or are affected by money contemporaneously. There are no restrictions in the lagged coefficients of the money demand function, and the rest of the identification scheme of this extended model is the same as in the basic model.

Figure 3.2: Impulse Responses in the Extended Model

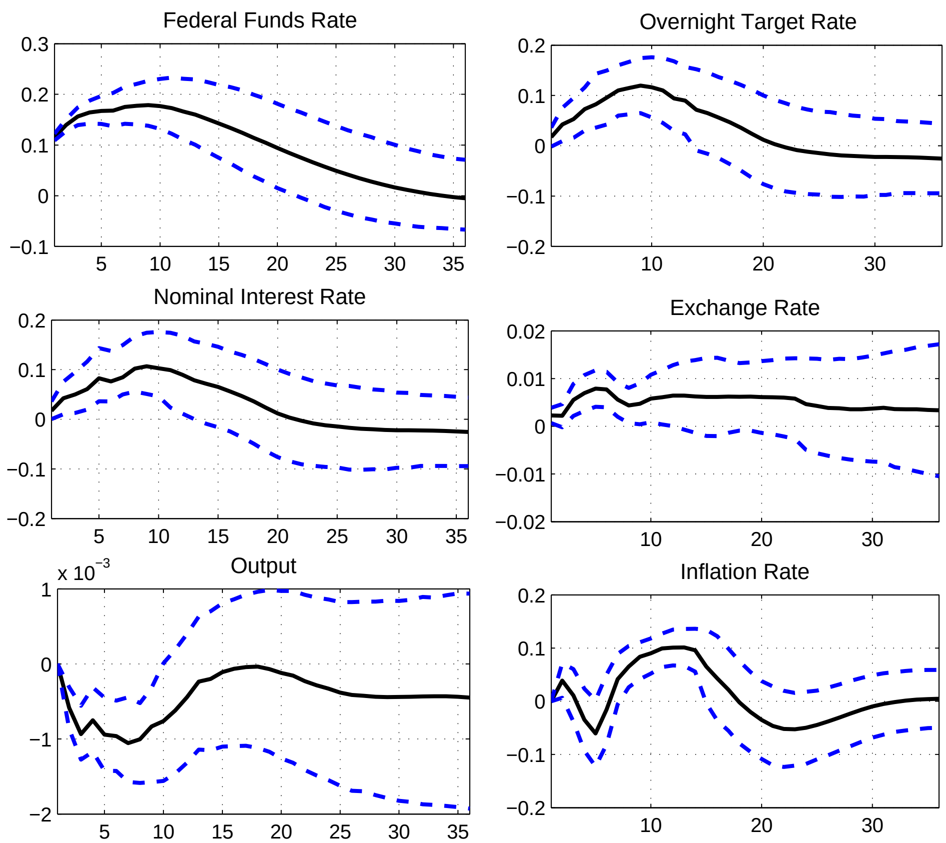


The impulse responses of the variables due to an overnight target rate shock in the extended model are reported in figure 3.2. The impulse responses in this figure are comparable with those in figure 3.1 since they are drawn on the same scale. We observe from the figure that there is no marginal contribution of the inclusion of money into the model: the pattern of dynamic responses of the variables due to the policy shock remains unchanged in the extended model, except that the responses of the exchange rate and output are little less significant. While the impulse responses of the other macroeconomic variables are robust to the incorporation of money into the model, the dynamic response of the money stock itself is not an exact mirror image of the dynamic response of the overnight target rate. Figure 3.2 shows that the contractionary monetary policy shock of increasing the overnight target rate peaks in the second month, followed by a gradual decline which becomes insignificant after about one year. In contrast, following the same shock, the money stock keeps declining, the highest impact of which is not realized until the end of the second year, and the effect remains statistically significant for about three years. This imprecise dynamic response of the money stock might be due to the fact that, in addition to the monetary policy decision, monetary aggregates are influenced by other factors in the economy, such as private-sector behavior. Therefore, this impulse response of $M1$ casts further doubt on the justification of using money as the policy instrument and rationalizes the use of the target rate as the policy instrument.

Since the Bank of Canada adopted an inflation-targeting monetary policy starting from February 1991, a natural question might be whether the estimated results are robust for this new policy regime. When I estimate VAR model for the inflation-targeting policy regime, I find that the qualitative results remain unchanged. In particular, I find that a contractionary monetary policy shock increases the market interest rate, appreciates the Canadian dollar, and lowers output and the inflation rate. The estimated results are also consistent with Dornbusch's overshooting hypothesis.

Given the relative size of the US economy and the trade relationship between the US and Canada, we assume that shocks to the US variables might play an important role in the movement of the Canadian variables. Therefore, I also investigate the

Figure 3.3: Impulse Responses Due to FFR Shock



dynamic responses of the Canadian macroeconomic variables due to shocks to the US federal funds rate. The impulse responses are presented in figure 3.3. We observe from the figure that the contractionary policy shock of increasing the federal funds rate is accompanied by an increase in the overnight target rate and the market interest rate. This result is consistent from the view point that the Bank of Canada would want to increase the interest rate to avoid the inflationary effect of its currency depreciation caused by the rise in the federal funds rate. Figure 3.3 also shows that the contractionary US monetary policy shock causes a short-lived depreciation of the Canadian dollar, increases the inflation rate, and lowers the Canadian GDP. The increase in the inflation rate is a consequence of the stimulated aggregate demand caused by the depreciation of the Canadian dollar. On the other hand, two opposite directional forces originating from the increase in the federal funds rate influence Canadian output. First, the depreciation of the Canadian dollar raises the aggregate demand for Canadian goods and hence Canadian output increases. Second, the increase in the Canadian interest rate following the increase in the federal funds rate dampens aggregate demand and reduces output. Since the Bank of Canada strongly reacts to the Federal Reserve System by adjusting its interest rate, the second effect dominates the first effect. Therefore, the exchange rate does not depreciate much and the level of output decreases.

Table 3.2: Forecast error variance decomposition of ouput

Months	Overnight Target Rate	Market Interest Rate	Exchange Rate	Output	Inflation	Foreign Variables
1	5.75	0	2.48	90.41	1.33	0
6	11.32	5.13	13.54	37.01	1.99	31.97
12	6.03	3.90	16.81	27.89	1.68	44.16
24	3.57	3.92	15.12	20.81	2.20	54.47
48	3.20	6.72	12.59	16.92	4.11	59.47

Note: Entries are in percentage points. Foreign variables include the federal funds rate, the US GDP, the US inflation rate, and the world export price index.

Finally, I report the sources of Canadian output fluctuations. Table 3.2 presents the variance decomposition of the Canadian GDP due to shocks to the home and foreign macroeconomic variables over different horizons. We see from the table that the monetary policy shock is not the dominant source of output fluctuations in Canada at any horizon. Among domestic shocks, those from the exchange rate and from domestic

GDP itself are the primary sources of output fluctuations. On the other hand, external shocks, which are shocks from the foreign block of variables, become the dominant source of output fluctuations after twelve months. These results are similar to the findings of Cushman and Zha (1997) and Kim and Roubini (2000) for Canada and Del Negro and Obiols-Homs (2001) for Mexico.

3.6 Conclusion

This chapter develops an open-economy Bayesian structural VAR model for Canada in order to estimate the effects of a monetary policy shock, using the overnight target rate as the policy instrument. The structural model developed here allows the financial variables of the model to interact contemporaneously with each other and with a number of other home and foreign variables. Since the identification involves simultaneous interactions in the contemporaneous relationships of the financial variables in the model, in order to increase the precision of the parameter estimates, I use a Bayesian Gibbs sampling method to estimate the model. This chapter finds that the liquidity effect and the exchange-rate effect of the policy shock are realized immediately, while output responds with a lag of over half a year, and the inflation rate responds with a lag of about one year.

The results of this thesis chapter differ from those of other studies in the literature in a number of important respects. While Cushman and Zha (1997) found that the transmission of the monetary policy shock to real output operates through the exchange rate channel only, I find that this transmission operates through both the interest rate and the exchange rate. I also find that, due to the contractionary policy shock, the exchange rate depreciates gradually after an impact appreciation, which offsets the higher return in home currency. This result differs from that of Eichenbaum and Evans (1995), who, in a recursive VAR model, found that the higher return in home currency is further magnified by a persistent appreciation of home currency for a prolonged period of time after the policy shock was introduced. On the other hand, in the extended model, the impulse response of $M1$ confirms that shocks to monetary aggregates reflect some other shocks in the economy, and hence, cannot be a good measure of exogenous monetary policy shocks. Finally, I find that the Canadian macroeconomic variables including the overnight target rate significantly respond to the federal funds rate, and external shocks are an important source of Canadian output fluctuations.

While the use of inflation expectations in chapter two and the use of a proxy for the inflation forecast in chapter three are important steps towards correctly identifying the monetary policy reaction function, the omission of other macroeconomic forecasts might also lead to an incorrect policy identification. For example, since the monetary policy shock affects real macroeconomic variables through the channels of the market interest rate and the exchange rate, a central bank might also observe the forecasts of these variables to conduct monetary policy. The next chapter of the thesis develops a forecast-augmented structural VAR model by using a number of forecasted macroeconomic variables, in addition to realized macroeconomic variables. The inclusion of the forecasted variables also gives me the opportunity to examine whether monetary policy reacts to or affects the forecasted and realized macroeconomic variables differently.

Chapter 4

Identifying a Forward-looking Monetary Policy in an Open Economy

4.1 Introduction

Econometricians can identify monetary policy shocks in a VAR model by conditioning the policy reaction function on a set of macroeconomic variables. However, to the extent that central banks and the private sector have information not reflected in the VAR, the measurement of an econometrician's policy innovations will be contaminated. Since monetary policy in practice is driven largely by anticipated future outcomes (especially for the central banks that target inflation), a standard VAR model, which uses *ex post* realized data of macroeconomic variables, identifies a policy function that is different from that of central banks. As a consequence, these standard models may estimate erroneous policy shocks and hence generate misleading impulse responses.

To overcome this problem, I next formulate a forward-looking monetary policy function in a structural VAR model by using forecasts of a number of key macroeconomic variables, in addition to the realized variables used in a standard VAR. Since forecast-augmented VARs models uses both forecasted and realized variables, and the standard model uses only realized variables, the latter model is nested in the former model. The forecast-augmented VAR model, apart from identifying a forward-looking policy function, provides a number of other advantages over a standard VAR model. First, since the macroeconomic forecasts I employ to identify monetary policy in the forecast-augmented model are based on many other variables that central banks and the private sector might observe, the identified policy function spans a bigger information set, without estimating a large model. Second, the estimated impulse response function of the monetary policy variable gives us an opportunity to examine how central banks, especially inflation-targeting central banks, react to shocks to inflation expectations or other forecasts that embody information about future inflation. Third, by contrasting the impulse response of the policy variable due to shocks in forecasted and realized variables, we can examine to which variables the central bank responds more significantly in designing monetary policy. Similarly, by observing the variance decomposition, we can examine the proportions of the movements in the policy variable explained by forecasted variables relative to realized variables. Fourth, by comparing impulse responses of forecasted and realized variables due to shocks to the policy variable, we can observe whether monetary policy affects these two types of variables differently. Finally, since the forecast-augmented model encompasses the standard model, by estimating both models, we can understand the contributions of identifying the forward-looking monetary policy using forecasted variables.

I apply this forecast-augmented VAR model to the Bank of England, which was one of the first central banks to target inflation. The macroeconomic forecasts I employ as inputs to the policy reaction function of the Bank are the forecasts of the inflation rate, the market interest rate, the exchange rate, and the US federal funds rate. I obtain inflation forecasts from the Bank of England's statistics department, which uses prices of inflation-indexed bonds to calculate market participants' expectations about the future inflation rate. I obtain interest rate forecasts and exchange rate forecasts from the FX4casts, a commercial firm that collects these forecasts from different professional forecasters. Finally, I calculate federal funds rate forecasts by observing market prices of federal funds futures from Bloomberg.

Since the UK is an open economy, I assume that the Bank of England also responds to a vector of foreign variables including the US and German monetary policy variables. As in chapter three, I develop the structural VAR model following the general procedure of Cushman and Zha (1997) but change it in a number of respects. First, unlike these authors, I do not use money in my model and therefore do not define a money demand function or a money supply function. Instead, I use the bank rate as the policy instrument, which is what the Bank uses to conduct monetary policy. I argue that unlike money and market interest rates, which were used as policy instruments in most previous VAR studies, the bank rate cannot be influenced by private-sector behaviour, except through the endogenous policy response of the Bank. Therefore, estimated policy innovations using the bank rate are more precise measures of exogenous monetary policy shocks. Second, in order to make the identification more realistic, I allow more contemporaneous interaction among the variables used in the model. Third, since the over-identified forecast-augmented VAR model developed in this chapter entails simultaneous interactions, in order to obtain accurate statistical inference, I employ the Bayesian Gibbs sampling estimation method of Waggoner and Zha (2003), who incorporated prior information into the VAR as suggested by Sims and Zha (1998). Therefore, the estimation techinque of this chapter is the same as that of chapter three.

Two specific results of the forecast-augmented model suggest that forecasted variables play a greater role than realized variables in identifying the monetary policy function and that the Bank of England conducts a forward-looking monetary policy. First, the impulse response of the bank rate suggest that monetary policy responds to shocks to inflation expectations and other macroeconomic forecasts more significantly than shocks to corresponding realized variables. Second, the variance decomposition also shows that shocks to inflationary expectations and other forecasts explain a higher proportion of the movements of the policy variable than do shocks to realized variables. These findings are consistent with the Bank's inflation-targeting monetary policy, that is, designing current policy based on the projections of the future economy in order to achieve the target inflation rate.

I also find that a contractionary policy shock of raising the bank rate almost instantaneously increases the market interest rate as well as the forecast of the market interest rate. This policy shock also appreciates both the British pound and the forecast of the pound on impact. Although the policy shock has a similar effect on the financial variables and their forecasts, the same is not true for the actual inflation rate and the forecast of the inflation rate. While the contractionary policy shock lowers the expected inflation rate almost immediately, the shock does not have a significant effect on the actual inflation rate until the beginning of the second year. The quicker response of inflation expectations reflects the credibility of the Bank of England's monetary policy: the public trusts the Bank's action will bring today's higher inflation down to the target level in the future, so they expect a lower inflation rate in the future. I also find that the contractionary policy shock lowers the level of output with a lag of about one year.

When I estimate the standard model nested in the forecast-augmented model I find that, while the pattern of the impulse responses of the market interest rate and output remains unchanged from that of the forecast-augmented model, there is a remarkable change in the impulse responses of the realized inflation rate and the exchange rate. Due to a contractionary monetary policy shock in the standard model, the realized inflation rate increases and remains significant for about one year. This response is at odds with what we expect from a contractionary policy shock. On the other hand, following the same shock, the British pound keeps appreciating for about six months after the shock. This response is inconsistent with Dornbusch's (1976) prediction that following a contractionary policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment to the initial value.

To examine which aspect of the forecast-augmented model absent from the standard model causes these puzzling responses, I put the forecasted variables into the standard model one after another. I find that the incorporation of the inflation forecast into the standard VAR reverses the puzzling response of the inflation rate, and the inclusion of both the market interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate. These findings confirm the importance of identifying a forward-looking monetary policy reaction function using forecasts of macroeconomic variables as inputs.

The remainder of the chapter is organized as follows: section 4.2 presents the context of the research, section 4.3 provides the data sources, section 4.4 describes the structural VAR models, section 4.5 presents the results, and section 4.6 draws conclusions.

4.2 Research Context

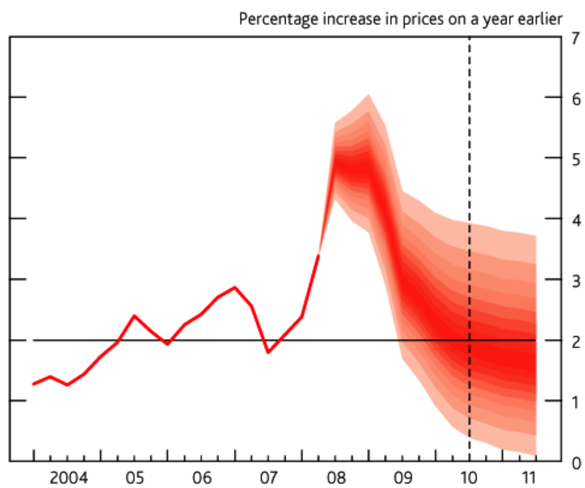
Svensson (1997, 2000) argues that current variables are relevant to the monetary authority only to the extent that they help to forecast an economy's expected future evolution. Empirically estimated single-equation monetary policy functions, such as those of Clarida, Galí, and Gertler (2000) and Orphanides (2001), suggest that policy reaction functions based on realized revised data yield misleading descriptions of historical monetary policy, and forward-looking specifications describe monetary policy better than Taylor-type specifications. Monetary policy simulations using econometric models imply that central banks implement a forward-looking policy rule with a forecast horizon of about two years in the future (see, for example, Coletti, Hunt, Rose, and

Tetlow (1996) for the Bank of Canada and Black, Cassino, Drew, Hansen, Hunt, Rose, and Scott (1997) for the Reserve Bank of New Zealand).

The practice of conducting forward-looking monetary policy has become further explicit since the early 1990s when many industrialized nations, such as the UK, New Zealand, Sweden, Canada, and Australia, officially adopted an inflation-targeting monetary policy. The operating procedure of the inflation-targeting approach is known as inflation-forecast targeting. As explained by Woodford (2007), under this approach, the central bank constructs quantitative projections of the economy's expected future evolution to design its current monetary policy. While some nations practice an explicit target for future inflation to conduct monetary policy, most others, including the US, also make forecast-based decisions without such an explicit target for inflation. In 2004 when he was a member of the Board of Governors, Ben Bernanke, the current chairman of the US Federal Reserve, said that the Fed primarily relies on the forecast-based approach for making policy.

The inflation-targeting approach involves a high degree of transparency and accountability on the part of central banks to the public. For example, the Bank of England publishes a quarterly *Inflation Report* that contains a chart, as shown in figure 4.1, in order to give an overview of the justification of the Bank's current monetary policy stance to the public. This fan chart, as of August 2008, indicates the probability distribution of possible evolutions of future inflation over the next three years, with the modal projection indicated by the most deeply shaded region. These projections are made based on the Bank's forecasts about the market interest rate and the exchange rate. If, for whatever reason, the inflation rate deviates more than one percentage point from the target rate of two percent, the Governor of the Bank of England is required to write an open letter explaining the reasons for divergence and the steps the Bank will undertake to bring the inflation rate back to two percent. Due to such a high degree of accountability and transparency, market participants are also aware of the projections of the future economy and can guess the probable policy actions of the monetary authority.

Figure 4.1: August 2008 Inflation Forecasts of the Bank of England



Note: This fan chart is taken from the Bank of England's Quarterly Inflation Report published in August 2008.

Since the central bank emphasizes the projections of the economy's future evolution, an econometrician also needs to identify a forward-looking monetary policy function. The importance of identifying the policy function by incorporating correct information can be illustrated by Sims's (1992) explanation of the so-called price puzzle.

Sims argues that if a central bank systematically tightens monetary policy anticipating future inflation, but an econometrician does not capture these inflationary signals, then the estimated policy shock in the VAR may in fact be the monetary authority's response to inflationary expectations. This explains the empirical finding of the increase in the price level following a contractionary policy shock, since the policy response is likely to partially offset the inflationary pressure. If this explanation for the price puzzle is correct, then all estimated impulse responses in traditional VAR models are incorrect. In reality, however, in addition to inflation expectations, forecasts of other macroeconomic variables, such as output, interest rates, and exchange rates, are also crucial considerations in central banks' policy decisions. Therefore, a VAR model that does not include these forecasts in the estimation process might also generate misleading results.

Some previous studies have also attempted to identify monetary policy functions by including future information into the VAR model. Sims and Zha (1995) suggested using a proxy variable that might contain information about the future inflation of the economy. Khan, Kandel, and Sarig (2002) and chapter two used measures of inflationary expectations as inputs to the monetary policy rule in a three-variable recursive VAR model. In a different approach to the same problem, Tharpar (2008) constructed forecast errors by replacing VAR-based forecasts with Greenbook forecasts. She then identified exogenous monetary policy shocks from the constructed forecast errors, assuming these Greenbook forecasts are more informative than VAR-based forecasts.

While the use of inflation expectations, or any proxies for inflation expectations, in these studies is a step towards identifying monetary policy correctly, the omission of other macroeconomic forecasts might also lead to erroneous policy innovations. Furthermore, the recursive approach used in these studies cannot incorporate the contemporaneous interrelationships among the variables used in the model. These recursive studies either assume that the market interest rate and the exchange rate do not react to the policy variable or that the policy variable does not respond to these macroeconomic variables within the month. In reality, however, the policy variable, the market interest rate, and the exchange rate interact with each other almost instantaneously. These studies also assume that non-US central banks do not respond to the Fed policy move until a month later, which is particularly inappropriate for an open economy like the UK. Another limitation of most previous VAR studies is that the smaller number of variables used in the model is unlikely to span the information used by central banks and the private sector.

Given the preceding literature, I make a number of contributions in this chapter. First, I employ more forecasted variables as inputs to the monetary policy function. I assume that, in addition to inflation forecasts, central banks might observe other macroeconomic forecasts to make policy decisions. Therefore, the omission of these variables will also misidentify the policy reaction function. Second, since the macroeconomic forecasts used in this chapter embody indirect information about many other domestic and foreign variables, the identified monetary policy function using these forecasts spans a bigger information set. Therefore, the proposed forecast-augmented VAR model is an alternative to Bernanke, Boivin, and Eliasz's (2005) factor-augmented VAR model that exploits indices of a dynamic factor model in order to condition the monetary policy function on a bigger information set. Third, since the forecast-augmented VAR model uses both forecasted and realized variables, I can examine which type of variable plays a greater role in monetary policy decisions. The forecast-augmented model also allows me to investigate whether the central bank reacts to and affects the forecasted and the realized variables differently. Fourth, since the forecast-augmented VAR model encompasses the standard VAR model, by estimating both models, we can understand the contributions of identifying the forward-looking monetary policy using forecasted variables. Finally, in order to make the identification more realistic, I develop my structural VAR models in an open-economy context, allowing more simultaneous interactions among the contemporaneous relationship of the variables. And, in order to obtain accurate statistical inference from these over-identified structural VAR models with simultaneous interactions, I employ a Bayesian Gibbs sampling method to estimate the posterior distribution of the parameters.

4.3 Monthly Data for the UK

In this section, I describe the forecasted and realized macroeconomic variables and their sources. The data run monthly from October 1988 to June 2008. For ease of understanding, I categorize the variables used in this chapter into four broad types:

the policy variable, the forecasted variables, the domestic realized variables, and the foreign realized variables. The policy variable is the bank rate, i_m, of the Bank of England. The block of forecasted variables, x^f, includes inflation rate forecasts, π^f; market interest rate forecasts (the three-month libor rate), i^f; exchange rate forecasts, s^f; and US federal funds rate forecasts, i_u^{*f}. Although the series of gross domestic product (GDP) forecasts is a good candidate to be included in the block of the forecasted variables, the monthly GDP forecast with a constant horizon is unavailable. Therefore, I do not include the GDP forecast in this block. The vector of the domestic realized variables, x^r, includes the inflation rate, π; gross domestic product (GDP), y; the market interest rate (the three-month libor rate), i; and the exchange rate, s, while the block of foreign variables, x^*, are the US federal funds rate, i_u^*; the US inflation rate, π_u^*; US industrial production, y_u^*; the German interest rate, i_g^*; German inflation rate, π_g^*; and the German industrial production, y_g^*.

I obtain the bank rate from the Bank of England's website (http://www.bankofe ngland.co.uk/monetarypolicy/decisions.htm). The inflation forecast, more precisely known as the break-even inflation rate, is a market-based measure of the expected inflation rate. I obtained this two-year horizon expected inflation rate series from the statistics department of the Bank of England.[1] The Bank calculates inflation expectations on a daily basis by observing market prices of indexed bonds and returns from nominal government bonds, following both the spline-based method (put forward by

[1] I thank Iryna Kaminska of the Bank of England for providing me with the data.

Waggoner (1997)) and the parametric method (put forward by Svensson (1994)).

Until recently, the Bank of England was calculating inflation expectations employing Svensson's (1994) parametric method subject to some modifications proposed by Deacon and Derry (1994) due to the eight-month lag in indexation of the coupon payments. To implement this method, the Bank first estimated the nominal term structure in the usual way to obtain an implied nominal forward rate curve. The Bank then fitted a real forward curve to prices of index-linked bonds using an initial assumption of market inflation expectations. Finally, the Bank applied the Fisher identity to each pair of points along the nominal and real forward rate curves in order to estimate a new measure of the inflation term structure. In the second round, the Bank used the estimated inflation term structure to re-estimate the real forward curve and compared this curve with the nominal interest rate curve to derive a revised estimate of the inflation term structure. This iterative procedure continued until the inflation term structure converged to a single curve. To derive these inflation term structures, the Bank assumed that there is no inflation risk premium so that the nominal forward rate equals the sum of the real rate and the expected inflation rate.

Recently, the Bank of England has been calculating inflation expectations following Waggoner's (1997) spline-based method subject to some modifications proposed by Anderson and Sleath (2001). The spline-based method also uses nominal and index-linked bonds to derive nominal and real yield curves, and then employs the Fisher relationship to estimate inflation expectations. The basic idea of the spline-based method is that rather than specifying a single functional form to fit forward rates as does Svensson (1994), it fits a curve to the data that is composed of many segments, with constraints imposed to ensure that the overall curve is continuous and smooth.[2]

These measures of inflation expectations are regularly presented to the Bank's Monetary Policy Committee (MPC) to inform the current assessment of future economic conditions. In order to increase the precision of the policy identification in my model, I collect the dates of the MPC meetings from the Bank's website (http://www.bankofengland.co.uk/monetarypolicy/ decisions.htm) and use the inflation expectation rate calculated immediately before the meeting day. The daily-basis calculation of inflation expectations allows me to use the latest inflation expectations as input to the policy function. In my sample, I use the parametric method's inflation expectations from 1988 until 2004, when the Bank stopped producing this series. For the rest of the sample I use spline-based inflation expectations, since the Bank has been employing these inflationary expectations in recent years. Unfortunately, due to the unavailability of indexed bonds of maturity less than two years, I cannot use inflation expectations of any shorter horizon. However, as an input to monetary policy, the expected inflation rate at a two-year horizon is more suitable than that of most other horizons since a rough benchmark is that monetary policy shocks affect inflation with a lag of about two years.

I obtain survey-based forecasts of the three-month horizon market interest rate and the three-month horizon exchange rate from a private firm, FX4casts. Each month

[2] For a detailed explanation of the spline-based method, see Anderson and Sleath (2001) and for the parametric method, see Deacon and Derry (1994).

FX4casts asks 45 different professional forecasters to provide their forecasts of exchange rates and 18 different professional forecasters to provide their forecasts of market interest rates for the end of the three-month horizon. FX4casts then calculates the geometric mean of these forecasts, which are commercially available for business entities and researchers. The other forecasted variable I use is public expectations about the future US federal funds rate, which I derive from 30-day federal funds futures traded at the Chicago Board of Trade. I collect these prices from Bloomberg. Then, assuming risk neutrality, I estimate a measure of federal funds rate expectations at a one-month horizon by deducting prices of these futures from 100. Table 1 summarizes the forecasted macroeconomic variables used in this chapter.

Table 4.1: Data Sources and Definitions of the Forecasted Variables

Variable	Definition	Forecast Horizon	Source
π^f	Expected Inflation Rate	2 Years	Bank of England
i^f	Interest Rate Forecast	3 Months	FX4casts
s^f	Exchange Rate Forecast	3 Months	FX4casts
i^{*f}	US Federal Funds Rate Forecast	1 Month	Bloomberg

As we see in Table 4.1, forecast horizons are different for different forecasted variables. For the inflation rate, selecting a shorter forecast horizon was not possible due to the unavailability of a sufficient number of indexed bonds required to calculate the expected inflation rate. However, a two-year forecast horizon for the inflation rate makes more sense than other horizons, because monetary policy affects inflation with a lag of about two years. In contrast, monetary policy interacts with the market interest rate and the exchange rate in a shorter period of time. Therefore, shorter forecast horizons would be more appropriate for these varibles. On the other hand, the only available maturity for the US federal funds futures, which I used to calculate the federal funds rate forecast, is one month. Therefore, the federal funds rate forecast at longer forecast horizons is also not available.

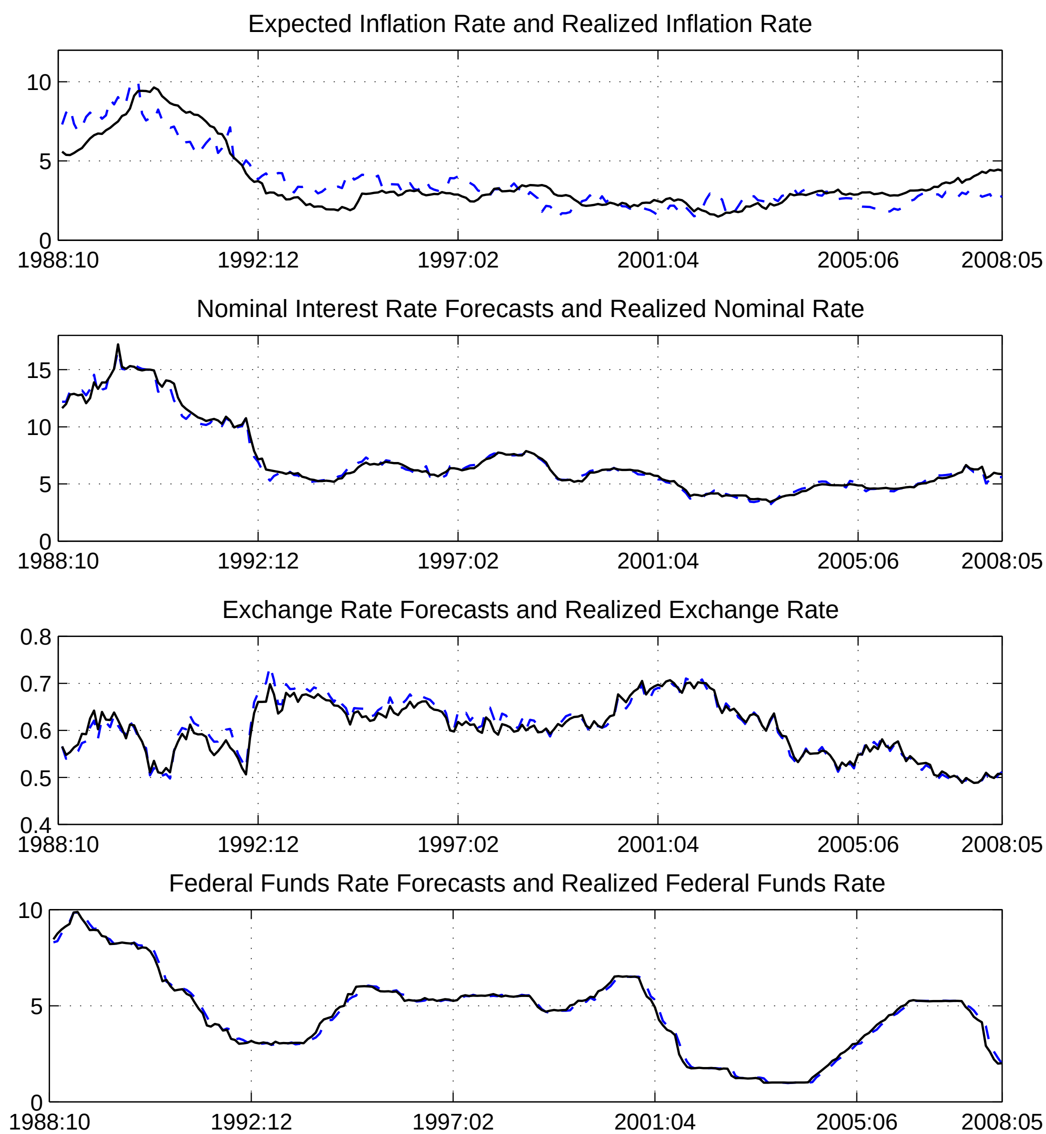
Another relevant question concerns the use of market-based forecasts for some variables and professional forecasts for some others. I do not use survey-based forecasts for the inflation rate because of the unavailability of this forecast at a fixed horizon for the UK. On the other hand, utilizing covered interest rate parity, I could obtain the forward exchange rate, which can potentially be treated as the market-based forecast of the spot exchange rate. However, since the forward rate is implied by the exchange rate and the home and foreign market interest rates, which are already included in the VAR model, it is unnecessary to use this variable. Also, since the uncovered interest rate parity condition does not hold, this market-based forecast of the exchange rate probably would not be an accurate measure of the expected future exchange rate. Similarly, employing the expectations hypothesis, one can calculate a market-based measure of the nominal market interest rate forecast. However, when I replace the professional forecast of the market interest rate with this market-based forecast, the estimated results remain unchanged.

I collect the monthly UK GDP from the National Institute of Economic and Social Research (NIESR).[3] I obtain all other variables from the *International Financial Statistics* of the International Monetary Fund. The labels of these variables are as follows: i, the UK market interest rate (IFS, 11260C..ZF..); π, the annualized monthly inflation rate calculated from the UK retail price index (RPI) (IFS, 11264..ZF..); s, the logarithm of the nominal exchange rate in units of British pounds per US dollar (IFS, 112..AC..ZF); i_u^*, the US federal funds rate (IFS, 11164B..ZF..); y_u^*, the logarithm of US industrial production (IFS, 11166..CZF..); π_u^*, the annualized monthly US inflation rate calculated from the US consumer price index (IFS, 11164..ZF..); i_g^*, the Bundesbank rate (IFS, 13460B..ZF..); y_g^*, the logarithm of German industrial production (IFS, 13466...ZF..); and π_g^*, the annualized monthly German inflation rate calculated from the German consumer price index (IFS, 13464...ZF..).

Next, I plot the forecasted variables against the corresponding realized variables in figure 4.2. The solid lines refer to the realized variables and the dashed lines refer to the forecasted variables. The series plotted in this figure are used in the estimation process of the forecast-augmented model. At each point of time, figure 4.2 compares the realized value of a variable with the value forecasted *at* that time *for* the future. Therefore, the vertical distances between the solid and dashed lines in every panel of the figure measure the difference in information between the forecasted and realized

[3] I thank James Mitchell of the NIESR for providing me with the GDP data. See Mitchell, Smith, Weale, Wright, and Salazar (2005) for a detailed explanation of how the monthly GDP series is calculated.

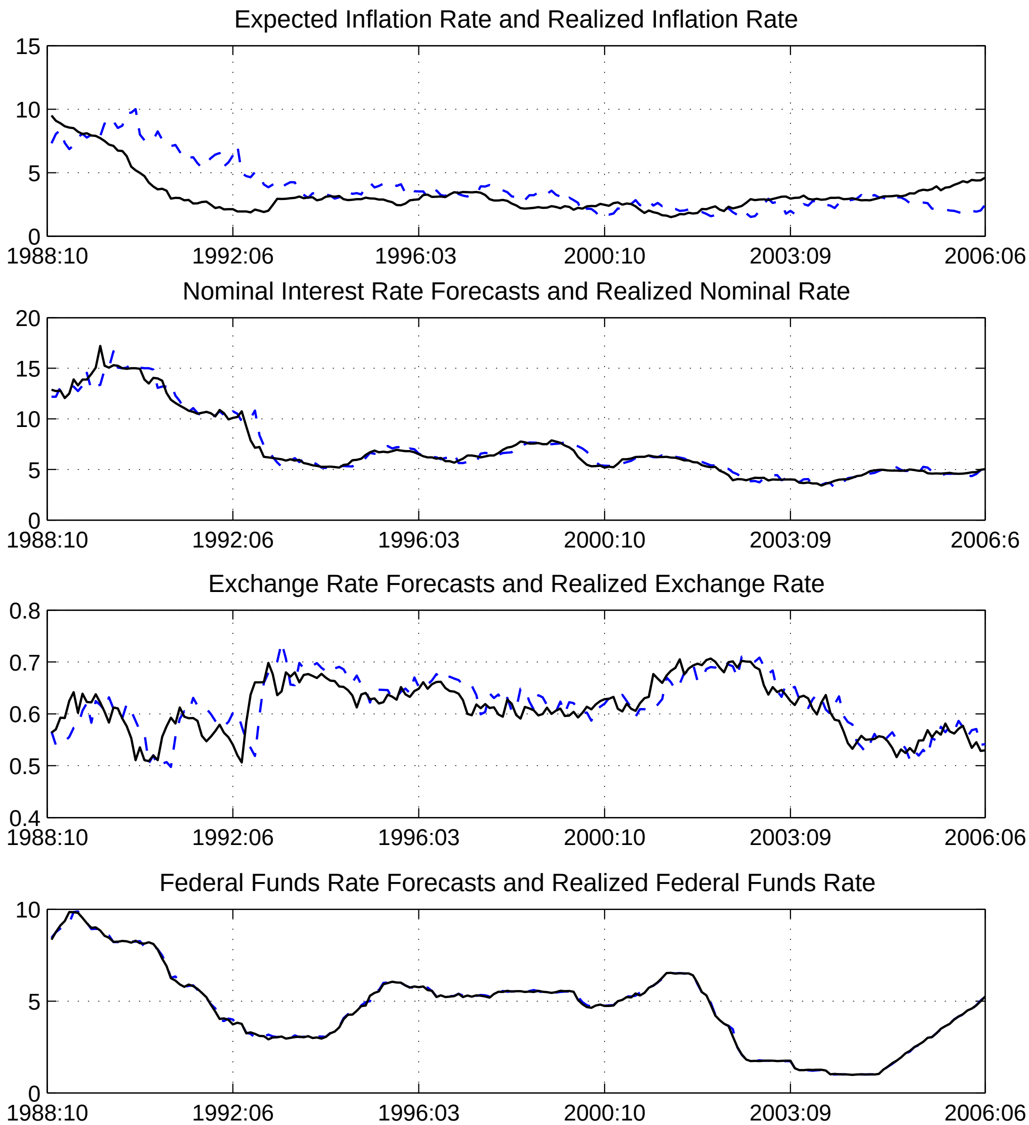
Figure 4.2: Forecasted and Realized Variables: Information Difference



Note: At each point of time, the figure compares the realized value of a variable (solid line) with the value forecasted at that time for the future (dashed line). The vertical distances between the solid and dashed lines in every panel measure the difference in information in the policy reaction function identified in the forecast-augmented VAR model compared to that in a standard VAR model.

variables. Hence, these vertical distances also measure the difference in information in the policy reaction function identified in the forecast-augmented VAR model compared to that in a standard VAR model.

Figure 4.3: Forecasted and Realized Variables: A Comparison



Note: At each point of time, the figure plots the realized values of a variable (solid line) against the values forecasted for that variable (dashed line) in the past. The vertical distances between the solid and dashed lines measure forecast errors of the variables.

On the other hand, figure 4.3, at each point of time, plots the realized values of a variable against the values forecasted *for* that variable in the past. Therefore, the vertical distances between the solid and dashed lines measure forecast errors of the variables. Figure 4.3 shows that the forecasts of the financial variables (the market interest rate, the exchange rate, and the federal funds rate) track the corresponding realized variables more closely than does inflation expectations track realized inflation. This difference in tracking might be due to the shorter forecast horizon of the financial variables than the inflation rate. Figure 4.3 also shows that expected inflation over-predicted actual inflation during the early 1990s, but under-predicted inflation in recent years. The over-prediction during the early 1990s might reflect the public's mistrust of the Bank's commitment to a low inflation rate due to the history of high inflation. On the other hand, the under-prediction in recent years might reflect the credibility of the central bank: the public trust that the Bank will take action to bring today's higher inflation back to the target level, so the public expects a lower inflation rate for the future.

4.4 Identification of the Forward-Looking Monetary Policy in a Structural VAR Model

Recall from chapter three that omitting constant terms, a typical structural VAR system can be written in the following linear and stochastic dynamic form:

$$Ax_t = \sum_{l=1}^{p} B_l x_{t-l} + \varepsilon_t, \tag{4.1}$$

where x_t is an $n \times 1$ column vector of endogenous variables at time t, A and B_l are $n \times n$ parameter matrices, ε_t is an $n \times 1$ column vector of structural disturbances, p

is the lag length, and $t = 1, ..., T$, where T is the sample size. The parameters of the individual equations in the structural VAR model (4.1) correspond to the rows of A and B_l. I assume that the structural disturbances have a Gaussian distribution with $E(\varepsilon_t \mid x_1, ..., x_{t-1}) = 0$ and $E(\varepsilon_t \varepsilon_t' \mid x_1, ..., x_{t-1}) = I$. As in chapter three, the structural system (4.1) can be re-written in the following matrix notation:

$$Ax_t = Bz_t + \varepsilon_t, \tag{4.2}$$

where $z_t = [x_{t-1}....x_{t-p}]'$ and $B = [B_1....B_p]$. Here z_t is the $np \times 1$ column vector of all lagged variables and B is the $n \times np$ matrix of all lagged coefficients.

Let us assume that the structural model (4.2) is the forecast-augmented VAR model that also encompasses the standard VAR model. Then, as mentioned in the previous section, the vector of endogenous variables x comprises four blocks of variables—the first block consists of the monetary policy instrument of the central bank, i_m, the second block includes the forecasted macroeconomic variables, x^f:$[\pi^f, i^f, s^f, i_u^{*f}]$, the third block comprises the realized macroeconomic variables, x^r:$[\pi, y, i, s]$, and the fourth block consists of the foreign variables, x^*:$[i_u^*, \pi_u^*, y_u^*, i_g^*, \pi_g^*, y_g^*]$. The variables in each block have been defined in the previous section.

I treat the US and Germany as the rest-of-the-world in relation to the UK. To explain the joint dynamics of these four blocks of variables, I rewrite the forecast-augmented structural VAR model (4.2) block-by-block in the following matrix notation:

$$\begin{pmatrix} A_{11}^m & A_{12}^f & A_{13} & A_{14}^* \\ A_{21}^m & A_{22}^f & A_{23} & A_{24}^* \\ A_{31}^m & A_{32}^f & A_{33} & A_{34}^* \\ 0 & 0 & 0 & A_{44}^* \end{pmatrix} \begin{pmatrix} i_m \\ x^f \\ x \\ x^* \end{pmatrix} = \begin{pmatrix} B_{11}^m & B_{12}^f & B_{13} & B_{14}^* \\ B_{21}^m & B_{22}^f & B_{23} & B_{24}^* \\ B_{31}^m & B_{32}^f & B_{33} & B_{34}^* \\ 0 & 0 & 0 & B_{44}^* \end{pmatrix} \begin{pmatrix} z_m \\ z^f \\ z \\ z^* \end{pmatrix} + \begin{pmatrix} \varepsilon_t^m \\ \varepsilon_t^f \\ \varepsilon_t \\ \varepsilon_t^* \end{pmatrix}. \tag{4.3}$$

In the structural model (4.3), the restriction that $A_{41}^m = A_{42}^f = A_{43} = 0$ follows from the assumption that the other blocks of variables do not enter into the foreign block contemporaneously, and the restriction that $B_{41}^m = B_{42}^f = B_{43} = 0$ follows from the assumption that they do not enter into the foreign block in lag. This block-exogeneity assumption makes sense due to the smaller size of the UK economy compared to the total size of the US and German economies. Zha (1999) demonstrated that failing to impose such exogeneity restrictions is not only unappealing but also results in misleading conclusions. When I test the joint block-exogeneity assumption of the US and Germany in relation to the UK, I find that the Chi-squared statistic $\chi^2(360) = 358.693$, implying that the null hypothesis is not rejected at a standard significance level. I also find similar results for the separate block-exogeneity test of the US and Germany.

It is easy to see from the forecast-augmented structural system (4.3) that, if we ignore the coefficients of the second row and the second column of the contemporaneous-coefficient matrix A and of the lagged-coefficient matrix B (that is, if $A_{21}^m = A_{22}^f = A_{23} = A_{24}^* = 0$, $A_{12}^f = A_{22}^f = A_{32}^f = 0$ and $B_{21}^m = B_{22}^f = B_{23} = B_{24}^* = 0$, $B_{12}^f = B_{22}^f = B_{32}^f = 0$), then the structural scheme boils down to a standard structural VAR model with block exogeneity, such as that of Cushman and Zha (1997) and chapter three. Therefore, the standard VAR model is nested in the forecast-augmented VAR model. For clarification, although the forecast-augmented model encompasses the standard model, these are two different models, and I estimate them separately. The structural system (4.3) also shows that the foreign block of variables is common to both models.

The next step is to impose identifying restrictions on the contemporaneous-coefficient matrix, A, of the structural model (4.2) in order to recover the structural shocks. The reduced-form version of the structural model (4.2) can be written as follows:

$$x_t = Ez_t + e_t, \tag{4.4}$$

where $E = A^{-1}F$ and $e_t = A^{-1}\varepsilon_t$. Let Σ be the variance-covariance matrix of the reduced-form residuals, e_t. Since the structural disturbances, ε_t, and the regression residuals, e_t, are related by $\varepsilon_t = Ae_t$, we can derive that:

$$\Sigma = (AA')^{-1}. \tag{4.5}$$

The right-hand side of equation (4.5) has $n \times (n + 1)$ free parameters to be estimated, while the estimated variance-covariance matrix of the residuals, Σ, contains $n \times (n+1)/2$ estimated parameters. Therefore, we need at least $n \times (n+1)/2$ restrictions on the contemporaneous-coefficient matrix, A, to identify the model. Since the number of variables in the forecast-augmented model is 15, we need a total of 120 restrictions on its contemporaneous-coefficient matrix to identify the model. On the other hand, the standard model has 11 variables, and we need 65 restrictions to identify the model.

I outline the identifying restrictions on the contemporaneous-coefficient matrix, A, of the forecast-augmented model, $Ax_t = Bz_t + \varepsilon_t$, in table 4.2. The restrictions on each row of this table identify the within-period relationship of a variable with the other variables in the model. I do not impose any restrictions on the lagged coefficients except the block-exogeneity restrictions on the foreign block of variables, as shown in the structural model (4.3). Table 4.2 also embodies the contemporaneous identifying restrictions of the standard model: if we ignore the shaded region of the table (rows and columns from 2 though 5), the table boils down to the contemporary identification scheme of the standard model.

The first row of table 4.2 shows the contemporaneous monetary policy equation of the forecast-augmented VAR model. In this model, I assume that the central bank contemporaneously reacts to the forecasted variables (the forecasts of the inflation rate, the exchange rate, the market interest rate, and the US federal funds rate), the realized financial variables (the market interest rate and the exchange rate), and the US and German monetary policy variables. The zero coefficients of outputs and the inflation rates for both the home and foreign countries reflect the fact that the Bank is unable to observe them within the month due to the lag in their publication.

If we ignore the coefficients corresponding to columns 2 through 5, the first row of table 4.2 presents the contemporaneous monetary policy identification of the standard model. Therefore, monetary policy in the standard model contemporaneously reacts to the realized values of the market interest rate and the exchange rate, as well as to the monetary policy variables of the US and Germany. Therefore, the within-period identification scheme of the monetary policy equation in the standard model is the same as that of Cushman and Zha (1997) and Bhuiyan (2008).

Table 4.2: Contemporaneous Identification of the Forecast-augmented VAR

	i_m	π^f	i^f	s^f	i_u^{*f}	i	s	y	π	i_u^*	π_u^*	y_u^*	i_g^*	π_g^*	y_g^*
i_m	a_1^1	a_1^2	a_1^3	a_1^4	a_1^5	a_1^6	a_1^7	0	0	a_1^{10}	0	0	a_1^{13}	0	0
π^f	a_2^1	a_2^2	a_2^3	a_2^4	0	a_2^6	a_2^7	0	0	0	0	0	0	0	0
i^f	a_3^1	a_3^2	a_3^3	a_3^4	0	a_3^6	a_3^7	0	0	a_3^{10}	0	0	a_3^{13}	0	0
s^f	a_4^1	a_4^2	a_4^3	a_4^4	0	a_4^6	a_4^7	0	0	a_4^{10}	0	0	a_4^{13}	0	0
i_u^{*f}	0	0	0	0	a_5^5	0	0	0	0	a_5^{10}	0	0	a_5^{13}	0	0
i	a_6^1	a_6^2	a_6^3	a_6^4	0	a_6^6	a_6^7	0	0	a_6^{10}	0	0	a_6^{13}	0	0
s	a_7^1	a_7^2	a_7^3	a_7^4	0	a_7^6	a_7^7	0	0	a_7^{10}	0	0	a_7^{13}	0	0
y	0	0	0	0	0	0	0	a_8^8	0	0	0	0	0	0	0
π	0	0	0	0	0	0	0	0	a_9^9	0	0	0	0	0	0
i_u^*	0	0	0	0	0	0	0	0	0	a_{10}^{10}	0	0	a_{10}^{13}	0	0
π_u^*	0	0	0	0	0	0	0	0	0	0	a_{11}^{11}	0	0	0	0
y_u^*	0	0	0	0	0	0	0	0	0	0	0	a_{12}^{12}	0	0	0
i_g^*	0	0	0	0	0	0	0	0	0	a_{13}^{10}	0	0	a_{13}^{13}	0	0
π_g^*	0	0	0	0	0	0	0	0	0	0	0	0	0	a_{14}^{14}	0
y_g^*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a_{15}^{15}

Note: The a_i^j, where $i, j = 1, 2, ..., n$, are elements of of the contemporaneous-coefficient matrix A of the forecast-augmented model, $Ax_t = Bz_t + \varepsilon_t$. If we disregard the shaded region (rows and columns from 2 though 5), the table becomes the contemporaneous identification scheme of the standard model. Row 1 is the contemporaneous monetary policy equation, rows from 2 though 5 show contemporaneous identifications of the forecasted variables, and rows from 6 through 9 show contemporaneous identifications of the realized variables. All the remaining rows are contemporaneous equations of the foreign variables. A zero entry means that the variable in the corresponding row cannot respond to the variable in the corresponding column within the month.

The second row of table 4.2 shows the contemporaneous identification of the expected inflation rate equation of the forecast-augmented model. I assume that current expectations about future inflation are affected by current monetary policy actions, the market interest rate forecast, the exchange rate forecast, and the realized values of the market interest rate and the exchange rate. As monetary policy in the UK is credible, market participants believe that the Bank will take action to bring today's higher or lower inflation back to the target level. Since monetary policy decisions affect inflation through the channels of the market interest rate and exchange rate, I assume that the forecasts of these variables as well as their realized values also influence inflation expectations within the month.

The third and the fourth rows, respectively, show the contemporary identification of the interest rate forecast equation and the exchange rate forecast equation of the forecast-augmented model. I assume that forecasts of both the market interest rate and the exchange rate affect each other within the month and are also affected by current monetary policy changes, inflation expectations, realized market interest rate, realized exchange rate, and foreign monetary policy decisions.

The seventh and the eighth rows of table 4.2, excluding the elements corresponding to columns 2 through 5, show the contemporaneous identification of the market interest rate equation and the exchange rate equation of the standard model. These variables in the standard model affect each other and are also affected by the monetary policy decisions of both the home and foreign countries. In the forecast-augmented model, in addition to these variables, the forecasts of the inflation rate, the market interest rate, and the exchange rate also affect the realized market interest rate and the realized exchange rate.

The eight and the ninth rows, respectively, are the contemporaneous identification of output and the inflation rate equations. I assume that output and the realized inflation rate in both the standard and the forecast-augmented models neither affect other variables nor are affected by other variables within the month.

Rows 10 through 15 show the contemporaneous identification scheme of the foreign block of equations. The identification of this block of variables is invariant across the forecast-augmented and the standard models. The domestic forecasted and realized variables do not affect the exogenous foreign variables. The contemporaneous-exogeneity assumption of the foreign variables is shown by the zero restrictions on the coefficients of all the domestic variables in the equations of the foreign variables. Since both the US and Germany are large countries, I assume that a monetary policy decision in one country affects the policy decision of another country within the month. On the other hand, output and the inflation rate of the US and Germany neither affect the other variables nor are affected by the other variables within the period due to the lag in publication of these variables.

4.5 Empirical Evidence of the Effects of Monetary Policy Shocks

First, I report the results of testing the over-identifying restrictions imposed on the contemporaneous and the lagged coefficients. Following Cushman and Zha (1997), I perform a joint test of the contemporaneous and the lagged identifying restrictions. In the forecast-augmented model, the contemporaneous-coefficient matrix, A, has 44 over-identifying restrictions, and with a lag-length of 6, the number of lagged restrictions on the foreign block is 360. Therefore, with a total of 404 restrictions, the estimated Chi-squared statistic $\chi^2(404) = 402.543$ implies that the null cannot be rejected at a standard significance level. Similarly, the estimated Chi-squared statistics for the standard models is $\chi^2(155) = 149.543$, implying that the null hypothesis is not rejected at a usual significance level for this model as well.

Next, I report the estimated results of the forecast-augmented model. The estimated contemporaneous coefficients of the forecast-augmented structural VAR model are reported in table 4.3. I do not present the estimated coefficients of the equations of the foreign variables, since I am interested only in the equations of the domestic variables. Lines 1 through 6 of table 4.3 are the estimated coefficients of the monetary policy equation, the expected inflation equation, the interest rate forecast equation, the exchange rate forecast equation, the realized market interest rate equation, and the realized exchange rate equation respectively. We observe from line 1 that all the contemporaneous coefficients of the forecasted variables in the monetary policy reaction function are statistically significant at less than the 0.05 level. Therefore, a policy function identified without using these forecasts will produce incorrect policy shocks, which in turn will generate misleading impulse responses. We also see that most of the simultaneously interacted coefficients are statistically significant at the 0.05 level. The significance of the simultaneously interacted coefficients indicates that both a recursive identification that cannot incorporate simultaneous interactions and a structural identification that does not include these simultaneous interactions will be erroneous.

In the monetary policy equation, the coefficient of the expected inflation rate is negative, and this sign will be positive if this variable is moved to the right-hand side of the monetary policy equation. This sign changing rule is true for all the coefficients reported in table 4.3. The negative and significant coefficient of the expected inflation rate implies that the Bank of England tightens monetary policy upon observing higher inflation expectations. Since the key objective of the Bank is to maintain a stable inflation rate at around 2 percent, contracting monetary policy after forecasting a higher inflation rate is consistent with the Bank's inflation-targeting policy. On the other hand, the positive and significant coefficient of the market interest rate forecast means that the central bank tightens monetary policy if it forecasts a lower interest rate. The negative and significant coefficient of the exchange rate forecast indicates that the Bank increases the bank rate upon forecasting any currency depreciation. Perhaps both the lower market interest rate (through a liquidity effect) and the depreciation of the pound sterling are indications of future inflation, so that tightening monetary policy under these circumstances is also consistent with the Bank's commitment to maintain a stable inflation rate. We also see that the coefficient of the federal funds rate forecast is negative and significant, implying that the central bank increases the bank rate after forecasting a higher federal funds rate.

Table 4.3: Estimated contemporaneous coefficients of the FVAR model

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	i_m	π^f	i^f	s^f	i_u^{*f}	i	s	i_u^*	i_g^*
	a_1^1	a_1^2	a_1^3	a_1^4	a_1^5	a_1^6	a_1^7	a_1^{10}	a_1^{13}
i_m	1.132	−0.842	0.774	−2.423	−0.247	0.695	0.814	−0.192	−0.156
	(0.423)	(0.212)	(0.357)	(1.114)	(0.110)	(0.304)	(0.408)	(0.095)	(0.092)
	a_2^1	a_2^2	a_2^3	a_2^4	a_2^5	a_2^6	a_2^7	a_2^{10}	a_2^{13}
π^f	0.649	3.441	4.876	−1.659	0	3.463	−0.873	0	0
	(0.296)	(1.032)	(3.098)	(0.873)	–	(1.569)	(0.276)	–	–
	a_3^1	a_3^2	a_3^3	a_3^4	a_3^5	a_3^6	a_3^7	a_3^{10}	a_3^{13}
i^f	−6.342	−2.345	1.124	−1.084	0	0.984	−1.267	−0.985	−0.739
	(2.456)	(1.843)	(0.436)	(0.486)	–	(0.398)	(0.574)	(0.627)	(0.583)
	a_4^1	a_4^2	a_4^3	a_4^4	a_4^5	a_4^6	a_4^7	a_4^{10}	a_4^{13}
s^f	4.854	−3.326	0.974	8.984	0	0.927	0.968	−1.349	−0.985
	(1.323)	(1.765)	(0.347)	(3.983)	–	(0.432)	(0.239)	(0.564)	(0.462)
	a_6^1	a_6^2	a_6^3	a_6^4	a_6^5	a_6^6	a_6^7	a_6^{10}	a_6^{13}
	−5.942	−2.648	1.723	−1.194	0	0.975	−1.387	−0.916	−0.790
i	(2.251)	(1.140)	(0.530)	(0.721)	–	(0.379)	(0.614)	(0.497)	(0.583)
	a_7^1	a_7^2	a_7^3	a_7^4	a_7^5	a_7^6	a_7^7	a_7^{10}	a_7^{13}
s	3.951	−3.129	0.871	7.973	0	0.729	0.968	−1.809	−0.916
	(1.873)	(1.485)	(0.447)	(3.793)	–	(0.372)	(0.239)	(0.394)	(0.619)

Note: Entries correspond to row 1 through row 4 and row 6 through 7 of the contemporaneous-coefficient matrix, A, identified in table 2, and apply to shocks to i_m, π^f, i^f, s^f, i, and s, respectively. Entries within brackets are standard errors. The sign of these coefficients will be the opposite if the corresponding variables are moved to the right-hand side of the equation.

We observe from row 1 of table 4.3 that the coefficients of the domestic realized variables and the foreign variables in the monetary policy function, except for the monetary policy variable of Germany, are also significant. The positive coefficient of the realized market interest rate implies that the Bank contracts monetary policy upon observing a lower market interest rate. Similarly, the negative coefficient of the exchange rate means that the Bank increases the bank rate after observing a depreciation of the pound sterling. These responses of the central bank are also consistent with its inflation-targeting policy. On the other hand, the negative coefficients of the foreign policy variables confirm the traditional belief that a small open-economy's central bank follows large countries' policy rules.

Column 1 of table 4.3 shows contemporaneous monetary policy effects on various macroeconomic variables. The positive and significant coefficient of the bank rate on the inflation forecast equation indicates that expectations about future inflation go down due to a rise in the bank rate. The negative and significant coefficient of the bank rate on the interest rate forecast equation shows that a contractionary monetary policy increases public forecasts about future market interest rates. Similarly, the positive and significant coefficient of the policy variable on the exchange rate forecast equation means that monetary tightening causes market participants to forecast an appreciation of the pound sterling. As we notice from column 1, the bank rate has similar contemporaneous effects on the realized market interest rate and the realized exchange rate as it has on their forecasts.

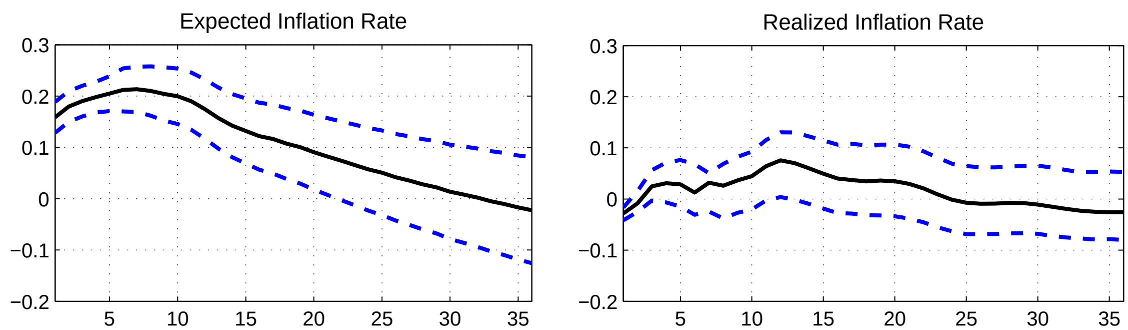
Most of the other contemporaneous coefficients of the forecast-augmented model are also statistically significant at the 0.05 level and have expected signs. However, the coefficient of the interest rate forecast on the inflation forecast equation, the coefficients of both the foreign policy variables on the interest rate forecast equation, the coefficient of the exchange rate forecast on the market interest rate equation, and the coefficient of the German policy variable on the exchange rate equation, are statistically insignificant. Although these coefficients are not significant at the 0.05 level, most of them are not far from significance either, and they all have expected signs.

Next, I discuss the impulse responses. First, I report the reaction of the central bank's policy variable due to shocks to the expected inflation rate and the realized inflation rate in figure 4.4. The left panel of the figure shows the impulse responses of the policy variable due to shocks to inflation expectations, while the right panel shows the response due to shocks to actual inflation. The panels are drawn on the same scale to allow comparison. The horizontal axis measures the response horizon in months. The solid lines are the estimated impulse responses, and the upper and lower dashed lines are one-standard-deviation error bands, derived using the Bayesian Gibbs sampling method of Waggoner and Zha (2003).[4]

Figure 4.4 shows that due to a one-standard deviation shock in inflation expectations, the bank rate increases by 20 basis points, and the effect remains significant for about two years. On the other hand, the increase in the bank rate due to the shock to the realized inflation rate is statistically insignificant as well as smaller in magnitude (about 8 basis points). These results—the significant policy response due to the expected inflation shock and the insignificant policy response due to the realized inflation

[4] The error bands are computed from a set of 10,000 draws. I gratefully acknowledge Tao Zha for helping me with the Matlab codes.

Figure 4.4: Policy Responses Due to Shocks to Expected and Realized Inflation

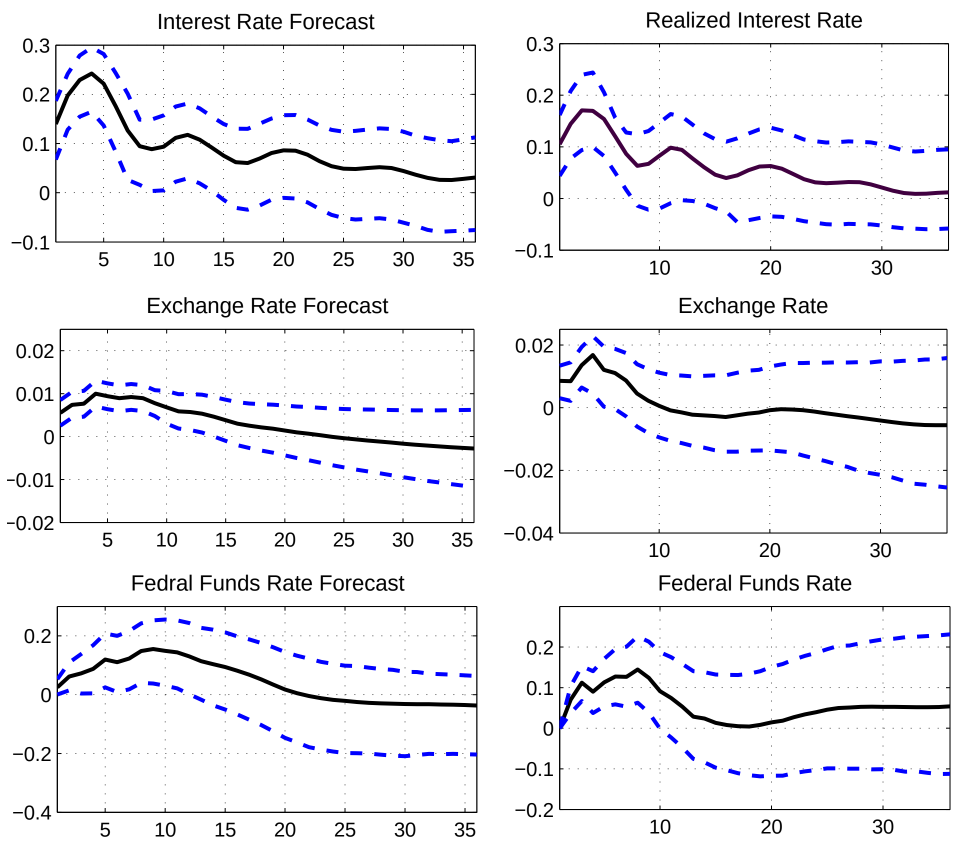


Note: Both figures are drawn on the same scale. The solid lines are point estimates of the impulse responses of the policy variable due to shocks in forecasted and realized inflation. The dashed lines are one-standard- deviation error bands.

shock—reflect the forward-looking policy behaviour of the Bank of England. These differential policy responses make sense because the Bank knows that it can affect inflation only with a lag, so the rational action would be to respond to the forecast of future inflation rather than current inflation. Therefore, any VAR models that do not use inflation expectations as policy inputs will estimate erroneous policy shocks and hence will generate misleading impulse responses.

I contrast the impulse responses of the policy variable due to shocks to the other forecasted and realized variables in figure 4.5. The left panels show the responses of the policy variable due to shocks in the forecasted variable, and the right panels show the responses due to shocks in the realized variables. These graphs are also drawn on the same scale. We observe that the Bank significantly responds to both the forecasts and their realized values. We see that the bank rate increases due to shocks in both the interest rate forecast and the realized interest rate, although the magnitude of the policy response is higher in the former than the latter. The Bank also tightens monetary policy upon forecasting a depreciation of the British pound and upon observing the current depreciation of the British pound. The figure also shows that the Bank contracts monetary policy upon forecasting a higher federal funds rate or if there is a positive shock in the current federal funds rate.

Figure 4.5: Policy Responses Due to Shocks to Forecasted and Realized Variables

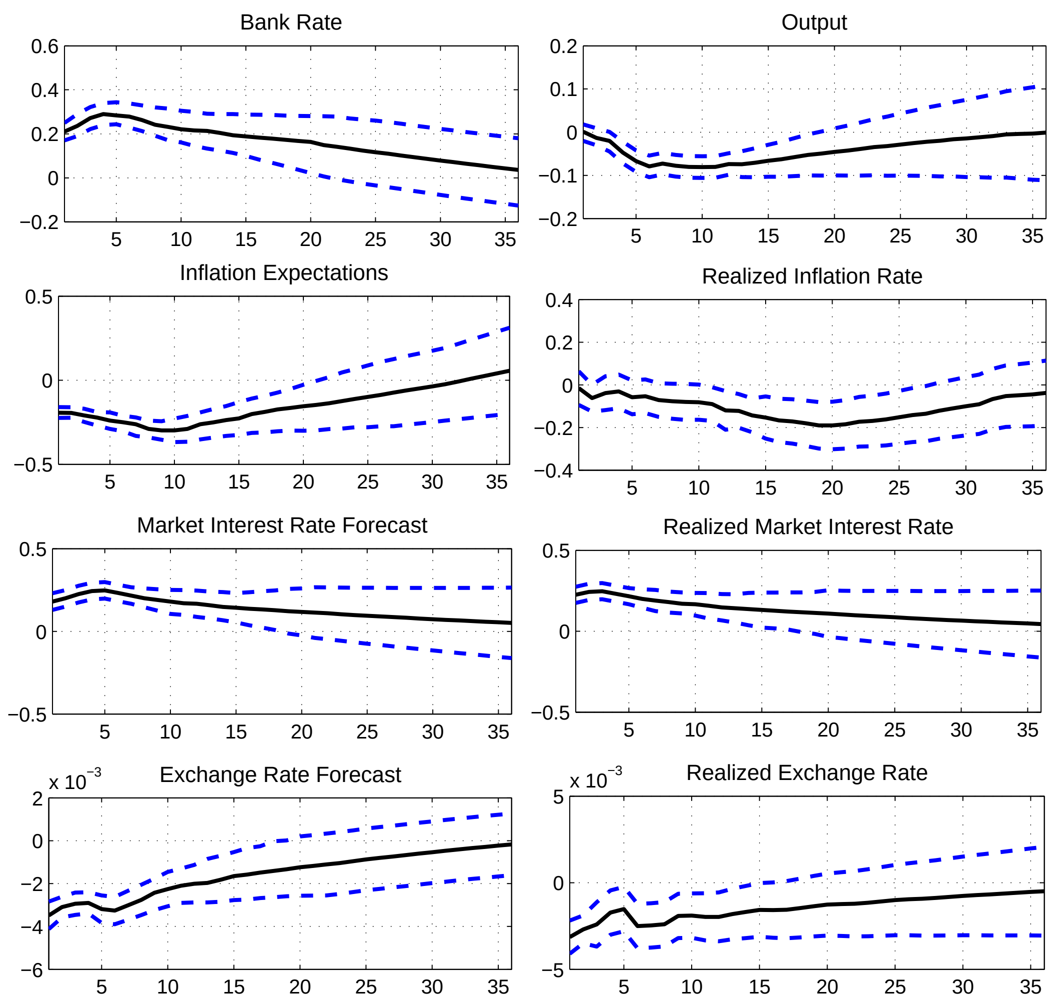


Note: The left and the right panels of the figure are drawn on the same scale. The solid lines are point estimates of the impulse responses of the policy variable due to shocks in forecasted and realized variables. The dashed lines are one-standard-deviation error bands.

Finally, I report the impulse responses of the forecasted and the realized macroeconomic variables due to shocks in the policy variable in figure 4.6. We find that a one-standard deviation shock of increasing the bank rate by about 30 basis points increases both the forecast of the market interest rate and the realized market interest rate by about 25 basis points, and the effects remain significant for about 18 months. Following the same shock, both the pound sterling and the forecast of the pound sterling appreciate on impact and then gradually depreciate towards the terminal value. Therefore, these impulse responses are consistent with Dornbusch's (1976) prediction that following a policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment.

We also observe that the contractionary policy shock lowers the level of output with a lag of about one year. Finally, this policy shock reduces the expected inflation rate by about 30 basis points and the realized inflation rate by about 15 basis points. The interesting result, however, is that, while the contractionary policy shock affects inflation expectations immediately (although the effect peaks after about six months), the policy shock affects the realized inflation rate only with a lag. The quicker response of inflation expectations reflects the credibility of the Bank of England's monetary policy: the public trusts that the Bank's action will bring today's higher inflation down to the target level in the future, so they expect a lower inflation rate in the future. And, indeed, this expectation seems very realistic, as we observe from the impulse response function of the realized inflation rate: following the contractionary policy shock, the inflation rate starts to fall at the beginning of the second year, and the effect peaks towards the end of the second year.

Figure 4.6: Impulse Responses Due to Policy Shocks in the Forecast-augmented Model



Note: The solid lines are point estimates of the impulse responses of the forecasted and realized variables due to a one-standard-deviation shock to the bank rate in the forecast-augmented model. The dashed lines are one-standard-deviation error bands.

Apart from impulse responses, variance decompositions are also useful tools to identify the variables that influence monetary policy decisions. I report the variance decomposition of the bank rate due to shocks to the forecasted variables, the realized variables, and the foreign variables in table 4.4. We see that at almost all horizons the block of the forecasted variables explains a higher portion of the movement of the bank rate than do shocks to the block of the realized variables. When I disaggregate the total share of the forecasted variables, I find that the relative share of inflationary expectation shocks underlying the fluctuations of the policy variable is higher than shocks to the other forecasted variables. These results reflect the importance of using the macroeconomic forecasts as inputs to the monetary policy reaction function and also stress the significance of inflationary expectations over other macroeconomic forecasts.

Table 4.4: Variance decomposition of the policy variable in the forecast-augmented model

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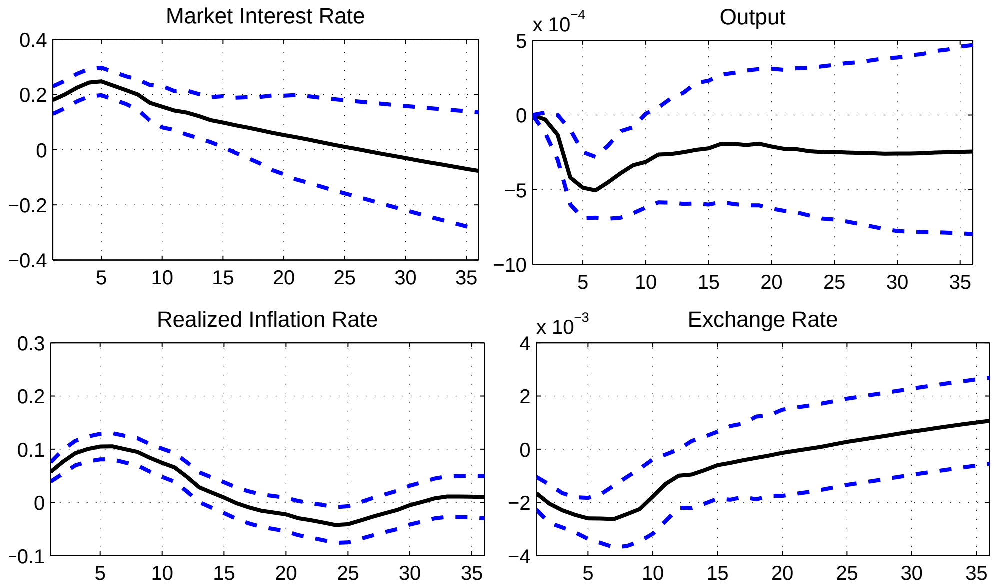
Months	x^f	=	$[\pi^f + i^f + s^f]$	x^r	x^*
1	**9.02**	=	$[4.27 + 3.88 + 0.87]$	**3.88**	**2.98**
6	**28.14**	=	$[13.56 + 11.96 + 2.62]$	**18.04**	**16.24**
12	**32.46**	=	$[20.45 + 9.87 + 2.14]$	**29.87**	**21.96**
24	**36.76**	=	$[25.14 + 8.99 + 2.63]$	**31.38**	**28.65**
48	**34.08**	=	$[23.19 + 9.09 + 1.80]$	**35.23**	**29.54**

Note: Bold entries (in percentage points) on the second, fourth and fifth columns, respectively, are the proportions of the movements of the bank rate explained by the forecasted, realized, and foreign block of variables. Entries in the middle column are shares of the individual forecasted variables.

I also examine the robustness of the results to a number of changes in the identification. First, I re-estimate the model imposing zero restrictions to the coefficients that are not significant at the 0.05 level. I find that the overall qualitative results due to the imposition of the zero restrictions are robust. However, the impulse response function of the exchange rate due to the policy shock becomes less significant if the contemporaneous coefficient of the German policy variable in the monetary policy equation is zero. I also re-estimate the model excluding the federal funds rate forecast. Again, while the overall pattern of impulse responses remains unchanged due to this exclusion, the response of the exchange rate due to the policy shock becomes less significant. These findings might imply that the exchange rate is an important channel through which shocks from both home and abroad spill over to the rest of the economy, as was found by Kim (2005) and in chapter three.

Next, I report the results of the standard model nested in the forecast-augmented model. The comparison of the impulse responses of the realized variables in the standard model with those in the forecast-augmented model will provide useful insights about the contribution of identifying the forward-looking monetary policy employing macroeconomic forecasts. The impulse responses of the standard model are reported in figure 4.7. We see that while the impulse responses of the market interest rate and output remain unchanged from those of the forecast-augmented model, there is a remarkable change in the impulse responses of both the realized inflation rate and the exchange rate. The figure shows that following a contractionary monetary policy shock, the realized inflation rate increases and remains significant for about one year. This response is at odds with what we expect from a contractionary monetary policy shock. On the other hand, following the same shock, the British pound keeps appreciating for about six months after the shock. This response of the exchange rate is inconsistent with Dornbusch's (1976) prediction that following a contractionary policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment to the initial value.

Figure 4.7: Impulse Responses Due to Policy Shocks in the Standard Model



Note: The solid lines are point estimates of the impulse responses of the forecasted and realized variables due to a one-standard-deviation shock in the bank rate in the standard VAR model. The dashed lines are one-standard-deviation error bands. These impulse responses are comparable to the impulse responses of the realized variables in the forecast-augmented model reported in the right panel of figure 4.5.

Next, I investigate which aspect of the forecast-augmented VAR model absent from the standard model causes the puzzling response of the inflation rate and the delayed response of the exchange rate. I incorporate the forecasted variables into the standard model one after another and check the impulse responses. I find that the incorporation of the expected inflation rate reverses the initial response of the inflation rate, while the inclusion of both the interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate.

This finding—that the inclusion of expected inflation as a policy input reverses the puzzling response of the inflation rate—indicates that a policy function identified without inflation expectations will estimate policy shocks that embody the endogenous policy response of the central bank. As explained by Sims (1992), since the endogenous policy response to future inflationary forces partially offsets the inflation rate, an econometrician's policy reaction function excluding inflation expectations is likely to produce a puzzling impulse response of the inflation rate.

On the other hand, the pioneering work by Obstfeld and Rogoff (1995) and a number of subsequent studies, such as those by Chari, Kehoe, and McGrattan (2002), Corsetti and Pesenti (2001), Galí and Monacelli (2004), and Kollmann (2001) argued that the monetary transmission mechanism operates through the channels of market interest rate and exchange rate. Therefore, the forecasts of these variables might also be considered by a central bank while making policy decisions, and a policy function identified without using them might be incorrect. The exclusion of these forecasts might explain the delayed overshooting response of the exchange rate found in some previous studies, such as those of Grilli and Roubini (1995), Eichenbaum and Evans (1996), and Faust and Rogers (2003).

I also check the robustness of the results for the sample period starting from May 1997 when government gave the Bank independence to set monetary policy by deciding the level of interest rates to meet the inflation target. I find that the qualitative results remain unchanged during this recent sub-sample period. I again find that the forecasted variables play a greater role than the realized variables in the monetary policy reaction function and that the exclusion of the inflation forecast and the exchange rate forecast causes a price puzzle and delayed overshooting response of the exchange rate.

4.6 Conclusion

I develop a forecast-augmented VAR model for an open economy using forecasts of key macroeconomic variables, in addition to the realized variables used in a standard VAR model. Two specific results suggest that forecasted variables play a greater role than realized variables in identifying the monetary policy function. First, the impulse responses of the policy variable suggest that monetary policy responds to shocks in forecasted variables on a greater scale than to shocks in realized variables. Second, the variance decomposition also shows that shocks to inflationary expectations and other forecasts explain a higher proportion of the movements of the policy variable than do shocks to realized variables. In the forecast-augmented model, I also find that a contractionary policy shock almost instantaneously increases the market interest rate as well as the forecast of the market interest rate. This policy shock also appreciates both the British pound and the forecast of the pound on impact. On the other hand, while the contractionary policy shock lowers the expected inflation rate immediately, the shock affects the realized inflation rate with a lag of eighteen months. I also find that the policy shock lowers the level of output with a lag of about one year.

When I estimate the standard model nested in the forecast-augmented model I find that, following a contractionary monetary policy shock, the realized inflation rate increases for about a year, and the British pound keeps depreciating for about half a year. The important result, however, is that the inclusion of inflation expectations into the standard VAR reverses the puzzling response of the inflation rate, and the inclusion of both the market interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate. These findings suggest that a standard VAR may incorrectly identify the policy reaction function and hence generate misleading results.

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