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The Impact of Monetary Policy Shocks on RMB Exchange Rate Fluctuations

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Abstract: *Research on the monetary and the exchange rate policy is constituted by reasonable measurement of the relation between those policies and exchange rate fluctuations. In this paper, we employ the structural vector autoregressive (SVAR) model and the symbolic vector autoregressive (VAR) model and combine short-term and long-term restrictions, to establish the impact of monetary policy shocks on the RMB real effective exchange rate index. We avoid both the selection problem of traditional recursive structure variable order, as well as the improper contemporaneous restriction problem of structure decomposition. Taking China's monthly data as the object of study, we performed an empirical study and the results show that. First, the identification methods of the two VAR models provide consistent results and these are more robust than the results of recursive decomposition. Second, the impact of monetary policy shocks on the RMB real effective exchange rate index leads to both the foreign exchange rate puzzle and the overshooting puzzle. However, the period of overshooting is obviously earlier. The impact of monetary policy shocks on output plays a positive role in the short-term, but, in the long-term, it manifests as raising the level of output. The impact of monetary policy shocks does not lead to the price puzzle and the proportion of a rise in price is the same as that of monetary expansion. According to the variance decomposition on the future forecasts of the RMB real effective exchange rate index, we find that the explanatory proportion of monetary policy shocks is about 20% between the estimates of foreign literature. Finally, we test model robustness and found that the results do not change with the increase of variables or the maximum number of restriction phases.*

1. INTRODUCTION

With the gradual enhancement of world economic integration, with each passing day the economic connections among various countries, all over the world, are being strengthened. In this context, both theoretical researchers and macroeconomic policy makers have to analyze national macroeconomic problems under the framework of an open economy. In an open economy, the magnitude of exchange rate fluctuations provides an important basis for interventions into the exchange rate by the central bank[1] [2][3]. It is thus of vital significance to investigate the impact of monetary policy on exchange rate fluctuations, its action mechanism and pathway. In fact, in an open economy, there are clear interactions between monetary policy and foreign exchange rate fluctuations. A reasonable measurement of the relation between the two variables constitutes important research on monetary policy and foreign exchange policy [4]. New Keynesians begin with the notion of dynamic stochastic general equilibrium (DSGE) and claim that the theory and practice of monetary policy in an open economy should pay close attention to exchange rate fluctuations[5][6].

The impact of monetary policy on exchange rate fluctuations is not a new topic in the international community; however, there are frequent contradictions between theoretical and empirical studies in the field. According to many theoretical studies, under the expansionary monetary policy formulated by the central bank, the foreign exchange rate has the maximum instant depreciation and the depreciation rate exceeds the percentage of monetary expansion, in which case the magnitude of exchange rate depreciation is equivalent to the proportion of monetary expansion. Price, because of its short-term stickiness, slowly increases to the proportion of monetary expansion, a phenomenon referred to as Dornbusch's overshooting theory [1]. However, the conclusion drawn by empirical studies is that the exchange rate is not instantly depreciated to the maximum extent, and that, instead, maximum depreciation occurs two or three years after monetary policy expansion. This phenomenon is named "the issue of delayed exchange rate overshooting". With regard to such phenomena, some scholars proceed from economic theories to offer a qualitative understanding. For instance, Kim (2005) holds that, in the case of foreign exchange rate fluctuations caused by monetary policy shocks, what the central bank adopts is an adverse intervention, which gives rise to delayed overshooting [7]. However, more scholars attempt to answer the aforementioned questions from an empirical perspective.

Early empirical studies on the relation between monetary policy shocks and exchange rate fluctuations primarily use the VAR model developed by Sims (1980) for identification purposes, through the recursive structure decomposition of the model [8]. This approach can effectively avoid the Lucas critique. Eichenbaum and Evans (1995) took the lead to employ this approach to explore the relation between monetary policy shocks and exchange rate fluctuations [9]. According to their study, because of the contractionary monetary policy of the US, the USD, relative to the currencies of other countries (Yen, Deutsche Mark, Franc and so forth), showed a phenomenon of delayed overshooting, which persisted for roughly two to three years. In investigating the impact of monetary policy shocks on the foreign exchange rate in G-7 countries, Grilli and Roubini (1996) also discovered the widespread delayed overshooting and the prevalent price puzzle, and it was found that such phenomena would not change substantially, even under different measurement settings [10]. Leeper et al. (1996) introduced more variables into their study, applied the same recursive structure identification procedure and reached consistent conclusions[11]. Mojon and Peersman (2003), as well as Favero and Marcellino (2004), tested the monetary policy shocks of some European countries [12][13] and Lindé (2003) focused his attention on Sweden[14]. They have all found that an expansionary monetary policy leads to exchange rate appreciation, i.e. the so-called puzzle of foreign exchange rates or gives rise to exchange rate depreciation. However, exchange rate depreciation usually occurs after several phases; that is, there is delayed overshooting or the forward discount puzzle. These conclusions are obviously contrary to Dornbusch's exchange rate overshooting theory and uncovered interest rate parity (UIRP). Kim and Robbini (2000) were the first to raise an objection to the above empirical results [15]. According to them, the recursive structure decomposition of the above VAR model is relatively effective for analyzing a closed type of economy. For instance, because of the limited impact of the policies of other countries, an open economy as large as the US can be deemed as a closed type of economy and applying the recursive structure decomposition of VAR for identification purpose can be effective. However, when it comes to a small open economy, the same VAR model may fail, because the exchange rate fluctuations of small open economies lead to inflation variations. Inflation is an important macroeconomic policy target for all countries. So, with exchange rate fluctuations, monetary policy is instantly adjusted, which suggests that there are contemporaneous responses between the exchange rate and monetary policy. To study monetary policy shocks, the classic recursive structure identification procedure must place the variable representing the monetary policy of the central bank before the exchange rate and monetary policy does not respond contemporaneously to exchange rate fluctuations. This setting is unnecessary and lead to the above phenomena. Similarly, Faust and Rogers (2003) believe that the recursive structure-based VAR is very sensitive to settings and is deficient when processing the simultaneity between monetary policy and foreign exchange rate, giving rise to deviations in results [16].

Because of the above problems with recursive structure, many studies unfold under the non-recursive structure decomposition of VAR. For instance, Cushman and Zha (1997), based on block-wise recursive structure, found that there was a phenomenon of delayed exchange rate overshooting between the USD and the Canadian Dollar [17]. Kim and Roubini (2000) used the structural VAR model to analyze the impact of monetary policy shocks on exchange rate in G-7 countries, and discovered that phenomena such as overshooting and the price puzzle existed only with some currencies; they claimed that considering contemporaneous correlation would provide one of the most important methods of effectively avoiding these puzzles [15]. Faust and Rogers (2003) introduced the sign restrictions between the current impacts of variables to identify the impact of monetary policy shocks on the exchange rate [16]. Jang and Ogaki (2004) adopted the long-term restrictions of the structural vector error correction model and discovered the phenomenon of delayed overshooting [18]. However, the peak occurred earlier than the recursive decomposition of the traditional VAR model. According to Kim (2005), the emergence of these puzzles in previous empirical studies can be explained from two aspects [7]: first, their models or methods were incorrect and second, when the monetary policy introduced a contractionary monetary policy, the foreign exchange rate would be appreciated, so the government would take adverse interventions to control the amplitude of appreciation. However, such interventions were temporary because foreign exchange rate appreciation would ultimately reach its peak (that is, giving rise to the problem of delayed overshooting). These results were confirmed by their example about the USD and the Canadian Dollar.

However, the recursive decomposition of VAR and the structure decomposition of short-term restrictions only pay attention to the current impact of variables, but neglect their long-term impact. Bjørnland (2009), combining long-term restrictions and classic short-term restrictions to investigate the long-term impact of monetary policy on the exchange rate, identified the problem of exchange rate overshooting in some countries and found that, in most countries, the phenomenon of delayed exchange rate overshooting did not exist[4]. This suggests that the afore-mentioned results about the impacts of monetary policy on output and price are consistent with the viewpoints of most economists; that is, in the short term, monetary policy has a certain effect for output, but, in the long term, its role is mainly embedded in price.

First, in recursive structure decomposition, different variable orders lead to different conclusions, and the meanings of shocks differ as well, not to mention that, in reality, we know little about variable orders. Second, no matter whether it is based on short-term, long-term restrictions or a combination of the two, the structure decomposition of the VAR model is always set with some improper current impact. The sign restrictions proposed by Uhlig (2005) impose loose requirements on variable orders and usually, one variable is fixed for studying its impact on other variables, thus avoiding both the selection problem of recursive structure variable order and the improper contemporaneous restriction problem of structure decomposition [19]. Scholl and Uhlig (2008) introduced a symbolic VAR test to investigate the impact of monetary policy on the foreign exchange rate [20]. Rafiq and Mallick (2008) adopted sign restrictions to decompose the effect of monetary policy for output [21]. Canova and Nicolo (2002) employed the sign restrictions of covariance structure to analyze the disturbances of monetary policy and economic cycle [22]. At present, there is more and more literature that adopt the symbol identification method of the VAR model in domestic research. For instance, Zhao and Zhang (2012), for the first time, introduced the symbolic VAR method to explore the impact of monetary policy shocks on the economy in China[23].

To make up for the deficiencies of the VAR model based on short-term restrictions, we adopt both the identification method, combining short-term and long-term restrictions and the VAR model based on symbol identification to empirically study the impact of monetary policy shocks on the exchange rate in China. We also attempt, from a quantitative perspective, to answer the question of the impact pattern of monetary policy shocks on the exchange rate in the domestic economy. To verify the reliability of this approach, we also perform a robustness test. The structural arrangement of the rest of this paper is as follows: Part II provides the models and methods, including the VAR model used to identify monetary policy shocks; Part III is the empirical study; Part IV unfolds the robustness test and conclusions are drawn in Part V.

2 MODELS and METHODS

2.1 Identification of the short-term and long-term restrictions of structural VAR

The simplified formula of a *p*-order lagged VAR model can be expressed as follows:

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + \cdots + B_p Y_{t-p} + e_t, t = 1, \cdots, T \quad (1)$$

Wherein, Y_t represents $m \times 1$-dimensional endogenous variable vector. B represents the coefficient matrix. e_t represents the error vector of the one-step-ahead forecast, the variance-covariance matrix of which is $E[e_t e_t'] = \Sigma$. How to further decompose future forecast error e_t into various basic shocks, constitutes a premise of producing impulse response and variance decomposition. Assuming that there are m basic shocks, that they are mutually independent and that their variances are normalized as 1, then the normalized orthogonal shock vector can be represented by ε, the dimension can be represented by $m \times 1$ and the diagonal matrix can be represented as $E[\varepsilon\varepsilon'] = I_m$. To identify the structural shock of the model's contemporaneous impact, the usual practice is to find a matrix A that meets $e_t = A\varepsilon_t$, wherein, the j^{th} column of A represents the impact of one unit of standard deviation shocks of the j^{th} variable on all endogenous variables. A satisfies:

$$\sum = E[e_t e_t'] = AE[\varepsilon_t \varepsilon_t']A' = AA' \qquad (2)$$

It is clear that $\sum$ is a symmetric matrix that can be directly estimated from the residual of the VAR model, however, to identify shock matrix A, at least $m(m-1)/2$ restrictions must be imposed on matrix A, otherwise it is impossible to identify matrix A. Based on our model design and data collection, assuming that Y_t is a (5×1)-dimensional macroeconomic variable, these variables can be ranked according to the following rule; that is, $Y_t = [i_t^*, IP_t, CPI_t, M_t, EX_t]'$. Wherein, i_t^* represents the federal fund rate of the US. IP_t represents the logarithm of seasonally-adjusted gross industrial output value in real terms. CPI_t represents the logarithm of seasonally-adjusted consumer price index. M_t represents the logarithm of seasonally-adjusted money supply. EX_t represents the logarithm of real effective exchange rate index. If the VAR system of Model (1) is stable, the VAR will be reversible and can be expressed in the form of a moving average. Regardless of intercept, time trend and other deterministic components, this model can be expressed as:

$$Y_t = B(L)e_t, \qquad (3)$$

Wherein, e_t represents the regression residual vector of (5×1)-dimensional simplified formula model. $e_t \sim iid(0, \Omega)$ represents independent identical distribution. Ω represents the independent positive definite covariance matrix. $B(L)$ represents the lag polynomial, i.e., $B(L) = \sum_{j=0}^{\infty} B_j L^j$. L represents the lag operator. Assuming that the orthogonal structural shock (ε_t) can be written as a linear combination of residual term (that is, $e_t = S\varepsilon_t$, wherein S represents the contemporaneous correlation matrix), then Formula (3) can be expressed as:

$$Y_t = C(L)\varepsilon_t \qquad (4)$$

wherein, $C(L) = B(L)S$ represents long-term impact matrix. To identify S, we first regularize ε_t as a unit variance. After expressing it as an uncorrelated structural shock (i.e., $\varepsilon_t = [\varepsilon_t^{i^*}, \varepsilon_t^{IP}, \varepsilon_t^{CPI}, \varepsilon_t^{M}, \varepsilon_t^{EX}]'$), we set matrix S according to the matrix setting requirements of contemporaneous impact, as follows:

$$\begin{bmatrix} i^* \\ IP \\ CPI \\ M \\ EX \end{bmatrix}_t = B(L) \begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \begin{bmatrix} \varepsilon^{i^*} \\ \varepsilon^{IP} \\ \varepsilon^{CPI} \\ \varepsilon^{M} \\ \varepsilon^{EX} \end{bmatrix}_t \quad (5)$$

However, the above short-term restrictions cannot satisfy the identification requirements and the structural VAR needs to satisfy $m(m-1)/2$ restrictions in just identification. According to the requirements of the VAR system based on short-term and long-term restrictions, only a just-identified model can be used for identification purposes. Based on the above short-term restrictions, we also need to set the matrix $C(L)$ of long-term restrictions according to the theory:

$$\begin{bmatrix} C_{11}(L) & C_{12}(L) & C_{13}(L) & C_{14}(L) & C_{15}(L) \\ C_{21}(L) & C_{22}(L) & C_{23}(L) & C_{24}(L) & C_{25}(L) \\ C_{31}(L) & C_{32}(L) & C_{33}(L) & C_{34}(L) & C_{35}(L) \\ C_{41}(L) & C_{42}(L) & C_{43}(L) & C_{44}(L) & C_{45}(L) \\ C_{51}(L) & C_{52}(L) & C_{53}(L) & C_{54}(L) & C_{55}(L) \end{bmatrix} = B(L) \begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \quad (4)$$

According to matrix expressions and the above analysis, on the one hand, monetary policy exerts a contemporaneous impact on exchange rate fluctuations. On the other hand, such impact only sustains on a short-term basis. Relative to the infinite-dimensional lag polynomial coefficient $\sum_{j=0}^{\infty} C_{54,j}$ =0 (wherein, $B(1)S = C(1)$, $B(1) = \sum_{j=0}^{\infty} B_j$, $C(1) = \sum_{j=0}^{\infty} C_j$) in Formula (5), this five-dimensional matrix has a long-term restriction, that is, $C_{54}(1) = 0$.

$$\begin{bmatrix} i^* \\ IP \\ CPI \\ M \\ EX \end{bmatrix} = \begin{bmatrix} B_{11}(L) & B_{12}(L) & B_{13}(L) & B_{14}(L) & B_{15}(L) \\ B_{21}(L) & B_{22}(L) & B_{23}(L) & B_{24}(L) & B_{25}(L) \\ B_{31}(L) & B_{32}(L) & B_{33}(L) & B_{34}(L) & B_{35}(L) \\ B_{41}(L) & B_{42}(L) & B_{43}(L) & B_{44}(L) & B_{45}(L) \\ B_{51}(L) & B_{52}(L) & B_{53}(L) & B_{54}(L) & B_{55}(L) \end{bmatrix} \begin{bmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \begin{bmatrix} \varepsilon^{i^*} \\ \varepsilon^{IP} \\ \varepsilon^{CPI} \\ \varepsilon^{M} \\ \varepsilon^{EX} \end{bmatrix} \quad (6)$$

From Formula (6) we can know that $B_{51}(1)S_{14} + B_{52}(1)S_{24} + B_{53}(1)S_{34} + B_{54}(1)S_{44} + B_{55}(1)S_{54} = 0$ $= C_{54}(1)$, which can be simplified as $B_{54}(1)S_{44} + B_{55}(1)S_{54} = 0$. In this case, the model is just-identified and the number of short-term and long-term restrictions combined is exactly equal to ten. For estimation purposes, this model must also be a just-identified model [4].

2.2 Sign restrictions approach for VAR model identification

What is analyzed above is the approach combining short-term and long-term restrictions, however, more restrictions are involved in this case. With the improvement of VAR identification technology, there is a new identification procedure called symbolic VAR, which only identifies the shocks of a specific variable and can be restricted to the current phase or multiple phases. According to Uhlig (2005), to identify monetary policy shocks, it is required to define the vector m_2 from monetary policy shocks [19], as it is a column of matrix A in Formula (2); that is, $m_2 \in R^m$. This column is also referred to as impulse vector by Uhlig, where A satisfies $AA' = \Sigma$. The impulse vector m_2 from monetary policy can be obtained through the Cholesky decomposition. Assuming that

$\Sigma = \tilde{A}\tilde{A}'$ is the Cholesky decomposition of Σ, there must be an $m \times 1$-dimensional vector α with a unit length of 1, which satisfies $m_2 = \tilde{A}\alpha$. Thus, impulse vector m_2 can be expressed as a linear combination of impulse responses obtained under the Cholesky decomposition of Σ. Under the Cholesky decomposition of variance-covariance matrix Σ, assuming that $r_i(k) \in R^m$ is the phase-k impulse response to the Cholesky decomposition of the i^{th} innovation shock of Σ, the impulse response vector $r_{m_2}(k)$ of monetary policy shocks m_2 can be expressed as:

$$r_{m_2}(k) = \sum_{i=1}^{m} \alpha_i r_i(k) \tag{7}$$

According to the error correction formula $E_t[Y_{t+k}] - E_{t-1}[Y_{t+k}]$ of k-step-ahead forecast, we can use $\varphi_{m_2,j,k}$ to represent the explanatory proportion of impulse vector m_2 in the error of a k-step-ahead forecast of variable j based on sign restrictions; that is, the explanatory proportion of future forecast variance. The specific formula can be expressed as:

$$\varphi_{m2,j,k} = \frac{(r_{m_2,j}(k))^2}{\sum_{i=1}^{m} (r_{i,j}(k))^2} \tag{8}$$

According to Formulas (7) and (8), we can perform symbol identification on the VAR system of multiple variables. To identify the impulse vector, *a*, of monetary policy shocks, considering an expansionary monetary policy, a positive integer *K* is given in advance to represent the maximum number of restriction phases and it is assumed that $0 \le k \le K$ represents the number of post-shock phases. For instance, under the framework of an expansionary monetary policy, the rules of our sign restrictions are that the short-term output presents a rise $IP(k) > 0$, that the consumer price index also shows a rise $CPI(k) > 0$ and that the monetary policy reveals a continuous rise $M_2(k) > 0$ because of inertia, wherein, $k = 0, \cdots, 5$ means that post-shock phases 1~5 are all positive.

3. EMPIRICAL STUDY

3.1 Data selection and description

The variable selection in this paper is primarily based on the settings of the small open economy model of new Keynesianism and is consistent with the variable selection of Bjørnland (2009) and other literature[4]. The specific variables include the logarithm (IP) of price-adjusted and seasonally-adjusted monthly Chinese industrial added value, the logarithm (CPI) of the month-on-month consumer price index, the logarithm (M2) of price-adjusted and seasonally-adjusted monthly broad money supply, the logarithm (EX) of real effective exchange rate index and the monthly federal fund rate of the US (i^*). The specific real effective exchange rate index is extracted from data released by the International Monetary Fund (IMF). The rise of the real effective exchange rate index represents the appreciation of the domestic currency and its decline represents the depreciation of the domestic currency. Real effective exchange rate, not only considers the currency fluctuations of the main trading partners of a country, but also eliminates the inflation factor, thus, more truthfully reflecting the external value of the currency of a country. Therefore, this paper adopts the real effective exchange rate index. Given that this index is expressed through indirect quotation, we use the reciprocal after logarithm taking to represent the real effective exchange rate, as is consistent with the habit of direct quotation. As for the variable of monetary policy, this paper introduces money supply. Western scholars may have some problems with adopting money supply as a proxy variable of monetary policy index (as money supply is subject to money demand shocks). However, they believe that, with the degree of interest rate liberalization currently being at a moderate level in China, money supply can still serve as a relatively satisfactory proxy index. This paper also selects money supply as the variable of monetary policy, due to the absence of monthly GDP data, this paper takes an approach consistent with that adopted by both foreign and domestic literature and, instead, adopts the data on monthly Chinese industrial added value. The absolute numbers of the monthly Chinese industrial added value, provided by the National Bureau of Statistics, are limited to 2007, so we use the year-on-year growth rate data to deduce the absolute numbers of subsequent months.

The reform of the foreign exchange system in 1994 unified the exchange rate of the foreign exchange adjustment market and the official exchange rate, resulting in a substantial depreciation of the exchange rate, followed by a constant small-amplitude appreciation until July 21, 2005; the day the People's Bank of China announced a one-off appreciation of the RMB by 2%. As a result, the USD-RMB exchange rate changed from 8.2765 on July 21, 2005, to 8.11 on July 22, 2005. Given that the weights of the USD in the nominal exchange rate index and the real exchange rate index had always been stabilized above 30%, this resulted in significant rises in the nominal exchange rate index and the real exchange rate index provided by both the Bank for International Settlements (BIS) and the IMF. If the study interval were to be set before 1994 or 2005, the data on the exchange rate index would show abrupt structures. Given that other contemporaneous data experienced no such policy-related change, this would complicate the study model and/or make it difficult to fit the relations among variables. Thus, this paper selects the period from July 2005 to February 2014 as its study interval.

3.2 Empirical result analysis

This paper adopts both the identification method combining short-term and long-term restrictions and the VAR model, based on symbol identification, to conduct an empirical study. In this empirical study, no test was performed on the unit root or co-integration of data, mainly because, in the VAR system, even if some variables contain a unit root or a higher integration order, there are still other variables that are stationary. As long as the VAR system is stable, it will not interfere with the judgment, forecast or decomposition of the VAR model [18]. In this paper, we increase one unit of standard deviation for money supply to express expansionary monetary policy shocks. According to the AIC and SC criteria on lag length selection, we determine the optimal lag length as four phases. Although the variables are instable, the roots of the model all fall within the unit circle and the maximum root is 0.75, suggesting that the model can be expressed in the form of a moving average. Next, we put the residual of the VAR model through three different structure decompositions to obtain the impact of monetary policy shocks on various variables.

3.2.1 Recursive structure decomposition of VAR

First, we use the traditional recursive structure to investigate the fluctuations in the RMB real effective exchange rate index caused by monetary policy shocks in the VAR model and obtain the impulse responses shown in Figure 1 through recursive structure decomposition. As can be seen from Figure 1, because of expansionary monetary policy shocks, the exchange rate experienced a moving process from appreciation to maximum depreciation. In the 13th step (month), even the impact of monetary policy shocks on the exchange rate was negative; that is, there was still an appreciation effect. Around the 25th phase, there was no longer any impact. The above results, first and foremost, suggest that the impact of monetary policy shocks on the exchange rate presents cyclic changes. Second, the explanation of monetary policy shocks by this model, contradicts classic monetary policy theories, possibly because of the following two reasons: 1) the orders of variable decomposition are different and 2) the exchange rate does not impact monetary policy in contemporaneous restrictions. To change this status, we use the structure decomposition of the VAR model based on short-term and long-term restrictions for the purpose of analysis.

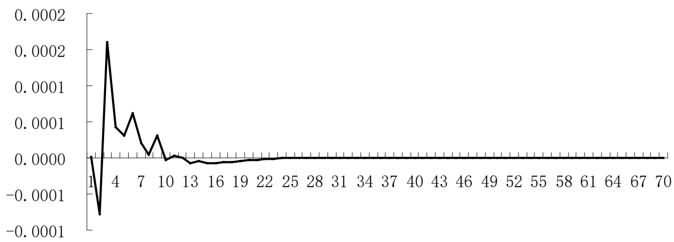

Figure 1: The impact of monetary policy shocks on exchange rate index

3.2.2 Decomposition of short-term and long-term restrictions

First, the above model only applies short-term restrictions in the form of recursive structure decomposition and gives consideration to long-term restrictions. However, according to theoretical analysis, monetary policy has no long-term impact on the exchange rate, which is consistent with the basic assumptions of standard macroeconomic models in an open economy. Second, Gali (1999), Blanchard and Quah (1988) et al. all adopt long-term restrictions to analyze the shock responses among variables in their empirical studies[24][25]. Considering that there are contemporaneous responses between exchange rate fluctuations and monetary policy in the short term, we introduce the approach combining short-term and long-term restrictions proposed by Bjørnland (2009)[4] for estimation purposes and the main identification restrictions are set as required by Formula (6). In this case, the model is just-identified and, through identification, we obtain the shock responses of various variables. For the purpose of simplification, this paper only plots the shocks of monetary policy on output, the price index and the RMB real effective exchange rate index.

As can be seen from Figure 2, the implementation of an expansionary monetary policy resulted in the rise of output, which reached its maximum, roughly, in the 20th month and then tended to stabilize thereafter. According to the standard explanation of macroeconomics, monetary policy exerts a certain impact on output in the short term, but has no long-term impact on the outcome. The empirical results of this paper verify this conclusion, and, in the long-term, it adopts the role of raising the output level. In Figure 3, an expansionary monetary policy exerted no significant short-term impact on the price index, mainly because of the stickiness of price in the short term. In the long term, it caused the price index to rise continuously, reaching its maximum in approximately the 25th month, consistent with the study conclusions drawn by Uhlig (2005)[19].

The next step was to study the core variable of this paper, i.e. the response of the foreign exchange rate to monetary policy shocks. As can be seen from Figure 4, the instant response of the foreign exchange rate to monetary policy shocks first appreciated and then gradually depreciated until reaching maximum depreciation in the 10th phase. However, after the 20th phase, the fluctuations in the RMB real effective exchange rate index presented a level condition. According to the results shown in Figure 4, in the face of monetary policy shocks, the RMB real effective exchange rate index first experienced a foreign exchange rate puzzle; that is, it rose (instead of declining) under expansionary monetary policy shocks. Second, there was an exchange rate overshooting puzzle; that is, the exchange rate continuously depreciated in an amplitude exceeding that of monetary expansion, followed by appreciation, but the overall amplitude of depreciation was consistent with the amplitude of monetary expansion. Compared with the aforementioned recursive results, this is obviously more consistent with reality and similar, to some degree, to international empirical studies. It also suggests that, on the one hand, the monetary policy of China may undergo contemporaneous changes with exchange rate fluctuations. For instance, the rise of the RMB real effective exchange rate requires the passive rise of money supply, so there is a foreign exchange rate puzzle. On the other hand, the time of exchange rate overshooting is obviously early, which further demonstrates the reliability and reasonability of the model, based on short-term and long-term restrictions.

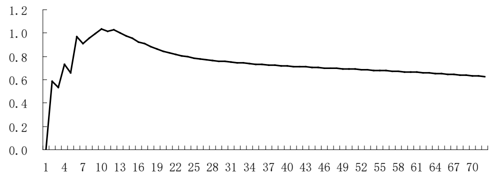

Figure 2: The impact of an expansionary monetary policy on output

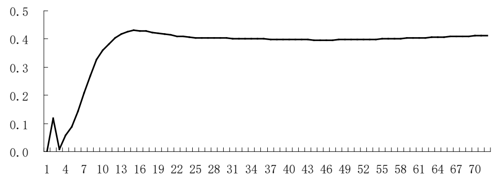

Figure 3: The impact of an expansionary monetary policy on the price index

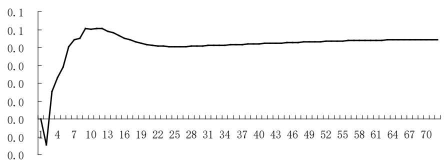

Figure 4: The impact of an expansionary monetary policy on the exchange rate index

3.2.3 Decomposition of sign restrictions

Bjørnland (2009) took symbol identification as an approach to performing a robustness test on short-term and long-term restrictions [4]. This paper regards sign restrictions as another important approach to identification and as a supplement to the existing approach. The short-term and long-term restrictions on sign restrictions are realized through setting the maximum K value in Formula (7). Wherein $K = 0$ represents a current restriction,while $K = 5$ represents a varying restriction whose impacts in the coming five phases are all positive or negative (specifically identified according to the positive sign or negative sign of column 4 in Formula (9); i.e. the monetary policy shocks vector column). In fact, values can be freely assigned to some variables in column 4, so this is an open system that is more flexible than both the decomposition based on short-term restrictions and the decomposition combining short-term and long-term restrictions. The confidence interval of the model based on short-term restrictions is obtained through re-sampling from posterior distribution and the confidence belt can be expressed by the quantiles 16% and 84%. If it obeys normal distribution, it will be equivalent to the range of fluctuation of one unit of standard deviation. We believe that monetary policy shocks already have an inertia effect for money supply, which continuously raises money supply. In fact, China's money supply has also witnessed a month-by-month rise in these years. The impacts of monetary policy shocks on the price index and output are positive and this is a standard conclusion drawn in monetary economics literature. In the end, we impose no restrictions, on either foreign exchange rate fluctuations, or the fluctuations in the federal fund rate of the US. This measure involves 3 relations; i.e. positive impact, negative impact or no impact (0). See the specific relations in Table 1 [or they can be expressed by column 4 in Formula (9)).

Table 1: Responses of various variables under expansionary monetary policy shocks

Various variables in the model	Foreign interest rate	GDP	Price index	Money supply	Foreign exchange rate
Response to expansionary monetary policy shocks	Free	+	+	+	Free

Note: "+" is used to represent non-negative sign restriction and "free" or "**.**" represents that no restriction is imposed on signs in the face of shocks

$$\begin{bmatrix} i^* \\ IP \\ CPI \\ M \\ EX \end{bmatrix} = \begin{pmatrix} . & . & . & free & . \\ . & . & . & + & . \\ . & . & . & + & . \\ . & . & . & + & . \\ . & . & . & free & . \end{pmatrix} \begin{bmatrix} \varepsilon^{i^*} \\ \varepsilon^{IP} \\ \varepsilon^{CPI} \\ \varepsilon^{M} \\ \varepsilon^{EX} \end{bmatrix} \quad (9)$$

Figure 5, Figure 6 and Figure 7 depict the impulse response diagrams of output, the price index and the RMB real effective exchange rate index under monetary policy shocks in month $k = 1, 2, \cdots K$, where the sign restrictions of Table 1 and Formula (8) are satisfied. Similarly, for the purpose of simplification, we have left out the response diagrams of the other two variables. We use dotted lines to represent the quantiles 16% and 84% of the impulse response [$r_{m_2,j}(k)$] of each variable under monetary policy shocks.

Figure 5 presents the response diagram of output under monetary policy shocks and we select phase five sign restrictions. As can be seen from Figure 5, under expansionary monetary policy shocks, output reached its maximum within a short period, followed by small-amplitude fluctuations. After phase 9, output showed level changes; that is, there was a long-term raising effect for output. This conclusion is consistent with that drawn by the approach combining short-term and long-term restrictions. Figure 6 presents the response diagram of the price index under expansionary monetary policy shocks. It is clear that, under monetary policy shocks, the price index experienced the maximum current rise, followed by a decline. In approximately the 9th month, the price index showed stationary changes. This conclusion is consistent with that drawn in the analysis combining short-term and long-term restrictions. The price puzzle (i.e. the drop of the price index caused by an expansionary monetary policy) did not occur in any case. It can also be observed from Figure 6 that the regularity of the price index was more obvious than that of the analysis combining short-term and long-term restrictions. Figure 7 describes the impact of an expansionary monetary policy on the RMB real effective exchange rate index. As can be seen from Figure 7, expansionary monetary policy shocks first caused a drop of the exchange rate index (i.e. the appreciation of the RMB); that is, there was a foreign exchange rate puzzle. However, what came after this was a depreciation of the RMB, which reached the maximum degree in phase 4. There was a decline in the depreciation degree, but the state of depreciation persisted. This decomposition was more reasonable than recursive structure decomposition, suggesting that an expansionary monetary policy still resulted in the decline of the RMB real effective exchange rate, consistent with Dornbusch's overshooting theory. However, the time of overshooting was brought forward obviously, roughly by three months, in comparison to that of previous studies. The results of sign restrictions also basically agreed with the results of the aforementioned short-term and long-term restrictions.

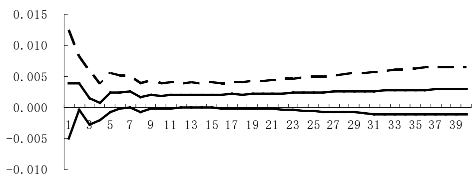

Figure 5: The impact of an expansionary monetary policy on output

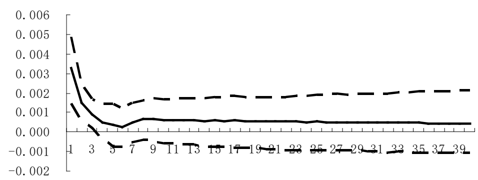

Figure 6: The impact of an expansionary monetary policy on the price index

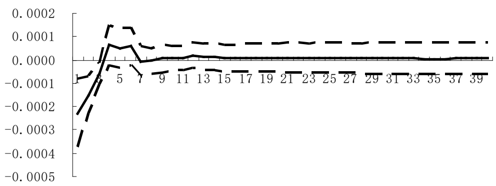

Figure 7: The impact of an expansionary monetary policy on the exchange rate index

3.2.4 Analysis of the explanatory proportion of monetary policy shocks for the forecast of future exchange rates

Quantitative analyses of the impact of monetary policy shocks on exchange rates are far from reaching consistent conclusions. Scholl and Uhlig (2008) claimed that, in previous literature, the explanatory proportion of monetary policy shocks for foreign exchange rate fluctuations accounted for about 5%~60%[20]. Clarida and Gali (1994) used the long-term restrictions proposed by Blanchard and Quah (1989) for the structure decomposition of the VAR model and concluded that, when taking supply, demand and monetary shocks into consideration, monetary policy shocks could explain exchange rate fluctuations to a very large extent[26]. Clarida, Gali and Gertler (2001) argued that the monetary policy of developed countries had indeed considered foreign exchange rate fluctuations, but that the importance attached to them was relatively low[27]. Ball (1999) held that the monetary policy of the central bank should be adjusted on the basis of foreign exchange rate fluctuations[28]. According to the conclusion drawn by him with a highly typical model, the explanatory proportion of monetary policy for the future forecasts of exchange rate fluctuations is 1/10 of that for the future forecasts of inflation and monetary policy has a stronger explanatory power for inflation. According to Svensson (2000), the foreign exchange rate, as a macroeconomic goal of a country, has a relatively low social welfare effect [29]. For the purpose of comparison, this paper also selected the explanatory proportion of an expansionary monetary policy for future exchange rate fluctuations. To meet the scope requirements, we only provide the explanatory proportion of the decomposition results of the VAR model under sign restrictions. As can be seen from Figure 8, the explanatory proportion of an expansionary monetary policy for the future forecasts of output was about 15%. However, according to the above impulse responses, monetary policy exerted a short-term impact on output and had a raising effect in the long term, but its explanatory proportion for the forecasts of output was not very high. Kim (2005) used a structural VAR model and found that post-war monetary policy shocks only explained a very small portion of output changes in G-7 countries[30]. Thus, this also conforms to the common sense of monetary economics literature.

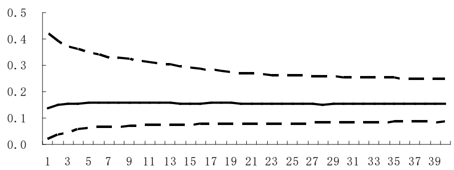

Figure 8: The explanatory proportion of an expansionary monetary policy for output

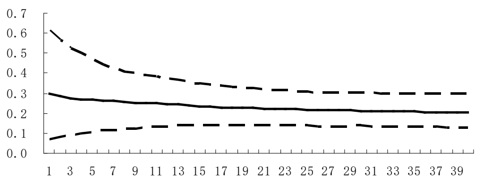

Figure 9: The explanatory proportion of an expansionary monetary policy for the price index

In Figure 9, the explanatory proportion of an expansionary monetary policy for the future forecasts of the price index was approximately above 25% as well as quite stable. Leeper et al.

(1996) claimed that monetary policy shocks were relatively unimportant for output and that its explanatory proportion for the future forecasts of the price index was approximately above 30%[11]. As can also be seen from the aforementioned empirical results, the explanatory power of an expansionary monetary policy for price was indeed higher than that for output.

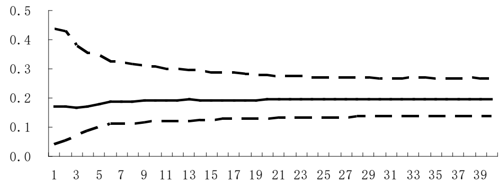

Figure 10: The explanatory proportion of an expansionary monetary policy for the exchange rate index

In Figure 10, the explanatory proportion of expansionary monetary policy shocks for the future forecasts of exchange rate fluctuations was about 20%, higher than that for output, which verifies that monetary policy shocks have a more significant impact on asset price fluctuations. Our estimates fall within the value range of previous studies (5%~60%), suggesting that our estimates are considerably reliable. Provided in the next section are the robustness test of the results.

4 ROBUSTNESS ANALYSIS

According to Leeper et al. (1996) and Faust (1997), the VAR model may lack stability when increasing the variables of the model [11]. To prevent such omitted variables from giving rise to incorrect estimates, we further introduced the producer price index and interest rate to see if the results are impacted. To be specific, the interest rate adopted is the rate of a one-year deposit. The producer price index adopted is the seasonally-adjusted month-to-month data, extracted from WIND database. For the sake of brevity, we have omitted the robustness test on the analysis approach combining short-term and long-term restrictions when more variables are introduced (in fact, the result of this test is similar to that of the aforementioned analysis). We primarily focus on analyzing the robustness of the VAR model under sign restrictions. This test consists of two parts: first, two variables are increased; that is, when the model has seven variables and is restricted to five phases, we found that the results of the model have not experienced any substantial change. Second, the test is performed under different K values without increasing the two variables. We found that, when K value increases from 1 to a maximum of 11 (both foreign and domestic literature usually adopt this as the maximum number, so this paper also adopts 11 as the maximum number of phases), the above results have not experienced any substantial change either. Figure 11, Figure 12 and Figure 13 describe the impacts of monetary policy shocks on output, the price index and the RMB real effective exchange rate index when the maximum number of restriction phases is 11.

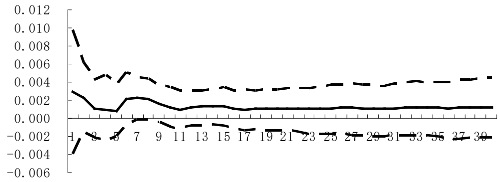

Figure 11: The impact of an expansionary monetary policy on output

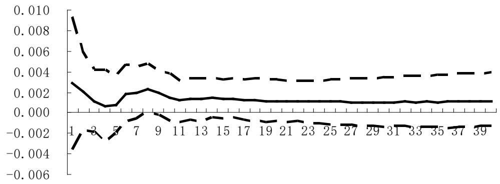

Figure 12: The impact of an expansionary monetary policy on the price index

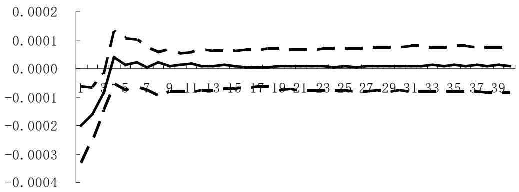

Figure 13: The impact of an expansionary monetary policy on the exchange rate index

From Figure 11 we can see that, under expansionary monetary policy shocks, the impulse response of output was basically similar to that in Figure 5, except that the impact in Figure 5 was more significant, stabilized earlier and became basically stable in phase 9 (corresponding to phase 17 in Figure 11). However, their basic results were consistent. From Figure 12 we can see that, under expansionary monetary policy shocks, the impulse response of the price index was similar to that in Figure 6, except that the impact in Figure 6 was more significant and stabilized earlier. However, their basic results were consistent. From Figure 13 we can see that, under expansionary monetary policy shocks, the impulse response of the exchange rate index was basically similar to that in Figure 7, except that the impact in Figure 7 was more significant. However, their basic trends were consistent. According to Fry and Pagan (2007), sign restrictions constitute a weak identification procedure, which gives rise to weak results. This identification procedure does not have a unique goal, as there are many impulse responses that can meet the requirements of sign restrictions[31]. To avoid this problem, here, we set the maximum number K of restriction phases with different values. The lack of substantial changes in the results of the model suggests that our model estimates are relatively robust.

5 CONCLUSIONS

This paper adopts both the identification method, combining short-term and long-term restrictions, and the VAR model based on symbol identification, to study the impact of monetary policy shocks on output, the price index and the exchange rate index, and draws the following conclusions. First, monetary policy shocks give rise to an obvious rise of output in the short term and play a vital role in raising the overall level of output in the long term. The explanatory proportion of an expansionary monetary policy for the variance decomposition of the future forecasts of output has reached 15%. Second, expansionary monetary policy shocks have not led to the price puzzle and price gradually increases to the proportion of monetary expansion, conforming to the anticipation of Dornbusch's overshooting theory about price. The explanatory proportion of an expansionary monetary policy for the future forecasts of the price index has reached 25%. Third, the impact of expansionary monetary policy shocks on the exchange rate index first presents the exchange rate puzzle, followed by the puzzle of overshooting. Overall, it meets Dornbusch's overshooting theory. The explanatory proportion of an expansionary monetary policy for the future forecasts of the exchange rate index has reached 20%, within the range of contribution values estimated in classic literature. The impact of monetary policy shocks on the exchange rate shows the phenomenon of delayed overshooting, but the period of overshooting is obviously better than that of traditional recursive structure decomposition. It can be seen that our improvement method does not deny Dornbusch's overshooting theory. In fact, it testifies to the correctness of this theory, on the one hand, and points out the improvements that can be made to it, on the other hand. Fourth, the robustness of the model suggests that the approach of increasing other variables and attempting to expand the VAR system does not alter the robustness of the results. In this study, we also found that the instant response of foreign exchange rate fluctuations to monetary policy in China is an interactive mechanism in passive form and that the appreciation of the exchange rate, to some extent, promotes the rise of money supply.

The impact of monetary policy shocks on the exchange rate is a very important task of economics. Considering that the Chinese economy is more and more obviously showing the characteristics of a small open economy, many domestic scholars are attempting to investigate the relation between monetary policy and foreign exchange rate fluctuations in China, in the context of open economics. For instance, Shi (2007) analyzed the data from the first quarter of 1991 to the third quarter of 2005 and showed that monetary policy shocks gave rise to the contraction of output, not "contractionary depreciation"[32]. Our conclusion about the impact of expansionary monetary policy shocks on output is consistent with his conclusion. However, the impacts of expansionary monetary policy shocks on other variables are obviously different, primarily because our method is more scientific and robust than that adopted by Shi. Zhao and Zhang (2012) used the monthly data from July, 2005 to March, 2011 to analyze the response of the foreign exchange rate to monetary policy shocks and claimed that the VAR model based on short-term restrictions and the symbolic VAR model could effectively avoid the price puzzle and the puzzle of foreign exchange rate overshooting [23]. This paper indicates that, while there is no price puzzle, there is the puzzle of exchange rate overshooting. However, the period of exchange rate overshooting is obviously earlier. That is, there is both the puzzle of foreign exchange rate and the puzzle of overshooting. Clearly, there is more and more literature on the macroeconomic effects of monetary policy shocks in an open economy, but conclusions in this regard are far from consistent, so the direction for future studies is to apply more suitable models and new data intervals.

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