An investigation of the monetary policy of Taiwan by using the sign restrictions methodology

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Abstract

In this paper, I employ the sign restrictions methodology proposed by Uhlig (2005) to identify monetary policy shocks and re-examine their effects on real GDP and price level in the context of Taiwan. I found that the negative effect on real GDP of a monetary policy shock is quite short-lived. It is only significant at the impact quarter and at the first quarter following the shock. Furthermore, monetary policy shocks play only a small role in the total variation of real GDP. In contrast, foreign exchange intervention shocks have a larger effect on both real GDP and exchange rate as compared to monetary policy shocks. I also noticed that part of the results is sensitive to the choice of monetary aggregates and prior distributions.

JEL Codes: C11, C32, E52

Key Words: sign restrictions, Bayesian VAR, monetary policy shocks
1 Introduction

Previous studies tend to conclude that monetary policy has negligible effects on the Taiwanese economy. Lin (2003), for instance, using impulse response analysis from VAR models, finds that innovations in interest rate have negligible effects on output and price. The results remain unchanged even when one includes foreign variables.

What previous studies relied on to identify monetary policy shocks is the Cholesky decomposition, which imposes a recursive structure on the VAR model. A nontrivial caveat of this approach is that the identification conditions are either unclear or ad hoc. In this paper, I employ the sign restrictions methodology proposed by Uhlig (2005) to identify monetary policy shocks and re-examine their effects on real GDP and price level. The novelty of this method is that it imposes a minimum set of sign restrictions that are reasonably agreed upon across economists, and leaves the question of interest open by design of the identification procedure. For instance, if one is interested in the effects of monetary policy on real GDP, one possible choice of the sign restrictions is as follows: a contractionary monetary policy shock does not lead to increases in broad money, decreases in interest rates, depreciations of exchange rates, or increases in consumer price index for a certain period of time following the shock. No restrictions are imposed on the response of real GDP to monetary policy shock. Thus, the question of interest is left, agnostically, open by design of the identification procedure, while the answer can be found in the data.

Faust (1998) is one of the earlier studies that employed the sign restrictions methodology. In contrast with the conventional structural VAR model, all identifying restrictions in Faust (1998) are imposed on impulse response functions, not on VAR coefficients; and the restrictions are stated explicitly. What Faust intended was to search through all possible identifications of the VAR for one that produces the largest responses of real variables to monetary policy shocks, whilst being subjected to the condition that the implied structural model must produce impulse responses that are conformable to the sign restrictions. In this regard, Faust’s method is the method that is most closely related, in both motivation and methodology, to Uhlig (2005). Canova and De Nicoló (2002) also employed the sign restriction approach to identify monetary shocks in the G-7 countries. Their sign restrictions are imposed explicitly and are deduced from a formal model. Their approach shares similarities with the one employed in this paper. The main difference is that their sign restrictions are imposed on pairwise cross-correlation functions, and not on impulse response functions as what I have done here. In practice, it may be the case that none or more than one monetary shocks can be identified. In
the latter case, efforts are required to disentangle the information content of the multiple monetary shocks. Canova and De Nicoló (2002) found that identified monetary shocks contribute significantly to the output and the inflation cycles in all G-7 countries. Taylor (2004) also proposed imposing additional qualitative restrictions to the identification of structural VAR models. He presumed that in the short run, aggregate supply shocks should raise the output and depress the price level while the aggregate demand shocks should raise both the output and the price level. Even though the intention of Taylor (2004) was to demonstrate that recursive long-run restrictions alone are not able to achieve a unique identification of VAR models, and that additional qualitative, theory-implied restrictions are necessary for that purpose, the spirit of Taylor’s method is consistent with the sign restriction methodology.

The application of sign restrictions methodology arose initially from the study of monetary policy. Uhlig (2005), using the U.S. data, found that contractionary monetary policy shocks have no clear effect on real GDP. At long horizon, monetary policy shocks account for less than 2 percent of the forecast error variance in the real output. Mountford (2005) applied the sign restrictions method to study the U.K. monetary policy. He found that contractionary monetary policy shocks have a permanently negative effect on real GDP. Despite the persistence of their effects, monetary policy shocks explain only a small proportion of the total variation of the variables in the VAR. He also found that aggregate supply shocks have a permanent and positive effect on real GDP, while the effect of non-monetary aggregate demand shocks is transitory. Other applications of the sign restrictions methodology include studies on the effects of fiscal policy shocks (Mountford and Uhlig, 2005) and the exchange rate puzzles (Scholl and Uhlig, 2006). Canova and De Nicoló (2002) argued that the sign restriction approach has three advantages over competing methods of identification. First, the approach separates the problem of obtaining orthogonal shocks from issues concerning the identification of structural shocks. Second, it avoids the imposition of short-run or long-run restrictions that may be inconsistent with implications of economic models or may involve distortions due to finite sample biases. Third, all restrictions are explicitly stated, thus allows for a systematic analysis of robustness.

This paper improves previous studies in several aspects. First, I employed a new algorithm (QR decomposition) that makes the identification of multiple shocks easier to implement, while the identified shocks are not affected by the sequence of the identification scheme. Second, my identification scheme takes explicitly foreign exchange intervention into account. I identified both monetary policy and foreign exchange policy shocks. Previous studies identify only monetary policy shocks when examining exchange rate behaviours.
The effects of monetary policy are likely to be ill measured if the foreign exchange intervention is not explicitly modelled, and vice versa. Third, to make sense of the monetary policy shocks identified from the sign restrictions, I undertook a thorough comparison of these shocks with narrative monetary indicators, shocks identified from the structural VAR model, and actual market events. Fourth, I examined whether the results of the sign restrictions methodology are robust upon the horizons of the sign restrictions, the choice of monetary aggregate, the possibility of monetary policy lag, and most importantly, the choice of prior distribution. I considered several priors that have been used in the Bayesian VAR literature. Such an exercise has not been conducted before in the literature. In using the sign restrictions methodology, I found that the negative effect on real GDP of a monetary policy shock is quite short-lived. It is only significant at the impact quarter and at the first quarter following the shock. Furthermore, monetary policy shocks play only a small role in the total variation of real GDP. In contrast, foreign exchange intervention shocks have a larger effect on both real GDP and exchange rate as compared to monetary policy shocks. I also noticed that part of the results is sensitive to the choice of monetary aggregates and prior distributions.

The arrangement of this paper is as follows. Section two describes and justifies the identifying sign restrictions employed in this study. Section three contains the main empirical results. I reported my data sources, innovation accounting of the structural shocks, and I devoted a subsection to qualify for the identified monetary policy shocks by comparing these shocks with the narrative approach, the structural VAR model, and market events. Section four reports a variety of robust tests, and the last section concludes.

2 Identifying sign restrictions

This section introduces our sign restrictions. The procedure to implement the sign restrictions is described in the appendix at the end of this paper. I have identified five shocks: a monetary policy shock, an oil price shock, an aggregate supply shock, a non-monetary aggregate demand shock, and a foreign exchange intervention shock. The shocks are identified by using the Uhlig’s sign restriction methodology. It is assumed that there are $m$ fundamental shocks, which are mutually orthogonal and normalized to be of variance one.\footnote{Following the VAR literature, the fundamental shocks here are assumed to be mutually independent and are normalized to have variance of one. Using correlated fundamental shocks would suggest that some remaining causal relationships between the shocks are} The sign restrictions identified five fundamental shocks in
the VAR and $5 < m$. By construction, all the identified shocks can have an instantaneous effect on all variables. I could have identified only the monetary policy shock. I identified multiple shocks by taking the following into consideration: Firstly, Taiwan is an energy importing country, therefore the volatility of international oil price is likely to have a significant impact on the domestic economy. Furthermore, there are domestic aggregate supply shocks and aggregate demand shocks that have to be explicitly taken into account. Secondly, an advantage of identifying multiple shocks is to reduce the chance of misidentification. Since a combination of other shocks can look like monetary policy shocks, identifying the other shocks explicitly may help to avoid this problem (Uhlig, 2005). Thirdly, in the context of Taiwan, where the monetary authorities tend to be ambiguous about their policy stance and policy instruments, the sign restriction method adopted here has a further advantage since we do not need to specify the policy instrument based on an a priori basis as is needed by the conventional VAR method. Instead, we let the time series properties of the variables reveal the policy instrument, which can be a short-run interest rate or a monetary aggregate, or a combination of the two.\(^2\) Given the identified shocks, our purpose is to investigate whether monetary policy shocks have significant effects on domestic output and price level.

Table 1 shows the sign restrictions imposed on each shock’s impulse responses in the first $K$ quarters following the shock. Currently we have set $K = 4$ and therefore the restrictions are for horizons $k$, $k = 0, 1, \ldots, K$. A contractionary monetary policy shock is identified as a shock that increases the interest rate, appreciates the exchange rate, and reduces the levels of money supply and domestic price.\(^3\) That is to say, I assume that a contractionary monetary policy shock does not lead to increases in broad money,

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left unexplained. Cover et al. (2006) proposed a method to obtain correlated aggregate demand and aggregate supply shocks. Their approach is not attractive to us for two reasons. First, the computed correlated shocks are of little use because one cannot do any analysis with them. To obtain impulse responses and variance decompositions, the authors have had to move one-step further and decompose these correlated shocks into truly pure shocks that are mutually uncorrelated. There are an infinite number of possibilities to do so. So why should we bother ourselves with these correlated shocks? Second, the deduction of the correlated fundamental shocks was obtained by using a very restrictive AD-AS model of the economy. It is not clear whether such a method is feasible in more general and multivariate VAR models.

\(^2\)In structural VAR models, it is possible to treat a short-run interest rate, or a monetary aggregate, or a combination of the two variables as the policy instrument. See Kim (2003) for a demonstration.

\(^3\)Nominal exchange rate is defined as the price of foreign currency in terms of domestic currency. A decline in nominal exchange rate means an appreciation of domestic currency.
decreases in interest rate, depreciations of exchange rate, or increases in consumer price index for a certain period following a shock. An oil shock is defined as a shock that causes the dollar price of oil to rise for four quarters following the shock. The dollar price of oil is included in the VAR because oil price shocks may have effects on the domestic economy. A positive aggregate supply shock is defined as a shock which increases output and decreases the price level for four quarters following the shock. Positive non-monetary aggregate demand shocks are identified as shocks that increase output and the price level for four quarters following the shock. A positive foreign exchange intervention shock is supposed to be associated with an increase in foreign reserves. Our sign restrictions are in broad consistency with the conventional view. For instance, Christiano et al. (1999) argued that even though the literature has not yet converged on a specific way of identifying monetary policy shocks, there is considerable agreement about the qualitative effects of a monetary policy shock. The consensus is as follows: following a contractionary monetary policy shock, short-term interest rates rise, and consumer price index, output and monetary aggregates fall. This consensus is consistent with the restrictions I have employed to identify monetary policy shocks. I do not restrict the consumer price level to increase following an oil price shock because retail petroleum prices in Taiwan are highly regulated and it is hard to presume a one-to-one correspondence between the international crude oil price and the domestic retail petroleum prices. Note that no restriction is placed on the long run response of any variable to a monetary policy shock. The identification scheme also places no restriction on the long run responses of output to an aggregate supply shock.

Our identifying scheme is an extension of Mountford (2005). In addition to his, our identification scheme takes explicitly the foreign exchange intervention into account. Kim (2003) suggested that in examining the effects of monetary policy on the exchange rate and in studying exchange rate behaviors, it is important to explicitly take into account the foreign exchange intervention, in addition to the monetary policy. The effects of monetary policy may be ill measured if foreign exchange intervention is not explicitly modeled. For countries (such as Taiwan) that pay strong attention to exchange rate movements, it is important to model explicitly both the foreign exchange intervention and the conventional monetary policy in order to clarify the effects of foreign exchange intervention and conventional monetary policy on the exchange rate movements. In my case, actual foreign exchange

\[4\]The dollar price of oil is available from the Federal Reserve Board of St. Louis’ website http://research.stlouisfed.org/fred2/. We use the logarithm of this oil price for the analysis.
interventions are not available. I used foreign exchange reserves as a proxy for foreign exchange intervention. In other words, foreign exchange intervention or foreign exchange policy is described as foreign exchange reserves setting policy. Furthermore, since I am mainly interested in the effect of monetary policy shocks on domestic output, I relax the sign restrictions imposed on the output and leave the answer to the data. This is in the spirit of sign restriction methodology in which the question of interest is left agnostically open by design of the identification procedure, and the answer is left to the data. In contrast, Mountford (2005) had restricted the response of the output to the monetary shock to be negative. The final difference as compared to Mountford (2005) is that I used pure sign restrictions, instead of the penalty-function approach.\textsuperscript{5} Appendix B of Uhlig (2005) compares the pure sign methodology with the penalty-function approach.

3 Empirical results

3.1 Data

I estimated a VAR model with seven endogenous variables. The seven variables included in the VAR are real gross domestic product (GDP), interest rate (IR), broad money (M2), exchange rate (EX), consumer price index (CPI), crude oil price (COP), and foreign reserves (FR). The choice of variables follows Lin (2003).\textsuperscript{6} Except for interest rate where I used the level, all variables were transformed by logarithm. The VAR system consists of these seven variables at quarterly frequency from the first quarter of 1981 to

\textsuperscript{5}Mountford’s VAR system consists of six variables at quarterly frequency, and has four lags, no constant or time trend, and uses the logarithm for all variables, except the interest rate where the level value is used. All variables except the interest rate and the dollar price of oil are seasonally adjusted.

\textsuperscript{4}Due to valuation effects such as foreign exchange fluctuations and capital gains, foreign exchange reserves might not be a good proxy for the foreign exchange intervention. To exclude valuation changes resulting from the fluctuation of exchange rates, I also experimented with the stock of central bank’s net foreign assets as a proxy for foreign exchange intervention. The construction of central bank’s net foreign assets followed Wang (2005). While Wang (2005) used the growth rate of net foreign assets, I used the level (in logarithm) of the net foreign assets as my intervention variable. I found that my results remain qualitatively the same when using the stock of net foreign assets as the intervention variable.

\textsuperscript{7}Lin’s VAR model includes the first five of our seven variables. Crude oil price and foreign reserves were not included in his model because he did not intend to identify oil price shocks and foreign exchange intervention shocks. Lin’s VAR model uses 5 lags and quarter data from 1982Q1 to 2002Q3. Lin (2003) did not adjust for seasonality. Instead, he chose a lag length of five to allow for seasonality in the data.
the last quarter of 2005, and has four lags, no constant and no time trends.\textsuperscript{8} Real gross domestic product, broad money, and consumer price index have been seasonally adjusted. Most of our data were obtained either from the Directorate-General of Budget, Accounting and Statistics or from the Central Bank of Taiwan’s website at http://www.cbc.gov.tw/. Variables plots (not reported) indicate that my variables are reasonably similar to that reported in Lin (2003), with a minor difference being that our interest rates are more volatile than his.

3.2 Innovation accounting

I computed the impulse responses and variance decomposition up to 40 quarters. The impulse responses of the five identified shocks are presented in Figures 1 to 5. The percentage of the total variation of each variable explained by the monetary policy shock and the foreign exchange intervention shock is shown in Figure 6 and Figure 7, respectively; while the percentage of the total variation of each variable explained by the other four identified shocks is shown in Figure 8. Figures 1 to 8 each plot three lines. These are the 16-th, 50-th and 84-th percentiles of the impulse responses (or variance decomposition) for each shock from a sample of 100 draws from the posterior distribution. These lines thus indicate the shape of the posterior distribution of the impulse responses, whilst providing a confidence band for these responses. The identifying restrictions for each shock are indicated by vertical lines at the fourth quarter after the shock, so that the area between the $y$-axis and the vertical line represents the zone where the impulse responses have been restricted.

Figure 1 displays the impulse responses to a monetary policy shock one standard deviation in size. The first column shows the responses of real GDP, interest rate, M2 and exchange rate. The second column shows the responses of CPI, crude oil price and foreign reserves. The interest rate reacts positively and significantly immediately to the monetary policy shock, and it declines quickly after 10 quarters and ultimately returns to zero. By looking at the median responses, one will find that a one-standard deviation monetary policy shock drives the interest rates up to 26 basis points and the output down to 0.2 percent on impact. This magnitude, found from my identified monetary shocks, is smaller than what has been reported in the literature. Christiano et al. (1999), for instance, reported that the impact effect of a monetary policy shock on the federal fund rate is about 70 basis

\textsuperscript{8}The VAR models in Uhlig (2005) and Mountford (2005) do not include an intercept or time trend. They estimated VAR model using levels of the logs of variables, rather than the first differences. Our model specification follows theirs.
points. The negative effect on real GDP of a monetary policy shock appears to be very short-lived. It is significant only at the impact period and at the first period following the shock. Thereafter, it becomes insignificant so that the 68 percent confidence interval always contains the zero line, although the median response remains negative for a long period of time. On impact, a one standard-deviation monetary policy shock drives broad money down to roughly 0.2 percent. The negative effect of a monetary policy shock on broad money is permanent and remains significant for about 15 quarters following the shock. The exchange rate appreciates by 1.1 percent on impact, but the responses quickly become insignificant. That is to say, nominal exchange rate appreciates on impact, and is followed by a gradual depreciation to the long-run value. I do not find evidence for any delayed overshooting as is commonly reported in the foreign exchange literature (Scholl and Uhlig, 2006). The response of nominal exchange rate to a contractionary monetary policy shock is confirmable to the prediction of Dornbusch (1976). The price level drops significantly during the first 5 quarters following the shock, and returns gradually to zero thereafter. The price puzzle is avoided by construction, and the effects of monetary policy shocks on crude oil price are insignificant. The responses of foreign reserves to monetary shocks are insignificant.

Despite the persistence of their effects in some cases, monetary policy shocks explain only a small part of the total variation of the other endogenous variables. Figure 6 shows that, using the median measure, monetary policy shocks account for less than 10 percent of the variation of almost all variables at almost all time horizons. The only two exceptions are the exchange rate, where monetary policy shocks account for about 31 percent of the variation on impact, and the interest rate where monetary policy shocks account for above 25 percent of the variation in the first few quarters after the shock. Monetary policy shocks account for about 6 percent of the variation of real GDP at the long run horizon. Figures 7 presents the variance decomposition due to the foreign exchange intervention shocks. In order to save space, I will not report the variance decomposition due to oil price, aggregate demand and aggregate supply shocks. In general, each of these shocks accounts for a larger part of the variance decomposition than the monetary policy shocks. Figure 8 displays the sum of the contributions of oil price, aggregate supply, aggregate demand and foreign exchange intervention shocks to the total variation of the variables in the VAR. These four shocks together explain about 61 to 70 percent of the long run variation in the endogenous variables. Together with the previous results, this implies that monetary policy has only negligible effects on real GDP.

In response to an increase in the dollar price of crude oil, Figure 2 shows that real GDP and broad money fall slightly, while price level rises slightly.
However, the impulse responses of these variables are insignificant. The reason is that the monetary policy has been loosened (rather than tightened), with interest rates falling significantly as a result of oil price shocks. An increase in international oil price is a negative supply shock that raises the equilibrium price level and decreases the equilibrium output level. The monetary authorities in Taiwan appear to react to such shocks by loosening the monetary stance, which aims to stimulate aggregate demand and mitigate the increase in price as well as the decrease in output level. The loosening of monetary policy is associated with a significant exchange rate depreciation in the medium-term. This response of the monetary authorities in the face of oil price shocks is quite different from that which has been found by existing studies, such as Garratt et al. (2003) and Mountford (2005) regarding the U.K., and Bernanke et al. (1997) and Scholl and Uhlig (2006) regarding the U.S., where monetary authorities tend to raise interest rates in the face of oil price shocks, thus inducing a further depressing effect on the output. An early study of Emery (1987) reviewed Taiwan’s monetary policy in dealing with the two oil crises and also found that the tightening of monetary policy was too small to contain the inflationary effects of oil price shocks. Even though Emery’s study covers an earlier period that is different from my study, his finding of the central bank reaction to oil shocks may reflect the central bank’s basic philosophy that continues into the latter periods.

Figure 3 shows the impulse responses to an aggregate supply shock. It indicates that a positive aggregate supply shock raises real GDP by about 0.4 percent and reduces the price level by about 0.3 percent on impact. The effects of aggregate supply shocks on output and price levels are significant up to 8 quarters following the shocks, and become insignificant thereafter. Interest rate and broad money remain unchanged in response to an aggregate supply shock. This implies that the monetary authorities of Taiwan tend to keep a constant policy stance in face of an aggregate supply shock. I found that exchange rate remained unchanged following the shocks, while foreign reserves increase somehow strongly in the medium-term. This can be rationalized by the monetary model, which predicts that an increase in real GDP will cause an increase in the foreign reserves as the result of a temporary trade balance if the exchange rates are not allowed to change. The responses of crude oil price to aggregate supply shocks are insignificant.

Figure 4 shows the impulse responses for the non-monetary aggregate demand shock. Both output and price levels increase significantly in response to a positive aggregate demand shock, and the 84-percentile of the distribution of their responses remain positive for about 15 quarters following the shock. The responses of both interest rate and broad money to the aggregate demand shocks are insignificant. Like the case of aggregate supply shock, I
did not find evidence that monetary policy stance is tightened or loosened in response to an aggregate demand shock. There is a nominal appreciation and an increase in foreign reserves in the first 4 quarters following the shock.

Figure 5 reports the impulse responses of each variable to one-standard deviation foreign exchange intervention shocks over 48 quarters. In response to foreign exchange intervention shocks (net purchases of foreign currencies), broad money increases significantly and interest rate decreases slightly on impact, indicating that intervention in the foreign exchange market may not be sterilized. The response of broad money is persistent and remains significant for about 23 quarters following the shocks. It is commonly perceived that net purchases of foreign currencies should weaken the domestic currency. Somehow puzzling, I found that exchange rate appreciates on impact, and appreciates further over time. The exchange rate appreciation differs from zero with a 68 percent probability. Such patterns can be explained by the unique features characterizing the Taiwanese economy: heavy intervention in the foreign exchange market and huge current account surplus. Except for some short-live turbulence periods, most of the time, New Taiwan dollar faces appreciation pressure. To relieve the appreciation pressures of domestic currency, monetary authorities of Taiwan tend to adopt a strategy of gradual accommodation by allowing the currency to appreciate step by step but not to the full extent and simultaneously buy up the excess supply of foreign currency. This kind of partial accommodation is associated with nominal appreciation and the build-up of foreign reserves, and this is exactly what the impulse responses have shown. In other words, the shocks identified reflected, to a large extent, demand shocks for foreign reserves in the foreign exchange market. The side effects of such partial accommodation are excess money supply. I found that output increases following the shocks; this is probably due to the monetary expansion. It is worth noticing that foreign exchange intervention shocks have a larger effect on both real GDP and exchange rate than the monetary policy shocks, either in terms of impulse responses or variance decomposition. I am not the first one to report such results. Kim (2003), one of the few papers to identify both monetary and foreign exchange intervention shocks, also reported similar results.

\[ I \text{ have assumed that price level should not increase following a contractionary monetary policy shock. To see whether that has distorted my results, I experimented with relaxing the sign restrictions on consumer price index and examine again the effects of monetary policy on output (results not reported). Without imposing sign restrictions on the CPI, I found a price puzzle as most of the VAR literatures have documented, in the sense that price level actually increases, not decreases, following a contractionary monetary shock (Christiano et al., 1999). However, even having relaxed the sign restrictions on price level, the effect of monetary shocks on output is still insignificant. } \]

\[ I \text{ One cannot over-emphasize the need to consider foreign exchange intervention in the } \]

\[ I \text{ 11} \]
3.3 Are the identified monetary policy shocks meaningful?

A useful way to evaluate the sign restrictions method is to plot the identified monetary policy shocks and assess how well these identified shocks correspond to the known central bank policy.\textsuperscript{11} We recover the monetary policy shocks by using the procedure described in Uhlig (2005) on page 387. Simply said, this is to find a non-zero vector $b$ of size $m \times 1$ that satisfies $(\Sigma - aa')b = 0$ and $1 = b'a$. The structural shocks are obtained by $v_t = b'u_t$. Since the identified monetary shocks are very noisy, we plot a four-quarter moving average of these shocks to smooth out some of the noises. The top panel of Figure 9 plots the identified monetary policy shocks. The three lines are the 16-th, 50-th and 84-th percentiles of the monetary policy shocks identified from a 100 draws from the posterior distribution. The middle panel plots the foreign exchange intervention shocks. The correlation between the two shocks is $-0.07$. The bottom panel of Figure 9 plots the median structural shocks with the central bank discount rate.

To qualify the identified monetary policy shocks, I first compare these shocks with monetary indicators constructed from the narrative approach. Romer and Romer (1989) argued that monetary indicators constructed from the narrative approach can identify truly exogenous changes in monetary policy and can thus avoid the endogeneity problem, which arises because the changes in monetary instruments are caused by reasons other than changes in the policy stance. The study we rely on is Shen and Chen (1996), who constructed narrative monetary indicators for the Taiwanese case by studying the central bank announcements after the committee meeting. Since the studies on monetary policy and exchange rate. I have experimented with a 6 variables VAR model that excludes the foreign reserves, and I ignored the foreign exchange intervention shocks. The results (not reported) indicate that monetary policy shocks have a strong and persistent effect on real GDP. This strong effect disappears once the foreign exchange intervention shock is taken into account. This experiment indicates that when foreign exchange intervention shocks are not explicitly taken into account, one may wrongly attribute the effects of foreign exchange intervention to the monetary policy shocks, and thus exaggerate the effects of the latter variable.

\textsuperscript{11}Rudebush (1998) argued that compared with structural shocks recovered from standard VAR identifications, innovations in the Federal Fund Future rate are more related to the market perceptions of what monetary policy shocks are. Therefore, a method to examine whether the identified monetary shocks are reasonable is to compare our monetary shocks with innovations in interest rate future. To construct the innovations in interest rate future, Canova and De Nicoló (2002) regressed interest rate future on a lag of itself and three lags of real GDP and interest rates. I am not able to carry out this exercise because the interest rate future market in Taiwan starts from May 2004 and therefore the historical data are very short.
wordings of the announcements are typically vague to avoid criticism of lack of credibility, it is difficult to assess the true policy stance of the central bank solely on the basis of the announcements. Shen and Chen (1996) employed macroeconomic data to complement the study of announcements. Specifically, they employed a lexicographical principle with a sequential priority rule placed on the authorities’ announcements, changes of the required reserves ratio, the discount rate and the monetary base. For instance, if no announcement is made by the authorities, and there is no change on the reserve ratio, the current policy stance is evaluated by examining the discount rate. The increase (decrease) of the discount rate is judged as a signal of tight (loose) monetary policy, no matter what the change of the monetary base is. The monetary indicators are obtained from Huang and Lin (2006), who updated the narrative monetary indicator to the second quarter of 1997. The monetary indicator is a discrete variable, which takes the value of 0 if an expansionary policy is adopted, 1 if no or a neutral action is taken, and 2 if a contractionary policy is implemented.

To explore the relationship between the narrative monetary indicator and the identified monetary policy shocks, I estimated an ordered probit model, using the narrative monetary indicator as the dependent variable and the structural monetary policy shocks as the explanatory variable. Implicitly, I am assuming a linear relationship between a latent variable $y^*_i$ and the structural shocks $x_i$:

$$y^*_i = x_i^\beta + \epsilon_i$$

where $\epsilon_i$ are independent and identically distributed random variables. The observed monetary indicator $y_i$ is determined from the rule:

$$y_i = \begin{cases} 0 & \text{if } y^*_i \leq \gamma_1 \\ 1 & \text{if } \gamma_1 < y^*_i \leq \gamma_2 \\ 2 & \text{if } \gamma_2 < y^*_i \end{cases}$$

Table 2 reports the estimated results. I found that the estimated coefficient is positive but insignificant. The same table also reports the marginal effects on the probability of falling in any of the three categories when the explanatory variable changes. On the one hand, $\partial \Pr (y_i = 0) / \partial x_i < 0$, meaning that given a contractionary policy shock, the probability of observing an expansionary narrative indicator is reduced. On the other hand, $\partial \Pr (y_i = 2) / \partial x_i > 0$, meaning that given a contractionary policy shock, it is more likely to observe a tight narrative monetary indicator. That is, the structural monetary shocks and the narrative monetary indicator point to the same stance of monetary policy, even though their correlation is not
statistically significant.

I further compared the structural shocks with policy shocks that have been identified as well using the vector autoregression, but with different identification assumptions. The model I used to compare is the structural VAR model of Kim (2003), which is expressed as:

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & g_{23} & 0 & 0 & g_{26} & g_{27} \\
g_{31} & g_{32} & 1 & 0 & g_{35} & 0 & 0 \\
g_{41} & g_{42} & g_{43} & 1 & g_{45} & 0 & g_{47} \\
g_{51} & 0 & 0 & 0 & 1 & 0 & 0 \\
g_{61} & g_{62} & g_{63} & g_{64} & g_{65} & 1 & g_{67} \\
0 & 0 & 0 & g_{74} & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
u_{GDP} \\
\vdots \\
u_{GDP} \\
u_{IR} \\
\vdots \\
u_{IR} \\
u_{M2} \\
\vdots \\
u_{M2} \\
u_{EX} \\
\vdots \\
u_{EX} \\
u_{CPI} \\
\vdots \\
u_{CPI} \\
u_{COP} \\
\vdots \\
u_{COP} \\
u_{FR} \\
\vdots \\
u_{FR}
\end{bmatrix}
= 
\begin{bmatrix}
u_{GDP} \\
\vdots \\
u_{GDP} \\
u_{IR} \\
\vdots \\
u_{IR} \\
u_{M2} \\
\vdots \\
u_{M2} \\
u_{EX} \\
\vdots \\
u_{EX} \\
u_{CPI} \\
\vdots \\
u_{CPI} \\
u_{COP} \\
\vdots \\
u_{COP} \\
u_{FR} \\
\vdots \\
u_{FR}
\end{bmatrix}
\]

where \(u\) denotes the one-step ahead prediction error, \(v\) denotes the orthogonal structural shocks, and \(GDP\), \(IR\), \(M2\), \(EX\), \(CPI\), \(COP\), and \(FR\) represent real GDP, short-term interest rate, broad money, exchange rate, consumer price index, crude oil price, and stock of foreign reserves, respectively. I took Kim (2003)’s model because he also explicitly identified both monetary policy shocks and foreign exchange intervention shocks, and the variables he used is the same as mine, except that I used crude oil price instead of commodity price. The most important setting of Kim’s model is equations two and seven, which represents monetary policy reaction function and foreign exchange intervention reaction function, respectively. Kim presumed that conventional monetary policy is an interest rate setting policy, while foreign exchange policy is described as foreign reserves setting policy. Equation two assumes that monetary policy does not react to contemporaneous developments in real GDP and price level, since published data on real GDP and price level are either incomplete or not available within a quarter. On the other hand, monetary policy is assumed to be able to react to contemporaneous developments in broad money, oil price, and foreign exchange policy. Equation seven assumes that foreign exchange policy can react to current development in exchange rate, but cannot react to other current variables. Monetary policy is allowed to react to foreign exchange policy because the monetary authorities may carry out sterilization measures. In contrast, foreign exchange intervention is not allowed to react contemporaneous to monetary policy per se. However, the model still allows monetary policy to contemporaneously affect foreign exchange policy through the effects of monetary policy on exchange rate and the contemporaneous reaction of foreign exchange policy to exchange rate. The structural disturbances in other equations are interpreted as real GDP shocks, money demand shocks, exchange rate shocks, CPI shocks and oil price shocks.
The structural VAR model has been estimated by using the same data. The likelihood ratio test suggests that over-identification restrictions are not rejected at the conventional significance level; the result is $\chi^2(2) = 0.757$ and the significance level is 0.685. I regressed the shocks identified from Kim’s model on the shocks identified from sign restrictions method, and the results are as follows:

$$v_{SVAR,t} = -0.005 + 0.271 \cdot v_{SIGN,t}, \quad R^2 = 0.09$$

$$v_{SVAR,t} = -0.008 + 0.746 \cdot v_{SIGN,t}, \quad R^2 = 0.28$$

where $SVAR$ denotes structural VAR model and $SIGN$ denotes sign restrictions method, while the numbers in parentheses are t-statistic. The first equation is the regression results for monetary policy shocks, while the second equation is the results for foreign exchange intervention shocks. I found a significant correlation between the structural shocks identified by the two different methods. This is especially the case for foreign exchange intervention shocks where the correlation is as large as 0.746. Probably because of this, I discovered that impulse responses for monetary policy shocks and foreign exchange rate intervention shocks obtained from the structural model are qualitatively similar to our results.

The final method I used to qualify the identified shocks is to chronologically compare these shocks with market events. An increase in the value of monetary shocks means that a contractionary policy has taken place. It should be stressed that these monetary policy shocks show how tight the monetary policy is, given the state of the economy and the other shocks. As a result, one cannot necessarily translate a contractionary monetary policy shock into a high discount rate. A positive shock indicates that movements in actual discount rate (or monetary variables) are much more than what is predicted based on the estimated VAR and the other shocks. I discovered 6 such episodes: 1984Q3, 1988Q1, 1992Q2, 1997Q3, 1999Q2, and 2001Q4. I also found 6 episodes in which the policy stances were relatively loose: 1983Q2, 1986Q4, 1989Q1, 1998Q2, 2000Q4, and 2004Q3. Two of the three contractionary episodes are classified as tight monetary policy using the narrative approach, and one is classified as easy policy. These episodes are 1984Q3 (easy), 1988Q1 (tight), and 1992Q2 (tight). While this is so, two of the three expansionary episodes are classified as easy monetary policy using the narrative approach, and one is classified as tight policy. These episodes are 1983Q2 (easy), 1986Q4 (easy), and 1989Q1 (tight). I was unable to compare the other episodes because the narrative monetary indicator is available only up to 1997Q2.
There is a strong correspondence between the identified episodes and market events. Starting from 1981, the impacts of the second oil crisis on Taiwan’s economy were apparent. In the face of a possible recession, the monetary authorities started from April 1982, a series of reduction in discount rate and required reserve ratio to stimulate the economy. These policies worked, and the economy had already showed sign of recovery in January 1983. However, monetary policy was eased further in such a way that the policy stance actually became too loose in the second quarter of 1983. Interest rates were liberalized in January 1984. The removal of interest rate ceilings caused nominal interest rates to increase temporarily, and led to a contractionary policy stance in 1984Q3. The monetary authorities of Taiwan lost their control over money growth in the second half of 1980s due to a policy of pegged exchange rates under persistent current account surpluses. The average annual growth rate of M2 during 1985-89 was as high as 21 percent.

The top panel of Figure 9 indicates that monetary policy had been continuously eased since 1985 and had reached its easiest stance in the last quarter of 1986. It is thus not surprising that the year 1987 witnessed the highest money growth rate in history. Beginning in 1988, in order to regain control over money supply and to repress speculations on real estates, the monetary authorities turned to a contractionary policy stance. The initial tightening in monetary policy caused mortgage interest rates to double. However, the contraction in monetary policy was not enough to curb the speculations, so the stance of monetary policy was still relatively loose on the eve of the stock market crashes.

The rapid growth of M2 contributed to the stock market boom that attained its peak in February 1990, and fell rapidly thereafter when the bubbles bursted. In the face of a stock market collapse, the first response of the monetary authorities was to ease the policy stance, as reflected in the expansionary policy shocks seen in 1991Q2. That expansionary policy was reversed in 1992Q2, when the monetary authorities started the new monetary strategy of monetary targeting.\textsuperscript{12} The period between 1993 and 1996 was a calm and stable period; it witnessed no significant monetary policy shocks. This partially reflected the facts that the newly implemented monetary targeting was successful in controlling the M2 growth rate within a reasonable range.

The following shocks appeared in tandem with the Asian financial crisis. The Bank of Thailand floated the baht on 2 July and the currency was devaluated by $15 - 20$ percent against the U.S. dollar. Since early July, the monetary authorities of Taiwan had been relying on spending foreign

\textsuperscript{12}Ho and Lin (2006) provide a description of monetary targeting in Taiwan, and the dilemma it faced in practice.
exchange reserves and raising short-term interest rates to defend the New Taiwan dollar. The attempt to resist devaluation caused a significant reduction in base money growth. My estimate indicates that the contractionary monetary policy stance, caused by the responses to a series of external events during the Asian financial crisis, was too tight in 1997Q3. In October, the monetary authorities abandoned its defense of the New Taiwan dollar, freed the currency and adopted a looser policy stance. The reversal was larger than necessary, as a result, the monetary policy actually became too loose in 1998Q2, and thus induced a series of resumed speculations in August and September 1998. The New Taiwan dollar stabilized and began to appreciate only after October 1998 when the policy stance was tightened again.

The U.S. stock market collapsed in 2000 and Taiwan economy entered a recession due to a slowdown in the U.S. aggregate demand. The period 2000-03 was a period during which Taiwan faced the danger of deflation. Beginning from 2004Q4, the monetary authorities started a series of reduction in discount rates. My estimate indicates that despite the efforts to stimulate the economy, the monetary policy was still relatively tight given the state of the economy. For example, the monetary authorities adjusted the required reserve ratio and the discount rate downward by 122 and 25 basis points, respectively, causing the largest reduction in history. However, the top panel of Figure 9 indicates that there was a contractionary shock during the same period, indicating that the ease of policy, judged from the systematic responses of monetary policy to other variables, was not large enough. Beginning from 2004, the economy recovered gradually from the recession. Possibly due to the uncertainty about whether or not the recession is over, the monetary policy had remained loose. In fact, it was too loose during the whole of 2004.

4 Robust tests

4.1 Horizon $K$ for the sign restrictions

How sensitive are the results to changes in $K$? This section shows that impulse response functions for real GDP when a variety of choices for $K$ are imposed. I had set 3-month ($K = 1$), 6-month ($K = 2$), 12-month ($K = 4$), and 24-month ($K = 8$) horizons.

Figure 10 shows the impulse response functions for real GDP when imposing a variety of choices for $K$. The first row shows the results for a 1-quarter and 2-quarter horizon, while the second row shows the results for 4-quarter and 8-quarter horizon. As one moves from shorter to longer horizons, the
error band seems to move up somehow, and the responses of real GDP become less persistent. Simply said, imposing a smaller $K$ will lead us to find more significant effects of monetary policy shocks. However, the effects of monetary policy shocks on real GDP are significant at most for the first 7 quarters. An exception for this is the case $K = 8$, where I found that imposing a larger $K$ actually makes the effects of monetary policy shocks become insignificant at the first few periods, but become significant in the long run. It should be noticed that a 24-month horizon is not only nontrivial but also very restrictive.

Figure 11 shows the impulse response functions for real GDP to foreign exchange intervention shocks when imposing a variety of choices for $K$. The choice of $K$ does not change qualitatively our results. The only change, if there is any, is that as one moves from shorter to longer horizons, the responses of real GDP to foreign exchange intervention shocks become more persistent.

4.2 Monetary aggregate

So far we have used broad money as the monetary aggregate. In this section I followed Uhlig (2005) and used non-borrowed reserves as the monetary aggregate. This choice is based on the argument of Christiano and Eichenbaum (1992) that innovations to non-borrowed reserves primarily reflect exogenous shocks to monetary policy, while innovations to broad money primarily reflect shocks to money demand. We assume that non-borrowed reserves are non-increasing following a contractionary monetary policy shock. Non-borrowed reserves are calculated as total reserves minus borrowed reserves (discount window). The data have been taken from *Financial Statistics Monthly* published by Taiwan’s monetary authorities.

Figure 12 presents the impulse response to a monetary policy shock. The negative effect on real GDP of a monetary policy shock appears to be very persistent, with the 84-th percentile of the distribution of response of real GDP remaining negative for about 15 quarters following the shock. By using the median response, a rise of about 22 basis point in the interest rate has a negative long-run effect on real GDP of about $-0.25$ percent. This roughly translates into a 1 percent rise in interest rate to a reduction of 1.1 percent in the long-run real GDP, which is almost threefold of the effect found by Mountford (2005) for the U.K. case. I have obtained a point estimate of 2.2 percent when using broad money as the monetary aggregate. This value,

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13Mountford (2005) finds that a 1 percent rise in interest rates reduces long run real GDP by 0.4 percent in the case of UK.
even though greater than the one when using non-borrowed reserves as the monetary aggregate, is statistically insignificant. A one standard-deviation monetary policy shock drives non-borrowed reserves down to 1.0 percent on impact. However, the decrease in non-borrowed reserves is only temporary and the long-run effect of a monetary policy shock on non-borrowed reserves is nearly zero. Another difference with the previous results is that foreign reserves decrease significantly in the medium-term. The responses of interest rate, exchange rate, consumer price index, and crude oil price are qualitatively the same as the previous results.

Figure 13 presents the impulse response to a positive foreign exchange intervention shock. There are two main differences with the previous results: the responses of real GDP has become insignificant, and there is no associated increase in monetary aggregate. To save space, I will not report the impulse responses for aggregate demand, aggregate supply, and oil price shocks. For oil price and aggregate demand shocks, the results are qualitatively unchanged. For aggregate supply shocks, the main differences with the previous results are that positive supply shocks now cause permanent increase in real GDP, interest rate, and monetary aggregate.

Summed up, using non-borrowed reserves as the monetary aggregate indeed brings qualitative changes to our results, in the sense that there is a stronger role for monetary policy shocks and a weaker role for foreign exchange intervention shocks on real GDP.

4.3 Delayed monetary policy shocks

So far I have not taken into account the implementation lag of monetary policy. That is, there is often a lag between the recognition of a need for policy change and the implementation of monetary policy. Furthermore, economic agents are forward-looking so that the expectation that monetary policy will be changed may cause movements in macroeconomic variables well before there are movements in the monetary variables. In this respect, the identified shocks resemble a type of news shock in monetary policy. The identifying restrictions can easily be adapted to address this problem. For the case of a tightening in monetary policy, the identifying restriction is that monetary variables tighten for a defined period only after the first quarter following the shock. I chose a lag of 1 quarter since decision and implementation lag in a monetary policy is perceived to be much shorter than a fiscal policy.

In practice, we take interest rates as the monetary variable, so that delayed monetary policy shocks require that (in addition to the sign restrictions) responses of interest rates to be restricted to zero for a quarter following the recognition of the shock. Implementation of these zero restrictions can be
reformulated as imposing restrictions on the random unit vector \( \alpha \). Specifically, zero restrictions, where the impulse responses of the \( j \)-th variable to an impulse vector \( a \) for the first quarter are set to zero, can simply be incorporated into the analysis. The restrictions can be written as a restriction on the draw \( \alpha \) such that

\[
0 = R\alpha
\]

where \( R \) is a \( 2 \times m \) matrix of the form

\[
R = \begin{bmatrix}
    r_{j1}(0) & \cdots & r_{jm}(0) \\
    r_{j1}(1) & \cdots & r_{jm}(1)
\end{bmatrix}
\]

where \( r_{ji}(k) \) denotes the impulse response of the \( j \)-th variable at horizon \( k \), to the \( i \)-th impulse vector. Since the zero restrictions are imposed on \( \alpha \) (not on the impulse responses), the problem becomes that of finding a \( \alpha \) that is of unit length, while at the same time satisfying the zero restrictions. In our cases where multiple shocks are to be identified, the zero restrictions means to impose restrictions on the \( \Omega \) matrix of the QR decomposition.\(^{14}\)

The responses to the delayed monetary policy shocks are given in Figure 14. The restrictions (both zero and sign restrictions) imposed on the interest rates are indicated by the shaded area on the graph. The figure shows that an expected contraction in monetary policy immediately depresses output and money supply, even though the interest rate is kept constant. After the implementation of the increase in interest rates, the responses of all variables look similar to Figure 1. Like the previous results, the responses of real GDP to monetary policy shocks are significant only at the impact period and at the first period following the shock, and the evolution of other variables are almost identical to the previous results. The long-run effects of a one standard-deviation monetary policy shock on real GDP and broad money are about \(-0.68\) percent and \(-0.55\) percent respectively, while previous results are \(-0.56\) and \(-0.48\) percent respectively. These estimates are approximately equal. Notice that in considering the possibility of an implementation lag in monetary policy, this affects only the identification of monetary policy shocks, and not the identification of other structural shocks. Therefore, the impulse responses for other structural shocks are identical to the previous results. I summarize that my results are robust to the delayed response restrictions that are imposed on the interest rates.

\(^{14}\)I have omitted the discussion on how to impose restrictions on the \( \Omega \) matrix. The details are available from the author.
4.4 The choice of priors

We have been using a natural conjugate prior, Normal-Wishart distribution, which is algebraically convenient. However, it should be noted that the results can be quite sensitive to the specification of an informative prior. Uhlig (2005) suspected that the results should be robust to the choice of prior. He suggested that it would be interesting to investigate that more carefully. However, this conjecture has not been examined so far. In this section I carried out a robust test on prior distribution and I considered 4 additional prior distributions that have been used in the Bayesian VAR literature (Kadiyala and Karlsson, 1997): the Minnesota prior, the Normal-Wishart and Diffuse priors, and the Normal-Diffuse prior.

I followed Kadiyala and Karlsson (1997) to set up the general prior beliefs in the VAR system. I set the prior mean for the parameters on the first own lag to unity and the prior mean of the remaining parameters to zero. As demonstrated by Nelson and Plosser (1982) and others, it is rather difficult to reject the null hypothesis that economic time series follow a random walk with drift. This implies that economic series are expected to follow a random walk, and the prior is specified to reflect this statistical regularity. The prior variances are controlled by the hyper-parameters $\pi_1$ and $\pi_2$, and the variances are scaled to account for differing variability in the variables. For simplicity, the covariances between the parameters have been set to zero. More specifically, the prior variances of the parameters in equation $i$ are specified as:

$$ \text{Var}(\beta_i) = \begin{cases} \frac{\pi_1}{k}, & \text{for parameters on own lags} \\ \frac{\pi_2}{k} \cdot \frac{s_i^2}{s_j^2}, & \text{for parameters on lags of variable } j \neq i \end{cases} $$

where $\beta_i$ is the $i$-th column of $B$, $k$ denotes the lag length and $s_i$ is the residual standard error of a $l$-lag univariate autoregression for variable $i$. The specification allows for the possibility that the importance of the lagged variables decreases with the lag length, so that the prior parameter variances are decreasing with the lag length and becoming tighter around zero. In practice, I let the prior variance decrease with the lag length by a factor $1/k$. As the value of $\pi_1$ decreases, the random walk prior is imposed with greater confidence so that the Bayesian part of the estimate becomes more important.

As the value of $\pi_2$ increases, the zero mean prior for the other parameters

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15 The lag tightness function adopted here is harmonic. Spencer (1993) recommended the use of a harmonic rather than a geometric function because the geometric function seems to get too tight too fast.
are imposed with less confidence and the vector autoregression part of the estimate becomes more important. A common value of the hyper-parameters are of the magnitude $0.05$ for $\pi_1$ and $0.005$ for $\pi_2$. Throughout this section, the tilde denotes parameters of the prior distribution, the bar represents the parameters of the posterior distribution, the least squares estimates of $B$ and $\Sigma$ are denoted by $\hat{B}$ and $\hat{\Sigma}$, respectively.

4.4.1 Minnesota prior

The Minnesota prior of Litterman is frequently used in Bayesian analysis of VAR models. See Litterman (1986) for a discussion and motivation of this prior. The residual variance-covariance matrix $\Sigma$ is taken to be fixed and diagonal. Since the prior distributions on the lags of the endogenous variables are independent Normal, the equations can be treated separately. For the Minnesota prior, the posterior distribution has a closed form solution and it is straightforward to draw from the posterior distribution. In writing the prior for equation $i$ as $\beta_i \sim N\left(\tilde{\beta}_i, \Sigma_i\right)$, we have the posterior as $\beta_i|y \sim N\left(\tilde{\beta}_i, \tilde{\Sigma}_i\right)$, with $\tilde{\Sigma}_i = \left(\Sigma_i^{-1} + X'X/s_i^2\right)^{-1}$ and $\tilde{\beta}_i = \Sigma_i^{-1}\tilde{\beta}_i + (X'X/s_i^2)\hat{b}_i$ where $\hat{b}_i$ is the least squares estimator for equation $i$.

Figure 15 presents the impulse responses to contractionary monetary policy shocks using the Minnesota prior. The Figure is based on 1000 effective posterior draws. The main qualitative difference with the previous results is that real GDP and broad money now decrease permanently following the monetary policy shocks. The negative effect on the real GDP of a monetary policy shock is significant and persistent, with the confidence band of the distribution of responses of real GDP remaining below the zero line for 40 quarters following the shock. The same is true for broad money. Using the median response, a rise of about 22 basis points in the interest rate has a negative long run effect on real GDP of about $-0.64$ percent. Another qualitative difference is that the responses of real GDP to foreign exchange intervention shocks have now become insignificant.

4.4.2 Diffuse prior and Normal-Wishart priors

With the Diffuse (or Jeffrey’s) prior distribution

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$^{16}$Our VAR system does not include intercept term and exogenous variables, so we omit the prior specification of these variables.

$^{17}$The Minnesota prior has been developed mainly by economists associated with the University of Minnesota and the Federal Reserve Bank of Minneapolis. Todd (1984) provided a detailed explanation of the Minnesota prior.
\[ p(\text{vec}(B), \Sigma) \propto |\Sigma|^{-(m+1)/2} \]

the posterior distribution of \( \Sigma \) is Normal-inverse Wishart, with \( \Sigma^{-1} \) following a Wishart distribution \( \mathcal{W}_m\left(\tilde{\Sigma}^{-1}/T, T - P\right) \) where \( P \) is the dimension of \( X \); and that given \( \Sigma \), the columnwise vectorized coefficient matrix \( \text{vec}(B) \) follows a Normal distribution \( \mathcal{N}\left[\text{vec}\left(\tilde{B}\right), \Sigma \otimes \left(X'X\right)^{-1}\right] \), where \( \tilde{B} \) and \( \tilde{\Sigma} \) are least squares estimates of \( B \) and \( \Sigma \) (Zellner, 1971). This is the exact same function of posterior distribution as the one we have been using so far, and it is deduced from a weak Normal-Wishart prior. See equation (4) of the appendix. The only difference is that equation (4) does not adjust for the degree of freedom, however, this is an adjustment that should not lead to qualitative changes in our results. For this reason we shall not pursue the robust test further by using a Jeffrey’s prior.

Like the Diffuse prior, a Normal-Wishart distribution relaxes the assumption of a fixed and diagonal residual variance-covariance matrix of the Minnesota prior. Proposition A.1 on page 670 in Uhlig (1994) states that if the prior is described by \( \tilde{B}, \tilde{N}, \tilde{S} \) and \( \tilde{v} \), then the posterior is described by \( \hat{B}, \hat{N}, \hat{S} \) and \( \hat{v} \), where

\[
\begin{align*}
\hat{v} &= T + \tilde{v} \\
\hat{N} &= \tilde{N} + X'X \\
\hat{B} &= \tilde{N}^{-1}\left(\tilde{N}\hat{B} + X'X\hat{B}\right) \\
\hat{S} &= \frac{2}{\hat{v}}\tilde{S} + \frac{2}{\hat{v}}\tilde{\Sigma} + \frac{1}{\hat{v}}\left(\hat{B} - \tilde{B}\right)'\tilde{N}^{-1}X'X\left(\hat{B} - \tilde{B}\right)
\end{align*}
\]

The parameters of the Normal-Wishart prior have been chosen so that the mean of \( \Sigma \) coincides with the fixed residual variance-covariance matrix of the Minnesota prior. That is to say, for the Wishart prior \( \mathcal{W}_m\left(\tilde{S}^{-1}/\tilde{v}, \tilde{v}\right) \), the diagonal elements of \( \tilde{S} \) are set to

\[
\left(\tilde{S}\right)_{ii} = s_i^2
\]

and the off-diagonal elements are set to zero. \( \tilde{B} \) is set equal to the prior means of the Minnesota prior, and \( \tilde{N} \) is chosen to match the prior variances of the Minnesota prior with the exception that \( \pi_1 = \pi_2 \). All equations are thus treated symmetrically when specifying the prior. Finally, the prior degree of freedom \( \tilde{v} \) is set arbitrarily equal to \( m + 2 \).

Figure 16 presents the impulse responses to contractionary monetary policy shocks by using the Normal-Wishart prior. Similar to the previous results, the responses of real GDP to monetary policy shocks are insignificant, except
for the impact and the first period following the shocks. The responses for
other structural shocks were also similar to the previous results. This is not
surprising because the Normal-Wishart prior we are now using is not much
different from the one we have been using in the main text.

4.4.3 Normal-Diffuse prior

The Normal-Diffuse prior avoids the Normal-Wishart type restrictions on
the variance-covariance matrix of \( vec(B) \) and allows the residual variance-
covariance matrix to be non-diagonal and asymmetric. This prior combines
the multivariate normal prior on the regression parameters of the Minnesota
prior with a diffuse prior on the residual variance-covariance matrix:

\[
vec(B) \sim \mathcal{N} \left( vec(\hat{B}), \hat{\Sigma}_{vec(B)} \right)
\]

\[
p(\Sigma) \sim |\Sigma|^{-(m+1)/2}
\]

It can be shown that the marginal posterior of \( vec(B) \) is proportional
to the product of the marginal prior distribution and a matricvariate \( t \)-
distribution. Even when the prior is specified with a diagonal matrix, the
matricvariate \( t \) part will result in posterior dependence between the equa-
tions. Since the Normal-Diffuse posterior does not have a closed form solu-
tion, we have to rely on Markov Chain Monte Carlo method to draw from
the posterior. Here we adopt the Gibbs sampler, which has been found to
perform better than importance sampling (Kadiyala and Karlsson, 1997). To
implement the Gibbs sampler, we need the conditional posterior distribution
of the parameters that are given below:

\[
vec(B) | \Sigma, y \sim \mathcal{N} \left( vec(\hat{B}), \hat{\Sigma}_{vec(B)}^{-1} + \Sigma^{-1} \otimes X'X^{-1} \right)
\]

(1)

\[
\Sigma^{-1}|vec(B), y \sim \mathcal{W}_m \left( \left( Y - X\hat{B} \right)' \left( Y - X\hat{B} \right) + \left( B - \hat{B} \right)' X' \left( X - \hat{B} \right) \right)^{-1}, T
\]

(2)

where

\[
vec(\hat{B}) = \left( \hat{\Sigma}_{vec(B)}^{-1} + \Sigma^{-1} \otimes X'X \right)^{-1} \left[ \hat{\Sigma}_{vec(B)}^{-1} vec(\hat{B}) + \left( \Sigma^{-1} \otimes X'X \right) vec(\hat{B}) \right]
\]

The Gibbs sampler basically switches between equations (1) and (2). I
started the Gibbs sampler by generating \( vec(B) \) from equation (1) with \( \Sigma \)
as the least squares estimate and used a burn-in period of 1000 draws.
Figure 17 presents the impulse responses to contractionary monetary policy shocks using the Normal-Diffuse prior. The Figure is based on 1000 effective posterior draws. Like the case using the Minnesota prior, the main qualitative difference with the previous results is that real GDP and broad money now decrease permanently following monetary policy shocks. The negative effect on the real GDP of a monetary policy shock is significant and persistent. The same is true for broad money. Furthermore, the responses of real GDP to foreign exchange intervention shocks have now become insignificant.

Summed up, I found insignificant effects of monetary policy and significant effect of foreign exchange intervention shocks when using the Diffuse or the Normal-Wishart prior. In contrast, the effects of monetary policy shocks have become significant and the effects of foreign exchange intervention shocks are weakened when using the Minnesota or the Normal-Diffuse prior. The choice of prior distribution does lead to qualitative changes in our results.

5 Conclusion

In this paper I employed the sign restrictions methodology to study the effects of monetary policy shocks. My results reconfirm the findings of previous studies that monetary policy shocks have insignificant effects on the Taiwanese economy. I showed that the results are robust to the horizons of the sign restrictions and the possibility of delayed monetary policy shocks. However, it should be noticed that the choice of monetary aggregates and prior distributions do lead to qualitative changes in my results.
Appendix: Sign restriction methodology

Consider a VAR in reduced form given by

\[ Y_t = \sum_{i=1}^{l} B(i)Y_{t-i} + u_t, \quad t = 1, 2, \ldots, T, \quad E[u_t' u_t'] = \Sigma \]  

where \( Y_t \) is an \( m \times 1 \) vector of the data, \( B(i) \) are coefficient matrices of the size \( m \times m \), and \( u_t \) is the one-step ahead prediction error with variance-covariance matrix \( \Sigma \). Rewrite the reduced form VAR as a moving average process

\[ Y_t = (I - B_1 L - \cdots - B_l L^l)^{-1} u_t = \sum_{s=0}^{\infty} C_s u_{t-s} \]

The \( i \)-th column of \( C_s \) is the impulse response to the \( i \)-th one-step ahead prediction error. In practice, responses to one-step ahead prediction errors are themselves rarely interesting to us. To interpret the VAR in an economically sensible way, one needs to disentangle the one-step ahead prediction errors \( u_t \) into structural shocks \( v_t \).

\[ u_t = Av_t \]

Let \( a \) be the \( i \)-th column of \( A \). It is easy to see that the impulse response of all variables at horizon \( s \) to the \( i \)-th structural shock is given by

\[ r_s = C_s a \]

Thus, the problem of computing impulse response is reduced to the problem of finding the impulse vector \( a \). Uhlig (2005) show that the impulse vector can be obtained by multiplying any decomposition of the covariance matrix that satisfies \( \tilde{A} \tilde{A}' = \Sigma \) with some vector \( \alpha \) of unit length.

\[ a = \tilde{A} \alpha \]

It should be noted that the shock thus defined is one-standard deviation in size, and it is a linear combination of all statistically orthogonal shocks. This is different to the conventional VAR, where a shock is defined as an increase in a specific variable, not an increase in a combination of all variables. Faust (1998) and Canova and De Nicoló (2002) have used the same definition of shock. See equation (9) in Faust (1998) and appendix of Canavo and De Nicoló (2002). It can be shown that the reordering of the variables and choosing a different decomposition will yield the same results. For convenience, Cholesky decomposition is employed in practice. One can perform variance decompositions as well. The variance of the \( k \)-step ahead forecast

26
revision $E_t [Y_{t+k}] - E_{t-1} [Y_{t+k}]$ due to the impulse vector $a$ is obtained by simply squaring its impulse responses. Let $a_j$ denote the $j$-th column of $\tilde{A}$, the total variance of the $k$-step ahead forecast error is obtained by summing over all $a_j$.

The above procedure is adequate for finding single structural shock. In our case we want to identify multiple shocks, and the above procedure need to be adjusted accordingly. Since structural shocks are assumed to be independent of each other, when identifying more than one structural shocks, each shock is restricted to be orthogonal to all previous identified shocks. Specifically, to identify more than one shocks, one has to take a draw $\alpha_1$ from the unit sphere with dimensions $m$ and calculate impulse vector $a_1 = A\alpha_1$. The same procedure has to be carried out for $\alpha_2$ and further, while satisfying the condition that $\alpha_1, \alpha_2, \ldots$ must be mutually orthogonal. The constraint that structural shocks should be orthogonal to one another is imposed sequentially in Mountford (2005). This sequential method implies that the structural shocks established first are given a greater degree of freedom in searching for impulse vectors that satisfy the sign restrictions than the structural shocks established second and so on. The fact that the order in which the shocks are established could influence the results should be noted.

To avoid this problem, here we follow the algorithm proposed by Rubio-Ramirez, Waggoner, and Zha (2005). The algorithm is more efficient than that of Uhlig (2005) and Mountford (2005). To implement the algorithm, we first draw an arbitrary independent standard normal matrix $\Omega$ with dimension $m \times m$, using the so-called QR decomposition of $\Omega$. This allows us to obtain an orthonormal matrix $Q$ and an upper triangular matrix $R$, where $QQ' = I$ and $QR = \Omega$. Thus we have impulse vectors directly from $AQ$ and the accompanied impulse responses. If the impulse responses fail to satisfy the sign restrictions, we go on to generate a new draw for $\Omega$. In comparison to Uhlig’s algorithm, it does not involve a recursive search procedure, which proceeds column by column. Instead, it draws the impulse vectors directly and simultaneously. It allows one to obtain a posterior distributions of impulse responses based on all simulated draws, without the need to discard any one.

The confidence bands are generated using the Bayesian approach of Sims and Zha (1998) and Uhlig (1994). The approach assumes that the reduced-form VAR errors are normal and i.i.d. and that the prior density for $(B, \Sigma)$ belongs to the Normal-Wishart distribution, thus the posterior density for $(B, \Sigma)$ will also belong to the Normal-Wishart distribution. A Normal–Wishart distribution is parameterized by a mean coefficient matrix $\tilde{B}$ of size $ml \times m$; a positive definite mean covariance matrix $S$ of size $m \times m$, a positive definite matrix $N$ of size $ml \times ml$ and a degrees of freedom $v$. 
The Normal-Wishart distribution specifies that $\Sigma^{-1}$ follows a Wishart distribution $\mathcal{W}_m(S^{-1}/v, v)$ with $E[\Sigma^{-1}] = S^{-1}$, and that conditional on $\Sigma$, the coefficient matrix in its columnwise vectorized form, $\text{vec}(B)$, follows a Normal distribution $\mathcal{N}(\text{vec}(\hat{B}), \Sigma \otimes N^{-1})$.

Assume again a VAR of dimension $m$ with $l$ lags. Parameters of the Normal-Wishart prior are described by $\hat{B}_0$, $N_0$, $S_0$ and $v_0$. Uhlig (2005) uses a weak prior $v_0 = N_0 = 0$ and sets $S_0$ and $B_0$ as arbitrary. Then parameters of the Normal-Wishart posterior are given by

$$\hat{B}_T = \hat{B} = (X'X)^{-1} X'Y$$
$$N_T = X'X$$
$$S_T = \hat{\Sigma} = \frac{1}{T} \left( Y - X\hat{B} \right)' \left( Y - X\hat{B} \right)$$
$$v_T = T$$

(4)

The following procedures are employed to generate the confidence band:

1. estimate the VAR expressed by equation (3) and obtain $\hat{B}$ and $\hat{\Sigma}$
2. use the formula (4) to calculate the parameters of the posterior distribution
3. take a draw of $(B, \Sigma)$ from the posterior distribution and calculate the Cholesky decomposition $\Sigma = AA'$
4. draw an arbitrary independent standard normal matrix $\Omega$ with dimension $m \times m$ and use QR decomposition of $\Omega$ to obtain an orthonormal matrix $Q$
5. calculate impulse vectors $AQ$
6. calculate the impulse responses to $AQ$. If they satisfy the sign restrictions, keep the joint draw $(B, \Sigma, AQ)$, otherwise discard
7. repeat the procedures (step 3 to 5) and collect the 100 impulse responses (and variance decomposition) and plot their 16-th, 50-th, and 84-th percentiles
References


Impulse Responses to Contractionary Monetary Policy Shocks

Figure 1: Impulse Responses to Contractionary Monetary Policy Shocks
Impulse Responses to Positive Oil Price Shocks

Figure 2: Impulse Responses to Positive Oil Price Shocks
Figure 3: Impulse Responses to Positive Aggregate Supply Shocks
Figure 4: Impulse Responses to Positive Aggregate Demand Shocks
Figure 5: Impulse Responses to Positive Foreign Exchange Intervention Shocks
Variance Decomposition due to Contractionary Monetary Policy Shocks

Figure 6: Variance Decomposition due to Contractionary Monetary Policy Shocks
Variance Decomposition due to Positive Foreign Exchange Intervention Shocks

Figure 7: Variance Decomposition due to Positive Foreign Exchange Intervention Shocks
Figure 8: Variance Decomposition due to Oil Price, AS, AD, and FX Intervention Shocks
Figure 9: Structural Monetary Policy Shocks, Foreign Exchange Intervention Shocks and Discount Rates
Figure 10: Different Horizons for the Sign Restrictions, Monetary Policy Shocks
Figure 11: Different Horizons for the Sign Restrictions, Foreign Exchange Intervention Shocks
Impulse Responses to Contractionary Monetary Policy Shocks

Figure 12: Impulse Responses to Contractionary Monetary Policy Shocks, Non-borrowed Reserves as Monetary Aggregate
Figure 13: Impulse Responses to Positive Foreign Exchange Intervention Shocks, Non-borrowed Reserves as Monetary Aggregate
Figure 14: Impulse Responses to Delayed Contractionary Monetary Policy Shocks
Impulse Responses to Contractionary Monetary Policy Shocks

Figure 15: Minnesota Prior
### Impulse Responses to Contractionary Monetary Policy Shocks

#### Real GDP

<table>
<thead>
<tr>
<th>Time (t)</th>
<th>Impulse Responses</th>
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<tr>
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</tr>
<tr>
<td>5</td>
<td>0.25</td>
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<td>1.75</td>
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#### Interest Rate

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<th>Impulse Responses</th>
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</thead>
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<td>0.00</td>
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<tr>
<td>5</td>
<td>0.25</td>
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<tr>
<td>10</td>
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<tr>
<td>35</td>
<td>1.75</td>
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#### Broad Money

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<th>Impulse Responses</th>
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<td>1.50</td>
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<tr>
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<td>1.75</td>
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#### Exchange Rate

<table>
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<tr>
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<th>Impulse Responses</th>
</tr>
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<tbody>
<tr>
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<td>30</td>
<td>1.50</td>
</tr>
<tr>
<td>35</td>
<td>1.75</td>
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#### Consumer Price Index

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<td>1.50</td>
</tr>
<tr>
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<td>1.75</td>
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#### Crude Oil Price

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<th>Impulse Responses</th>
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<td>1.75</td>
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#### Foreign Reserves

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<th>Impulse Responses</th>
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<tr>
<td>35</td>
<td>1.75</td>
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</tbody>
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**Figure 16:** Normal-Wishart Prior
Table 1: Identifying Sign Restrictions

<table>
<thead>
<tr>
<th>Shocks</th>
<th>Real Interest GDP rate</th>
<th>M2 rate</th>
<th>Exchange rate</th>
<th>CPI (US$)</th>
<th>Oil price</th>
<th>Foreign reserves</th>
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<tbody>
<tr>
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<td>Positive oil price</td>
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<tr>
<td>Positive aggregate supply</td>
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<td>Positive aggregate demand</td>
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<tr>
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Table 2: Ordered Probit Model

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<thead>
<tr>
<th>Narrative monetary indicator</th>
<th>Coefficient</th>
<th>z-statistic</th>
<th>$\frac{\partial Pr(y_i=0)}{\partial x_i}$</th>
<th>$\frac{\partial Pr(y_i=1)}{\partial x_i}$</th>
<th>$\frac{\partial Pr(y_i=2)}{\partial x_i}$</th>
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</thead>
<tbody>
<tr>
<td>Monetary policy shocks</td>
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<td>-0.121</td>
<td>0.039</td>
<td>0.082</td>
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Observations: 59

Probability (LR-statistic): 0.523

LR index (Pseudo-$R^2$): 0.004