

The Multifactor Time-Varying Effects of Risk Shocks on Foreign Exchange Reserves

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Abstract. This paper employs the TVP-SV-VAR model to analyze the time-varying characteristics of China's foreign exchange reserve changes from the perspectives of interest rates, exchange rates, and inflation, with a focus on four critical periods. The findings reveal that the positive impact of the federal funds rate on foreign exchange reserves is more pronounced in the medium to long term, while the negative impact is more significant in the short term. During the 2008 financial crisis, the impulse effects of various variables on foreign exchange reserves were more pronounced compared to other crisis periods.

Keywords: foreign exchange reserves, time-varying characteristics, TVP-SV-VAR, risk shocks

1. Introduction

China's foreign exchange reserves grew rapidly after its accession to the WTO and became the world's largest in 2006. By the end of January 2026, China's foreign exchange reserves stood at \$3,399.1 billion, ranking first in the world for 20 consecutive years (from 2006 to the present). Adequate foreign exchange reserves have not only enhanced China's international creditworthiness and overall national strength, but also created conditions for maintaining RMB exchange rate stability and advancing RMB internationalization. Meanwhile, large-scale foreign exchange reserves entail relatively high exchange rate risks and opportunity costs.

In recent years, amid frequent volatility in the international financial market, mounting downward pressure on the domestic economy, and various emerging risks including major shocks such as the Russia-Ukraine conflict, it is crucial to accurately assess the impact of major risk shocks on China's foreign exchange reserves. The stability of foreign exchange reserves is of great significance to the balance of payments, domestic currency stability, financial market stability, and overall national creditworthiness. Based on monthly data from 2000 to 2023, this paper employs the TVP-SV-VAR model to investigate the time-varying effects of exchange rate, interest rate and inflation on China's foreign exchange reserves under risk shocks in different periods.

2. Literature Review

Foreign exchange reserve risk can be divided into several types, including exchange rate risk, interest rate risk, credit risk, market risk, and political and geopolitical risk. Previous research on foreign exchange reserves mainly focused on the optimal scale of foreign exchange reserves and factors affecting foreign exchange reserves. Triffin (1947) ^[1] first proposed using the proportional method to measure the size of foreign exchange reserves, and the optimal size of foreign exchange reserves can be calculated by the ratio of foreign exchange reserves to imports. The comparison between foreign exchange reserves and import volume should be controlled at 0.25, at which point the scale of foreign exchange reserves reaches a relatively appropriate level. Yang Yi and Tao Yongcheng (2011) ^[2] selected macroeconomic data from the past fifteen years and used utility analysis to explore the scale of China's foreign exchange reserves. They found that the optimal scale of foreign exchange reserves was reached when the ratio of China's foreign exchange reserves to China's output was between 0.2 and 0.3. Aizenman (2003) ^[3] proposed a cautious savings model for foreign exchange reserves and empirically studied the reasons for the rapid growth of foreign exchange reserves in

some countries, including China, after the Asian financial crisis. The study found that many countries increased their foreign exchange reserves to maintain the stability of their domestic financial system and meet the demand for international debt payments, thereby reducing the impact of financial crises. Russell Mei and Zhang Yijia (2015) ^[4] conducted an in-depth analysis of the short-term and long-term factors affecting China's foreign exchange reserves, mainly using the VAR model, and obtained the interrelationships between foreign exchange reserves and various influencing factors, thus deeply analyzing the decision-making mechanism of foreign exchange reserves. The study concluded that exports are the direct and short-term factors affecting foreign exchange reserves, while the RMB exchange rate and foreign direct investment are the long-term factors affecting foreign exchange reserves.

It can be seen that most existing studies on foreign exchange reserves focus on maintaining an optimal scale of reserves to guard against external financial risks and crises, while neglecting that major risks can also affect foreign exchange reserves, thereby restricting their role in adjusting the balance of payments and stabilizing the foreign exchange market. Gong Jian et al. (2018) ^[5] took variables such as real interest rate, real international interest rate spread, and real foreign investment as the main considerations. Through theoretical derivation, they constructed a smooth-transition autoregressive generalized conditional heteroskedasticity model that incorporates macro factors reflecting China's real economic fundamentals and the exchange rate transmission mechanism. They examined the direct feedback intensity and direction of foreign exchange reserves to these factors, as well as the indirect impacts of these factors on foreign exchange reserves through the exchange rate channel. The study found that in addition to the direct channels affecting foreign exchange reserves, various macroeconomic variables also exert an indirect transmission effect on foreign exchange reserves through the real effective exchange rate. Cai Yueyang (2018) ^[6] applied the TVP-SV-VAR model to highlight the impacts of interest rate shocks and exchange rate shocks on China's foreign exchange reserves, and investigated the time-varying characteristics and structural changes in the impact of Federal Reserve rate hikes on China's foreign exchange reserves.

With reference to relevant literature, this paper takes into account the stochastic volatility characteristics of major factors affecting foreign exchange reserves, including the exchange rate and interest rate. By constructing a time-varying parameter vector autoregressive (TVP-SV-VAR) model, we empirically analyze the dynamic time-varying impacts of external risk shocks on China's foreign exchange reserves from two perspectives: different time points and different forecast horizons.

3. Methodology

The TVP-SV-VAR model (time-varying parameter vector autoregression model) used in this article is an extension of the VAR model. The VAR model is a model used to describe the dynamic relationships between multivariate time series, assuming that each variable is a linear combination of its own lagged value and the lagged values of other variables. The TVP-SV-VAR model incorporates time-varying parameters and random fluctuations based on the VAR model. It assumes that the coefficient matrix and covariance matrix are time-varying, allowing us to capture the potential time-varying properties of potential structures in the economy in a flexible and robust manner, thereby better capturing dynamic changes and potential structural fractures in the data. This article draws on Nakajima's (2011) ^[7] TVP-SV-VAR modeling method to set up relevant models.

The TVP-SV-VAR model is composed of four state-space equations, one measurement equation, and three transition equations, together aimed at accounting for both the evolution in the parameters and the stochastic volatilities.

The measurement equation of the TVP-SV-VAR can be expressed, as follows

$$y_t = c_t + B_{1,ty_{t-1}} + \dots + B_{p,ty_{t-p}} + u_t = X_t \theta_t + u_t \quad (1)$$

4. Empirical analysis

4.1. Data selection and processing

To explore the mechanism of the main influencing factors of China's foreign exchange reserves in the context of global economic recession, this paper selects China's foreign exchange reserves as the research object, and uses the US dollar to RMB exchange rate, US federal funds rate, and China's consumer price index as explanatory variables. Eviews software is used to preprocess the monthly data of each variable from 2008 to 2023. Firstly, all variables were seasonally adjusted for Census X-12, as the value of foreign exchange reserves is relatively large compared to the other three variables. Therefore, logarithmic processing was applied to foreign exchange reserves. Secondly, ADF unit root tests were conducted on each of the four variables, and the results are shown in Table 1. With the inclusion of trend and intercept terms, after first-order differencing, all variables can reject the null hypothesis at a 5% confidence level.

Next, a cointegration test was conducted on the original data to determine whether there is a long-term cointegration relationship between variables. The cointegration test results showed that None, At most, At most2, and At most3 were not significant. The cointegration test was performed on the variables after first-order difference, and the results were all significant. Finally, it was decided to use the first-order difference data for modeling.

Table 1. ADF stationarity test

Variable	P Value	Is it stable
CPI	0.084	NO
d_CPI	0.000	YES
ER	0.979	NO
d_ER	0.000	YES
lnFER	0.952	NO
d_lnFER	0.000	YES
FFR	0.859	NO
d_FFR	0.000	YES

4.2. Impact setting for model estimation

This article analyzes the time-varying effects of interest rates, exchange rates, and inflation shocks on China's foreign exchange reserves in the short, medium, and long term under three scenarios: 1 period in advance, 6 periods in advance, and 12 periods in advance. Set time point shocks based on the occurrence time of landmark events (September 2008, July 2018, January 2020, and February 2022). In September 2008, the bankruptcy of Lehman Brothers, the fourth largest investment bank in the United States, marked the official outbreak of the international financial crisis, leading to a sharp deterioration of global financial markets and a tightening of liquidity funds. To save the crisis, the Federal Reserve of the United States has implemented quantitative easing policies, lowering benchmark interest rates to near zero. This financial crisis may affect the contribution of interest rates and exchange rates to changes in China's foreign exchange reserves. On July 6, 2018, the United States imposed a 25% import tariff on the first batch of \$34 billion worth of goods imported from China. China took countermeasures and also imposed a 25% import tariff on American goods of the same scale on the same day, officially beginning the China US trade war. Due to the impact of trade competition, China's exports, foreign direct investment, exchange rates, and interest rates have been greatly affected, leading to fluctuations in foreign exchange reserves. In January 2020, the COVID-19 broke out in an all-round way, and its impact on the foreign exchange market was mainly reflected in the change of global market expectations. The epidemic panic has caused a temporary impact on

the RMB exchange rate. If the impact of the epidemic lasts for a long time, it will have more drag on economic growth, which will affect the accumulation of China's foreign exchange reserves to some extent. On February 24, 2022, Russia announced a special military operation against Ukraine, and on that day, the entire territory of Ukraine entered a state of war. The impact of the situation between Russia and Ukraine on China's economy is more reflected in inflation: the Russia-Ukraine conflict caused a sharp rise in global commodity prices, and the rise in the prices of imported bulk raw materials and transportation costs was directly transmitted to industrial products, leading to an increase in the production price index. According to the law of price transmission, the Producer Price Index (PPI) has a certain impact on the Consumer Price Index (CPI). The fluctuation of the overall price level generally first appears in the production sector, then spreads to downstream industries through the industrial chain, and finally affects consumer goods in the circulation sector, that is, prices slowly pass from production products to consumer goods. The rising inflation rate tends to push up interest rates, which in turn affects the accumulation of foreign exchange reserves.

4.3. Analysis of MCMC simulation results

This article uses Oxmetrics to estimate the TVP-SV-VAR model. According to the SIC information selection criteria, the lag period is determined to be 3, and 10000 MCMC simulation samples are conducted. The parameter estimation results are shown in Table 2. The results show that the posterior mean values of the parameters are all within the 95% confidence interval, and the Geweke convergence diagnostic values are all less than 1.96, indicating that the null hypothesis of the posterior distribution cannot be rejected at the 5% significance level. This suggests that the posterior distribution of the parameters converges to 0, and the invalid factors are all less than 100, indicating that the model sampling results are valid and can be used for posterior inference.

Table 2. MCMC simulation results

Parameter	Mean	Std	95%L	95%U	Geweke	Invalid factor
sb1	0.0228	0.0026	0.0184	0.0284	0.977	11.31
sb2	0.0228	0.0026	0.0184	0.0286	0.252	21.22
sa1	0.0380	0.0072	0.0273	0.0552	0.086	27.36
sa2	0.0437	0.0098	0.0302	0.0685	0.026	30.05
sh1	0.4966	0.0913	0.3362	0.6951	0.505	54.68
sh2	0.4548	0.0661	0.3417	0.6008	0.302	67.89

Note: sb1 and sb2 refer to parameters related to the supply side; Sa1 and sa2 refer to parameters related to the demand side; Sh1 and sh2 refer to parameters related to policies or external shocks

4.4. Variable Trend and Volatility Analysis

Fig 1 and Fig 2 reflect the changes and volatility of China's resident consumption index, US federal funds rate, US dollar to RMB exchange rate, and China's foreign exchange reserves over time from January 2000 to December 2023. It can be seen that there are multiple peaks in the US federal funds rate, China's resident consumption index, and China's foreign exchange reserves, and the peaks of each variable are similar in the same year, indicating a certain correlation between these four variables. Among them, the fluctuation amplitude of the resident consumption index is the largest, showing cyclical changes, and the fluctuation of the exchange rate has been relatively stable since 2004.

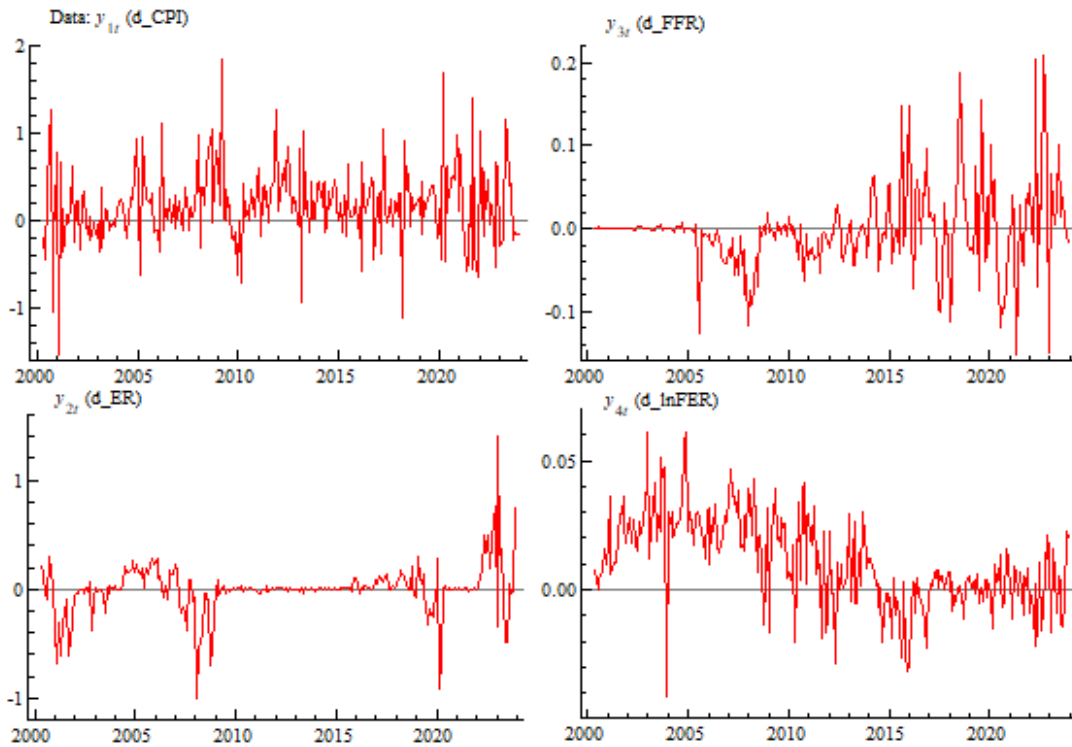


Fig. 1 Trend changes of various variables

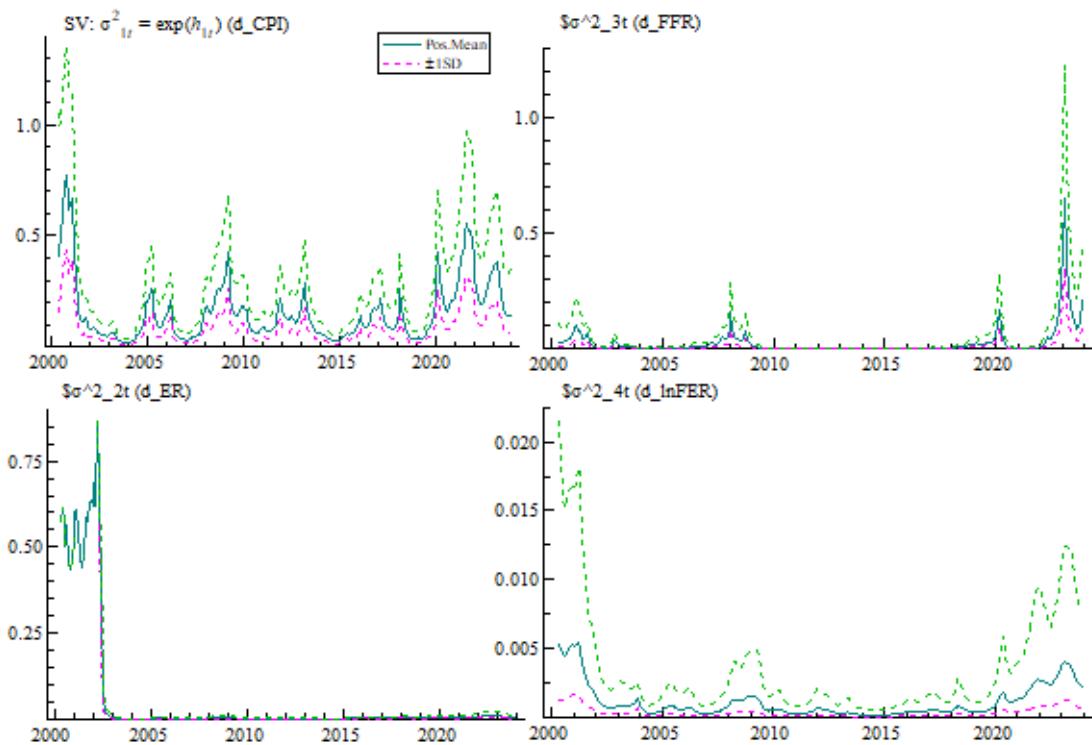


Fig. 2 Changes in volatility of various variables

4.5. Descriptive Statistics

In Table 3, the descriptive statistics of the processed variables show that the difference between the maximum and minimum values of foreign exchange reserves is small, with a maximum value of 0.0611 and a minimum value of -0.0416; The difference between the maximum and minimum values of the resident consumption index is significant, with a minimum value of -1.5365 and a maximum value of 1.8508.

Table 3. Descriptive statistics

Variable name	Mean	Median	Max	Min	Std	Skewness	Kurtosis
d_CPI	0.1786	0.1668	1.8508	-1.5365	0.4355	0.0471	5.4097
d_ER	-0.0039	-0.0018	0.2098	-0.1540	0.0490	0.8441	7.1210
d_FFR	-0.0011	0.0030	1.4106	-1.0073	0.2222	0.0316	12.0627
d_lnFER	0.0106	0.0078	0.0611	-0.0416	0.0173	0.1434	3.0449

4.6. Time-varying impulse analysis

The TVP-SV-VAR model provides two different types of impulse response functions, namely equidistant impulse response function and time point impulse response function. The impulse response function is time-varying, where the equidistant impulse response function is used to observe the dynamic characteristics of the dependent variable at equal intervals after giving an impact to the independent variable at each time point. The time point impulse response function is used to observe the dynamic characteristics of the dependent variable after giving an impact to the independent variable at a specific time point. The impulse response function can describe the response of variables to error shocks. Specifically, it describes the impact of applying a standard deviation shock to the current and future values of endogenous variables on a random error term. Next, we will analyze the dynamic impact of various explanatory variables on foreign exchange reserves.

4.6.1. The dynamic impact effect of interest rates on foreign exchange reserves

In Fig 3, according to the equidistant impulse response diagram, from 2004 to 2008, the US federal funds rate had a significant positive impact on foreign exchange reserves, with the strongest positive impact occurring 6 periods ahead of schedule, followed by 12 periods ahead of schedule, and finally 1 period ahead of schedule. This indicates that during this period, the federal funds rate had the greatest medium-term impact on foreign exchange reserves; During the period from 2008 to 2020, the positive impact of the federal funds rate on foreign exchange reserves significantly decreased, with the most significant decline in the value of the one period advance impulse function. During this period, the federal funds rate had a negative impact on foreign exchange reserves, but the negative impact effect gradually decreased over time, and the impulse response function value returned to near zero. In comparison, the impulse response function values of the six period advance and twelve period advance were relatively stable. Overall, the positive impact of the federal funds rate on foreign exchange reserves was more significant in the medium to long term, and the negative impact on foreign exchange reserves was more significant in the short term.

From the time point impulse response chart, it can be seen that the impact trend of interest rate shocks on foreign exchange reserves is roughly the same at most time points, gradually converging towards 0 in the third period, and the speed of restoring steady state is relatively fast. Among them, negative shocks were caused at all three time points, but the trend during the 2008 financial crisis was different from other time points. The time point shocks in 2008 first turned positive and negative, and began to rebound in the second period. In the third period, the impulse response function value reached its maximum, and then gradually converged to 0. In the 2008 financial crisis, the impact of the federal funds rate on China's foreign exchange reserves was different from other crisis moments. This may be due to the tightening of global liquidity after the Fed's interest rate hike cycle from 2004 to 2006. When the 2008 financial crisis broke out, the Fed began to cut interest rates, releasing liquidity. This round of interest rate policy shift placed 2008 at the turning point of the Fed's interest rate hikes and cuts, which had a positive impact on China's foreign exchange reserves and was conducive to the accumulation of foreign exchange reserves. During the 2018 US China trade war, interest rates had a significant negative impact on foreign exchange reserves in the 0th period, lasting for a long time, and began to converge in the 3rd period. The other two time points are both in the low interest rate cycle of the US federal funds rate, with relatively small fluctuations in interest rates. Therefore, the

impact of the federal funds rate on China's foreign exchange reserves is not significant, mainly in a negative direction.

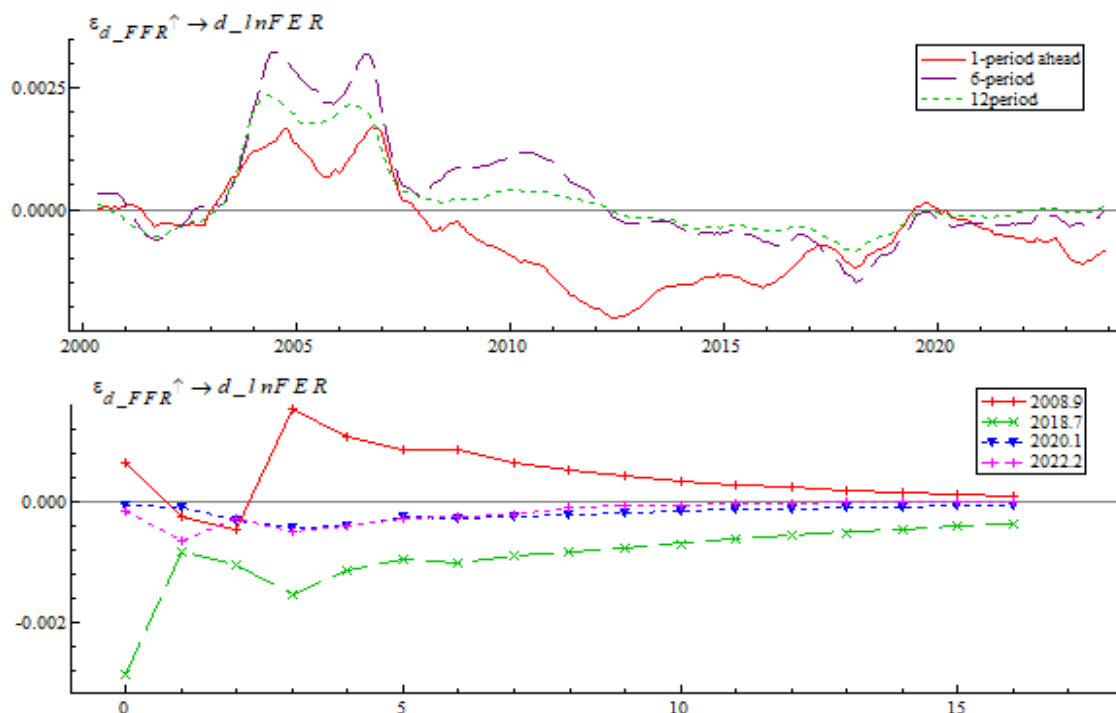


Fig. 3 Function diagram of equidistant impulse response and time point impulse response of interest rate to foreign exchange reserves

4.6.2. Dynamic impact effect of exchange rate on foreign exchange reserves

From Fig 4, it can be seen that the impulse response function value that is one period ahead of schedule is the smallest, and the impulse response function value that is 12 periods ahead of schedule has the smallest fluctuation amplitude and relatively large function values. This indicates that when the exchange rate of the US dollar against the Chinese yuan rises, that is, when the Chinese yuan depreciates, it is not conducive to the accumulation of foreign exchange reserves in China from 2005 to 2020, especially in the short term. The impulse response function values of the exchange rate to foreign exchange reserves are all negative, indicating that the short-term exchange rate rise is not conducive to the accumulation of foreign exchange reserves. From 2000 to 2005 and after 2020, the depreciation of the Renminbi was beneficial for the accumulation of China's foreign exchange reserves. The possible reason is that China's import and export trade did not meet the Marshall Lerner condition in theoretical analysis from 2005 to 2020. In the Marshall Lerner condition, the impact of exchange rate on foreign exchange reserves depends on the demand elasticity of imports and exports. Only when the sum of import and export demand elasticity is less than 1, can RMB depreciation increase foreign exchange reserves.

From the results of point shocks (Figure 1b), it can be seen that during the 2008 financial crisis, the exchange rate had the greatest impact on foreign exchange reserves, mainly in a negative direction. The negative impact was greatest in the 0th period, and gradually decreased after the 3rd period. During the 2008 financial crisis, the exchange rate between China and the United States showed a downward trend, which had a direct impact on China's imports and exports. The exchange rate had a negative impact on China's foreign exchange reserves, meaning that the decline in the exchange rate was conducive to the accumulation of foreign exchange reserves. In the other three time point shocks, the impact of exchange rate on foreign exchange reserves is mainly positive, and the impact is small. In 2022, the Russia-Ukraine conflict has the largest positive impact on foreign exchange reserves, reaching two peaks in the second and fifth periods.

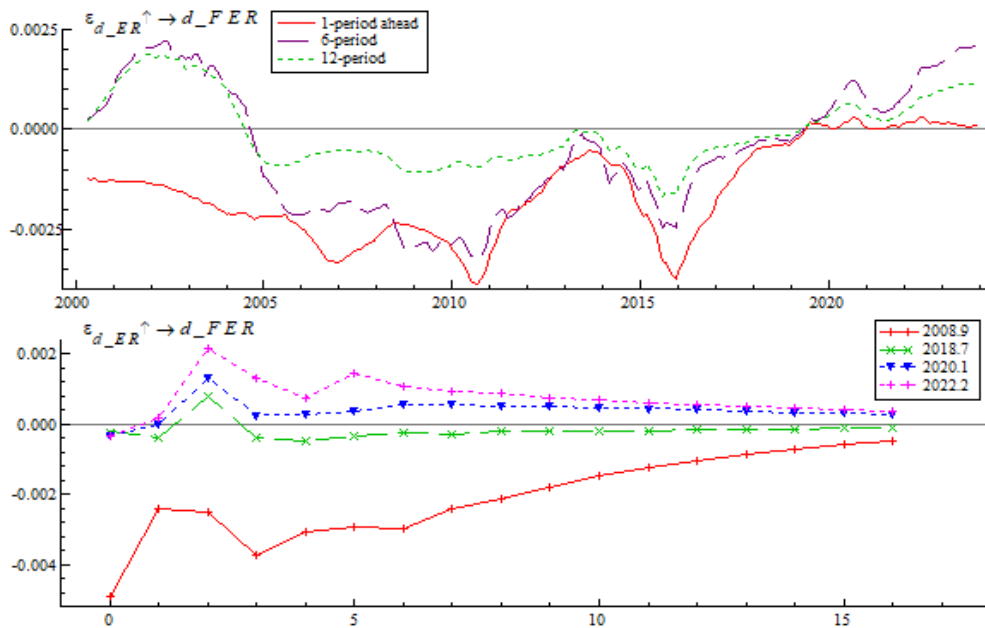


Fig. 4 Function diagram of equidistant impulse response and time point impulse response of exchange rate to foreign exchange reserves

4.6.3. The dynamic impact of inflation on foreign exchange reserves

In Fig 5, according to the equidistant pulse function chart, it can be seen that the impact of CPI on foreign exchange reserves shows a fluctuating trend from 2000 to 2023, with negative shocks as the main shock effect. The pulse function values reached their lowest point in 2004 and 2013, and the volatility of the pulse function values one period ahead of schedule is greater than that of those six and twelve periods ahead of schedule. In terms of time point shocks, the impact of inflation on foreign exchange reserves was relatively small in 2018 and 2020, showing a convergence trend in the first period. The other two time points began to show a convergence trend in the third period. During the 2008 financial crisis, the dynamic impact of inflation on foreign exchange reserves was mainly positive, reaching two peaks in the 0th and 3rd periods; During the Russia-Ukraine conflict in 2022, the CPI index had a negative impact on foreign exchange reserves, reaching two peaks in the 0 and 2 periods, and the impact of CPI on foreign exchange reserves at the other two time points was small.

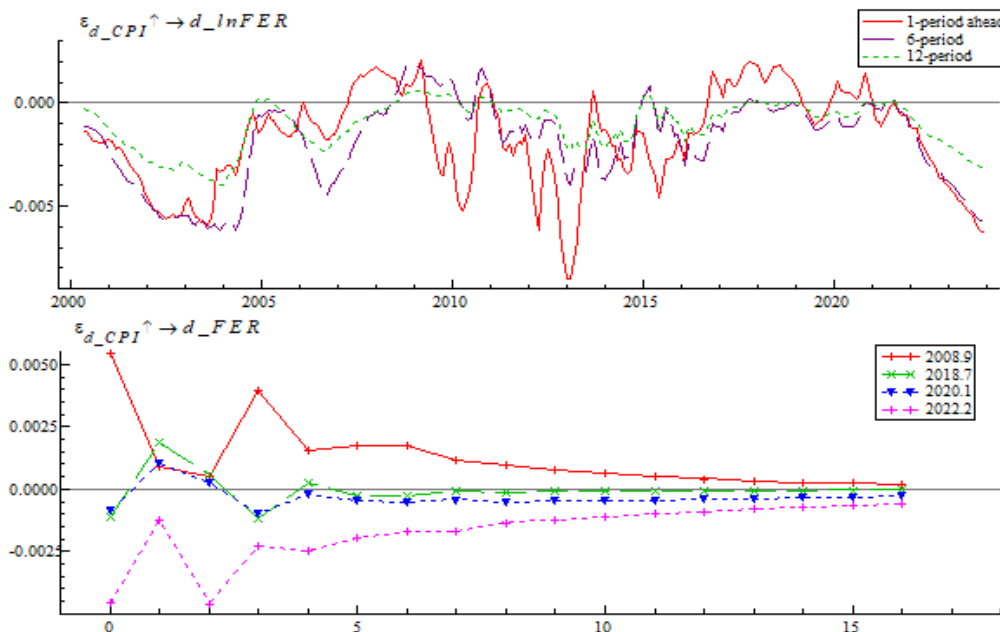


Fig. 5 The equidistant impulse response and time point impulse response function diagram of CPI on foreign exchange reserves

5. Conclusion

This article constructs a time-varying parameter vector autoregressive model with random fluctuations (TVP-SV-VAR) to analyze the main influencing factors and formation mechanisms of changes in China's foreign exchange reserves. The following main conclusions are drawn:

Against the backdrop of a global economic recession, the impact of exchange rates, interest rates, and inflation on foreign exchange reserves exhibits time-varying characteristics: the positive impact of the federal funds rate on foreign exchange reserves is more significant in the medium to long term, while the negative impact on foreign exchange reserves is more significant in the short term; The exchange rate mainly has a negative impact on foreign exchange reserves in the short term, which is consistent with the conclusion that exchange rate appreciation and RMB depreciation are not conducive to the accumulation of foreign exchange reserves. In some time intervals, such as from 2000 to 2005 and after 2020, RMB depreciation is beneficial to the accumulation of foreign exchange reserves in China. The possible reason is that China's import and export trade did not meet the Marshall Lerner condition in theoretical analysis from 2005 to 2020; Inflation mainly has a negative promoting effect on foreign exchange reserves, and its contribution to the increase in foreign exchange reserves is relatively stable. Even if there is a sudden shock, foreign exchange reserves quickly respond to the impact of inflation and return to stability in a short period of time. From the perspective of timing shock effects, the 2008 financial crisis resulted in a different impact of the federal funds rate and the US China exchange rate on foreign exchange reserves compared to other crisis moments. Each variable had a more significant impact on foreign exchange reserves. During the financial crisis, interest rates and inflation had a mainly positive impact on foreign exchange reserves, while exchange rates had a mainly negative impact; The impact of the COVID-19 and the Russia-Ukraine conflict on foreign exchange reserves tends to converge. In the long run, the impact of the three explanatory variables on foreign exchange reserves gradually disappears. This time-varying feature may be the result of the gradual improvement of China's macro-control ability and the deepening reform of the foreign exchange market. In the early days, China's economy was relatively small in size and lacked resilience in economic growth, making the foreign exchange market easily affected by major international events. In addition, compared with the Sino US trade competition, the COVID-19 and the Russia-Ukraine conflict, the impact of exchange rate on foreign exchange reserves is more significant under the impact of the global financial crisis. Interest rates and inflation affect China through the exchange rate pathway. Continuing to promote the reform of the RMB exchange rate and fully leveraging the decisive role of market supply and demand in the formation of the exchange rate, a flexible exchange rate formation mechanism can better play the instrumental role of the exchange rate and weaken the impact of external shocks on foreign exchange reserves in the current global economic recession and turbulent financial environment.

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