What are the Effects of Monetary Policy Shocks? Sign Restrictions and Endogeneity of Monetary Policy Actions

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Abstract

Uhlig (2005) proposed VAR models with sign restrictions on impulse responses to identify monetary policy shocks by avoiding the most notorious puzzles in the literature, namely, the price and liquidity puzzles. However, a careful examination of Uhlig (2005)'s results suggest that new puzzles arise as contractionary monetary policy shocks lead to a short-run, if any, rise in output and a long-run decline in the price level without a long-run fall in monetary aggregates. This paper suggests that these new puzzles arise because the identifying restrictions imposed by Uhlig (2005) may fail to separate exogenous monetary policy actions from endogenous, counter-cyclical, monetary policy actions to cost-push supply-side shocks. To identify exogenous monetary policy shocks by avoiding these new puzzles, this paper proposes to identify monetary policy shocks conditioned on supply-side shocks. The results further indicate that the effects of monetary policy shocks on key macro variables, such as stock price, consumption, and employment, change substantially when the modified identification method is used. This finding may imply that the modification of the method is crucial for inferring the effects of monetary policy shocks on the economy.

Keywords: Monetary Policy Shocks, VAR, Sign Restrictions, Supply Shocks, Endogenous Monetary Policy

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1. Introduction

Monetary policy actions are endogenous to the state of the economy, thereby making it difficult to estimate the effects of monetary policy actions on the economy. Unless the exogenous parts of the monetary policy actions are identified properly, the true effects of monetary policy actions are not easily inferred because the effects of monetary policy actions are likely to be mixed with the effects of economic changes that lead to the endogenous monetary policy actions. Therefore, the literature on the effects of monetary policy shocks has evolved by developing various methods to identify exogenous monetary policy shocks. For example, many past studies suffered from various puzzles, such as the price and liquidity puzzles. These puzzles are often regarded as indications that exogenous shocks to monetary policy are not properly identified in the model. Confronted with these puzzles, past studies have developed methods to resolve these puzzles and to identify exogenous monetary policy shocks.[1]

Uhlig (2005) proposed the method of imposing sign restrictions on VAR models to identify monetary policy shocks. The method that is considered brilliant. The nature of the puzzles found in past studies is that the signs of impulse responses of certain variables are problematic. Thus, by imposing proper sign restrictions, the puzzles can be avoided. For example, by imposing the sign restriction that the impulse response of the price level to contractionary monetary shocks is negative, the price puzzle is eliminated. In fact, the restrictions used by Uhlig (2005) are imposed to avoid the two most notorious puzzles in the literature, that is, the price and liquidity puzzles. Uhlig (2005)'s method was perceived as a tremendous success, and it has been widely used not only in studies on monetary policy shocks but also in studies on other structural shocks such as technology and fiscal policy shocks.[2]

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[1] In a monetary expansion, the interest rate is expected to decrease. However, when a monetary expansion is identified by innovations in monetary aggregate, the interest rate increases in some past studies. This is called the "liquidity puzzle." On the other hand, in a monetary contraction, the price level is expected not to increase. However, when a monetary contraction is identified by innovations in the interest rate, the price level increases in some past studies. This is called the "price puzzle." Refer to Sims (1992), Christiano, Eichenbaum, and Evans (1999), and Kim (2013) for a survey of the literature.

[2] For example, see Scholl and Uhlig (2008), Vargas-Silva (2008), and Castelnuovo, E., and P. Surico (2010) for applications on the effects of monetary policy shocks, and Dedola, L. and S. Neri (2007), Enders, Müller, and Scholl (2011), and Mountford and Uhlig (2009) for applications on the effects of fiscal and technology shocks.

However, although two puzzles are avoided by imposing those sign restrictions, Uhlig (2005) found an unconventional result on the effects of monetary policy shocks on output. Uhlig (2005) reported that the effects of monetary policy shocks do not have a clear effect on output and concluded that the neutrality of monetary policy shocks is not inconsistent with the data. However, a careful examination of Uhlig (2005)'s results suggests that contractionary monetary policy shocks lead to, if anything, a rise in output in the short run. In addition, the price level falls in the long run in response to contractionary monetary policy shocks that do not have a clear long-run effect on monetary aggregates. These are puzzling results in view of many of the theoretical monetary models.

This paper suggests that these new puzzles arise due to the failure in identifying exogenous monetary policy actions. Furthermore, the paper provides a simple explanatory story as to why Uhlig (2005)'s identification method may fail to identify exogenous monetary policy actions and why it may produce new puzzles. Based on the story, this paper further suggests how to avoid the new puzzles by providing a modified identification method. The paper also investigates whether the inference on the effect of monetary policy shocks on key macro variables significantly changes if the modified identification method is used in place of the original Uhlig (2005) identification method.

Section 2 explains the VAR models with sign restrictions and new puzzles produced under Uhlig (2005)'s identification method. Section 3 discusses why Uhlig (2005)'s identification method fails to identify exogenous monetary policy shocks, proposes a modified identification method, and show the effects of monetary policy shocks on other key macro variables when the modified identification method is used. Section 4 presents the conclusions and summarizes the findings.

2. Monetary Policy Shocks in Uhlig (2005)

2.1. VAR models with Sign Restrictions

A reduced form of the VAR model is considered:

$$Y_t = B(L)Y_{t-1} + C(L)X_t + u_t, \tag{1}$$

where Y_t is an $l \times 1$ vector of endogenous variables, X_t is an $m \times 1$ vector of exogenous variables, u_t is an $l \times 1$ residual vector, $E(u_t) = 0$, $E(u_t u_t') = \Sigma$, and *B(L)* and *C(L)* are $l \times l$ and $l \times m$ matrix polynomials in lag operator *L*.

In general, reduced-form residuals (elements of u_t) can be written as the linear combinations of structural shocks (elements of v_t) as follows:

$$u_t = Av_t, \tag{2}$$

where A is an $l \times l$ matrix, v_t is an $l \times 1$ vector of structural shocks, $E(v_t) = 0$, and $E(v_t v_t') = 1$. Previous studies recovered orthogonal structural shocks from reduced-form residuals by determining A. For example, the recursive identification strategy developed by Sims (1980) recovers A as a lower triangular matrix by applying Cholesky decomposition on Σ.

Uhlig (2005) has identified structural shocks by imposing sign restrictions on impulse responses. The study has identified only one type of structural shock in particular, that is, monetary policy shock, which amounts to identifying a single column $a \in R^m$ of the matrix A. Uhlig (2005) has defined the impulse vector as follows.

> Definition 1. The vector $a \in R^m$ is called an impulse vector if matrix A exists; thus, $AA' = \Sigma$ and a is a column of A.

Uhlig (2005) has shown that any impulse vector a can be characterized by $a = \tilde{A}\alpha$, where $\tilde{A}\tilde{A}' = \Sigma$ is a Cholesky decomposition of Σ and α is an l-dimensional vector of unit length. Thereafter, the vector impulse response $r_a(k)$ for a can be expressed by the following: $r_a(k) = \sum_{j=1}^{l} \alpha_j r_j(k)$, where $r_j(k) \in R^l$ is the vector response at horizon k to the jth variable in a Cholesky decomposition of Σ. A list of inequality restrictions on the entries of the vector impulse response $r_a(k)$ at various horizons k is then imposed.

Uhlig (2005) suggested the pure-sign restriction and the penalty function approaches. In the pure-sign restriction approach, the draws (from simulation) that do not satisfy the sign restrictions are simply excluded, and the impulse responses with the probability bands are constructed based on the draws that satisfy the sign restrictions on impulse responses, with an equal weight. In the penalty function approach, a monetary policy shock is exactly identified by minimizing some penalty function, which gives a very high penalty on the case in which sign restrictions on impulse responses are not satisfied. Refer to Uhlig (2005) for more detailed explanations on two approaches.

2.2. New Puzzles?

First, I reproduce the results from the baseline model of Uhlig (2005). The following six variables are included in the model: the federal funds rate (FFR), non-borrowed reserves (NBR), total reserves (TR), real GDP (RGDP), commodity price index (CMP), and GDP deflator (PGDP). To identify (contractionary) monetary policy shocks, the following sign restrictions on impulse responses are imposed up to six months after the shock; the federal funds rate increases, but the non-borrowed reserves, commodity price index, and consumer price index decrease. Twelve lags and the constant term are included in the model, and monthly data from 1965 to 2003 are used, as in Uhlig (2005). Figure 1 reports the results using the pure sign restriction approach while Figure 2 reports the results using the penalty-function approach. As in Uhlig (2005), 68% probability bands are reported.[3]

By construction, the federal funds rate increases while the price level, the commodity price, and the non-borrowed reserves fall. Accordingly, neither the liquidity puzzle nor the price puzzle is found. However, the output response is puzzling. In response to contractionary monetary policy shocks, output increases in the short run. In the pure sign restriction approach, the short-run output increase at the third- and the fourth-month horizons is different from zero with more than an 84% probability. In the penalty-function approach, the short-run output increases in the first six months are different from zero with more than an 84% probability. In addition, the increases from the twelfth- to the fourteenth-month horizons are also different from zero with more than an

[3] The main conclusion of this paper still holds when 90% probability bands are used.

84% probability. Given that most theories predict that output will not increase following an exogenous monetary contraction, this may be called the "output" puzzle.

In addition, the relative responses of the prices and the monetary aggregates do not appear to be conventional. Many monetary theories suggest that monetary policy shocks affect the price level and money proportionately in the long run. In fact, some past studies have exploited such a restriction to identify monetary policy shocks in the VAR framework. For example, Fung (1998) imposed a cointegrating relation between the price level and the monetary aggregate to identify monetary policy shocks. Gali (1992) assumed that monetary policy shocks do not affect the real money balance in the long run. However, the results show that the price level and the commodity price index tend to decrease in the long run, while non-borrowed reserves and total reserves do not decrease. In both approaches, the price level decline in 5 years after the shock is different from zero with 84% probability, even though 68% of the probability bands include zero responses of non-borrowed reserves and total reserves in 5 years after the shock. This finding is also puzzling.

3. New Identification Method

3.1. Why are New Puzzles Found?

Uhlig (2005) developed a method to identify monetary policy shocks by imposing sign restrictions to avoid the two most notorious puzzles in the literature, but the identification method seems to produce new puzzles. Intuitively, imposing the sign restrictions to avoid the two puzzles may be necessary to identify monetary policy shocks, but it may not be sufficient. In particular, there may exist structural shocks other than monetary policy shocks that satisfy the sign restrictions.

An example is as follows. Suppose there is a supply-side shock, such as a cost-push shock, that increases output and decreases commodity prices (and also decreases price level over time). Further suppose that the monetary authority takes a contraction to stabilize output and that the effect of the supply shock is partially offset by monetary stabilization. In this case, output would still increase because the stabilization is only partial. The federal funds rate would increase and monetary aggregates would decrease

due to monetary contractions while the price level would decrease due to both cost-push shocks and monetary contractions.

Note that Uhlig (2005)'s sign restrictions cannot rule out such a case. The federal funds rate would increase, but monetary aggregates and the price level would decrease, thus satisfying Uhlig (2005)'s sign restrictions. That is, Uhlig (2005) imposed a set of sign restrictions to identify monetary policy shocks, but this case - cost-push shock with endogenous monetary policy - cannot be excluded. This means that the monetary policy shocks identified by Uhlig (2005)'s method may include not only truly exogenous monetary policy shocks but also cost-push shocks with endogenous monetary policy actions.

Further, if the above conjecture is correct, the newly identified puzzling responses are likely to be observed when truly exogenous monetary policy shocks and cost-push shocks with endogenous monetary policy actions are mixed. Because cost-push shocks are stabilized only partially, output is likely to increase, especially in the very short run, as Figures 1 and 2 show, when the effects of monetary policy shocks on output are still weak. In addition, both the price level and the monetary aggregates are likely to decline because of monetary contractions, but there is an additional force (cost-push shock) to cause the decline in the price level. Therefore, the price level is likely to decline more than the monetary aggregates. Further, if the effects of supply shocks on the price level are persistent while the effects of monetary policy shocks on the monetary aggregate are temporary, the price level will decline in the long run, but the monetary aggregate will not, as in Figures 1 and 2.

3.2. A Modified Identification Method

Although it is not easy to formally prove that the above conjecture is correct, herein, I modify the original identification method of Uhlig (2005) by assuming that the conjecture is correct. I then show that the impulse responses to monetary policy shocks appear more conventional under this modified identification method to illustrate that the conjecture may be correct.

First, I identify cost-push supply-side shocks by imposing sign restrictions that output increases but the commodity price decreases. I then identify monetary policy

shocks that are orthogonal to cost-push supply-side shocks to exclude cost-push supply side shocks from the identified monetary policy shocks.[4] To identify monetary policy shocks, I impose the same sign restrictions used by Uhlig (2005). The restrictions are imposed up to 6 months after the shock, as before. The same six variables are included in the model.

Figures 3 reports the impulse responses to supply-side and monetary policy shocks based on the pure-sign restriction approach. In response to supply-side shocks, the real GDP increases and the commodity price index declines by construction. For other variables, the probability bands include the zero responses for all horizons. The impulse responses to monetary policy shocks then indicate that the puzzling responses disappear. First, the output increase is weaker and now the probability bands include the zero responses for all horizons. Second, both prices and monetary aggregates decrease in the long run, and the decreases are different from zero with 84% probability.

Figure 4 reports the impulse responses based on the penalty function approach. In response to supply-side shocks, the real GDP increases and the commodity price index declines by construction. The price level declines over time, which is different from zero with more than an 84% probability. Interestingly, the federal funds rate increases initially, which may imply that the monetary authority takes a monetary contraction to stabilize output in reaction to the cost-push supply-side shock. This is consistent with the conjectured story.

In Uhlig (2005)'s results, the increase in output is stronger in the case of the penalty function approach than in the case of the pure-sign restriction approach, as reported in Figures 1 and 2. When the modified identification method is used, the puzzle regarding output response disappears in the case of the penalty function approach. Output decline is different from zero with more than an 84% probability. In addition, the prices and the monetary aggregates decrease in the long run, with more than an 84% probability. The sizes of the declines in the price level and the monetary aggregates are also similar, and the median estimates show that the price level, non-borrowed reserves, and total reserves all decline by 3 to 4% in five years.

[4] Refer to Mountford and Uhlig (2009) for technical details

Overall, although it is not so easy to prove the conjecture that monetary policy shocks identified by the original Uhlig (2005) method are contaminated by supply-side shocks with endogenous monetary policy actions, some puzzling responses disappear under the modified identification method based on the conjecture. Accordingly, this may support the conjecture and the modified identification method.

3.3. Effects on Other Key Macro Variables

In this section, I examine how inferring the effects of monetary policy shocks on other macro variables changes when the modified identification method, rather than the original Uhlig (2005) identification method, is used. Each model is extended to include an additional variable. Three macro variables are considered: stock price, consumption, and employment. The first two variables in nominal terms are converted to real terms by dividing each variable by the consumer price index.

Figure 5 reports the impulse responses to monetary policy shocks. At the top of each column, the names of methods are denoted. The first and the third columns of the graphs show the case of the original Uhlig (2005) identification method with the pure-sign restriction (PSR) approach and the penalty-function (PF) approach, respectively. The second and the fourth columns of the graphs represent the case of the modified identification method. At the far left of each row, the names of the responding variables are denoted.

The results show that inferring the effects of monetary policy shocks on these macro variables can change substantially if the modified identification methods, rather than the original Uhlig (2005) method, is used. When Uhlig (2005)'s method is used to identify monetary policy shocks, contractionary monetary policy shocks increase the stock price, and this increase is clearly different from zero with more than an 84% probability for the penalty-function approach. However, the increase is not strong when the modified method is used as even a short-run decrease, which is different from zero with an 84% probability, is found for the penalty-function approach. Similarly, consumption and employment tend to increase in response to contractionary monetary policy shocks when Uhlig (2005)'s method is used, but they tend to decrease when the modified method is used. Such a tendency is clear for the penalty-function approach.

Overall, the effects on key macro variables such as stock price, consumption, and employment change substantially when the modified method is used. This may suggest that using the modified method is crucial when inferring the effects of monetary policy shocks.

4. Conclusions

Uhlig (2005) proposed a innovative method for identifying monetary policy shocks in the VAR framework, which imposes sign restrictions on impulse responses. The imposed restrictions are designed to identify monetary policy shocks without the two most notorious puzzles, namely, the price and liquidity puzzles. However, the method generates other questionable responses as the identified monetary contraction leads to a short-run increase in output and a long-run decline in the price level without long-run declines in monetary aggregates.

This paper suggests that these unconventional results are likely to be due to the failure in identifying exogenous monetary policy actions. In particular, the restrictions imposed by Uhlig (2005) are not strong enough to separate exogenous monetary policy actions from endogenous, counter-cyclical, monetary policy actions to cost-push supply-side disturbances. To avoid new puzzles, this paper proposes a modified identification method, that is, to identify monetary policy shocks conditioned on supply-side shocks. This paper further shows that such a modification is crucial for inferring the true effects of monetary policy shocks on the economy because the effects on key macro variables such as stock prices, consumption, and employment change substantially when the modified method is used.

In general, the results of the current study suggest that researchers should be careful in identifying a limited number of structural shocks by imposing sign restrictions, for example, only monetary policy shock as in Uhlig (2005). The imposed sign restrictions to identify a particular shock may not rule out other types of structural shocks that can satisfy the sign restrictions. In such a case, the identified shock would be mixed with other types of structural shocks, and thus, the identification method may fail. The current study offers such an example.

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Figure 1. Impulse Responses to Monetary Policy Shocks in the Baseline Model: Pure-Sign Restriction Approach

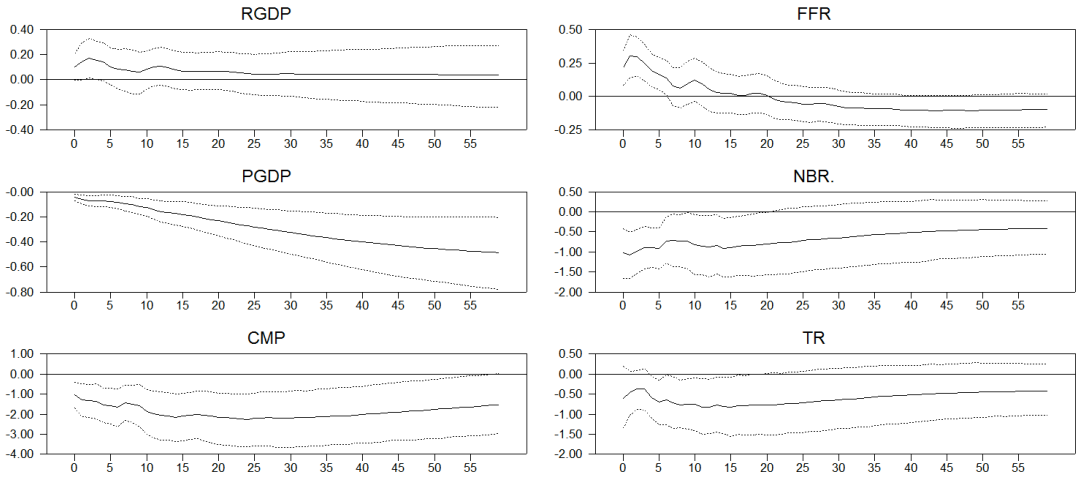


Figure 2. Impulse Responses to Monetary Policy Shocks in the Baseline Model: Penalty-Function Approach

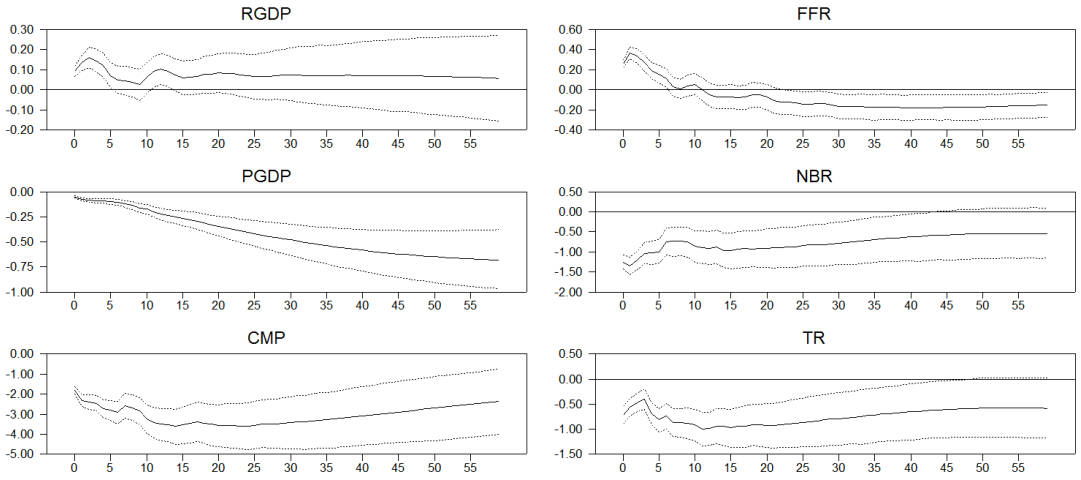
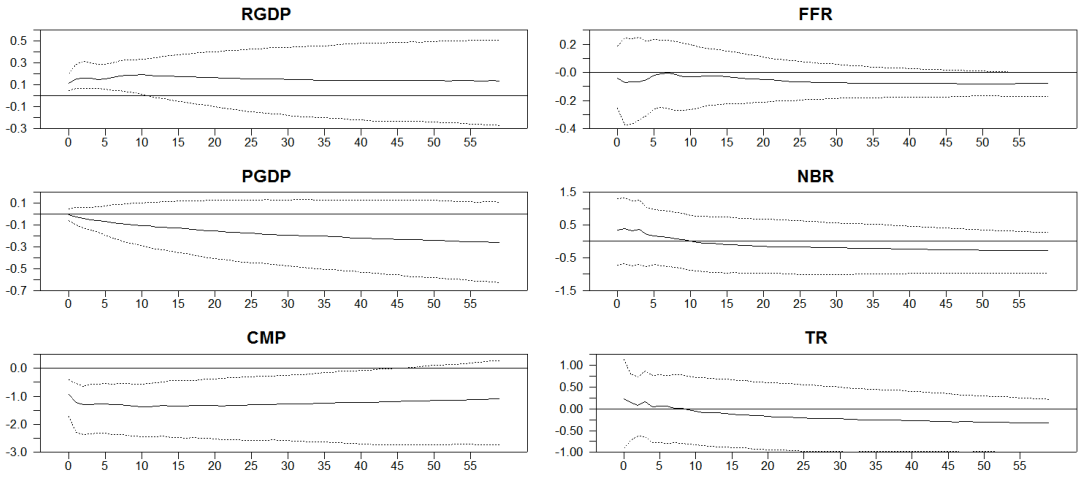


Figure 3. Impulse Responses in the Modified Model: Pure-Sign Restriction Approach

(1) Impulse Responses to Supply Shocks



(2) Impulse Responses to Monetary Policy Shocks

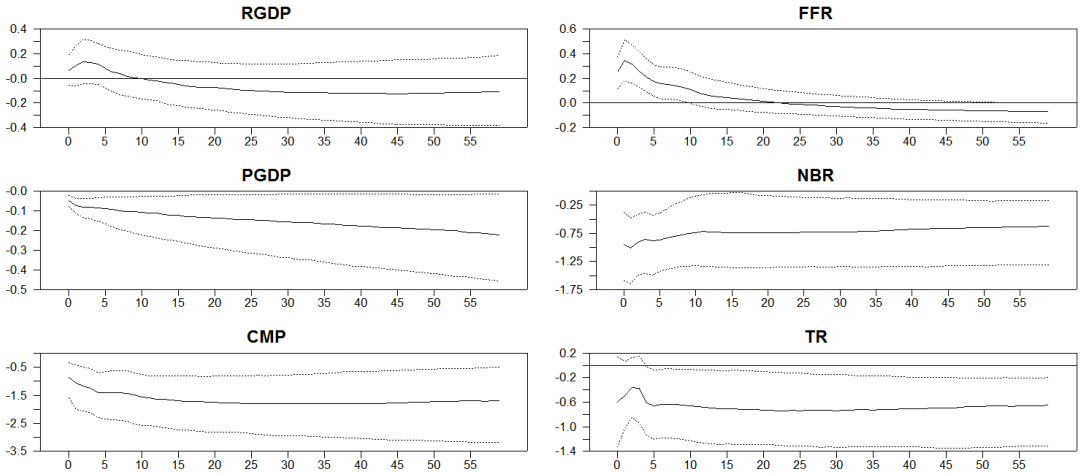
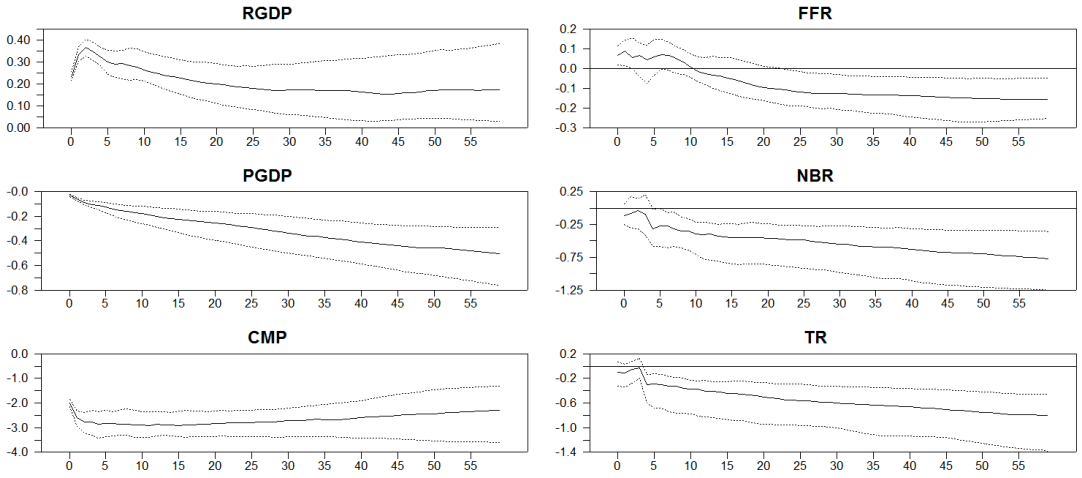


Figure 4. Impulse Responses in the Modified Model: Penalty Function Approach

(1) Impulse Responses to Supply Shocks



(2) Impulse Responses to Monetary Policy Shocks

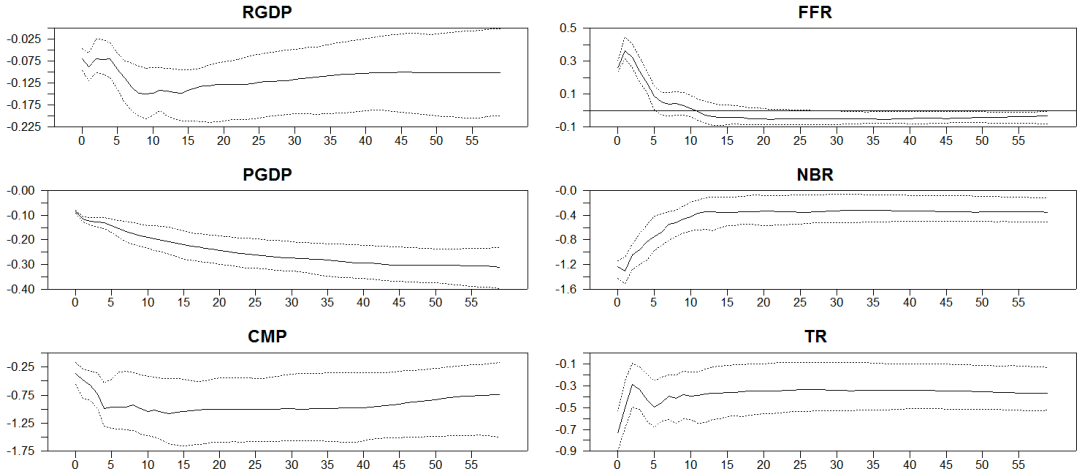


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Figure 5. Impulse Responses to Monetary Policy Shocks: Extended Experiments