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Spillover impact of the U.S. monetary policy shock on China's economy: capital flow channel

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ABSTRACT
This study builds an open economy theoretical model with financial frictions to analyse the spillover impact of the U.S. monetary policy shock on China's economy through capital flow channel. Bayesian technique is employed to estimate the TVP-VAR model and obtain three main results. First, the increase in the U.S. nominal interest rate causes the decline in China's capital inflow, which has a negative spillover impact on China's economy and leads to the decline in China's real output. Second, this negative spillover impact on China's economy has no structural time-varying characteristics. Third, the pass-through effect from international capital flow to China's real output is greater than that of international capital flow itself.

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1. Introduction

In September 2021, the Federal Reserve announced Taper, indicating the United States will enter into a new round of interest rate increase cycle in the near future, which determines the fluctuation of capital flow and macro-economic of emerging market countries, especially for China with the second largest GDP in the world. A massive capital inflow loosens domestic financial conditions, which stimulates investment and leads to an economic boom. By contrast, a huge international capital outflow tightens the financial environment, resulting in a decline in domestic investment and output (Dedola et al., 2017; Magud & Vesperoni, 2015; Schmitt-Grohé & Uribe, 2016).

The U.S. monetary policy shock not only trigger the fluctuation of global capital flow (Albagli et al., 2019; Kalemli-Özcan, 2019), but also drive the global financial cycle (Miranda-Agrippino & Rey, 2020). Bräuning and Ivashina (2020) find that when the U.S. adopts a loose monetary policy, the amount of foreign bank loans obtained by borrowers in emerging market countries is 32% higher than that in developed markets. By contrast, when the U.S. implements a tight monetary policy, it

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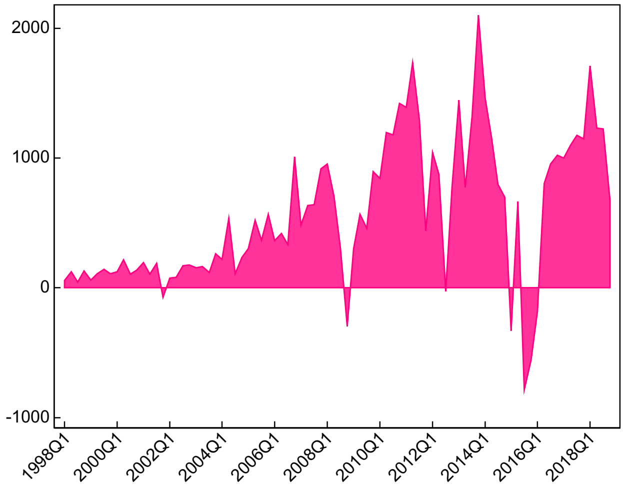

Figure 1. The Trend of China's Capital Inflow. The data sample covers the period from quarter 1 (Q1) of 1998 to quarter 4 (Q4) of 2018 and is sourced from www.safe.gov.cn. China's international capital inflow is given by the net value of China's non-reserve financial liabilities.

causes the same scale of credit contraction in emerging countries. The U.S. monetary policy shocks can explain 20% of economic fluctuations in emerging market countries (Uribe & Yue, 2006). Cerutti et al. (2019) argue that the sensitivity of capital flows in different emerging countries to global shocks is heterogeneous.

As a large emerging market country, China is an important investment market for international investment institutions. In 2021, China's non reserve financial capital inflow reached $661.6 billion dollars. The United States and China have highly close ties in financial and economic. We cannot ignore the spillover impact of the Fed's monetary policy shock on China's economy. Yan and He (2021) point out that the U.S. monetary policy shock could trigger the fluctuation of China's financial and economic cycle. Wu et al. (2021) find that the increase in the U.S. interest rate lead to the decline of China's asset price, exacerbating the capital outflow through the financial accelerator. At the same time, Ouyang et al. (2022) propose that the U.S. monetary policy uncertainty can generate a positive spillover effect on China's systematic financial risks mainly through short-term capital flow channels.

Figure 1 depicts China's net capital inflow covering the period from 1998 to 2018. Before 2002, China's international capital inflow remained at similar levels and the inflow scale was small. After China's entry into the World Trade Organization in 2002, the capital inflow to the country started expanding. However, after the global financial crisis, China's international capital inflow declined sharply and reached a trough at the end of 2008. To manage the financial crisis, the U.S. continued to reduce the federal funds rate and began the quantitative easing monetary policy. Thus, from the beginning of 2009, China's capital inflow started to increase again. By the end of the second round of the U.S. quantitative easing monetary policy in June 2011, China's capital inflow decreased significantly and reached a trough in late 2012. The third round of quantitative easing monetary policy was implemented in January 2013, and China entered its third cycle of increasing capital inflow, which reached a peak at the end of 2014. In early 2014, when the Federal Reserve gradually withdrew

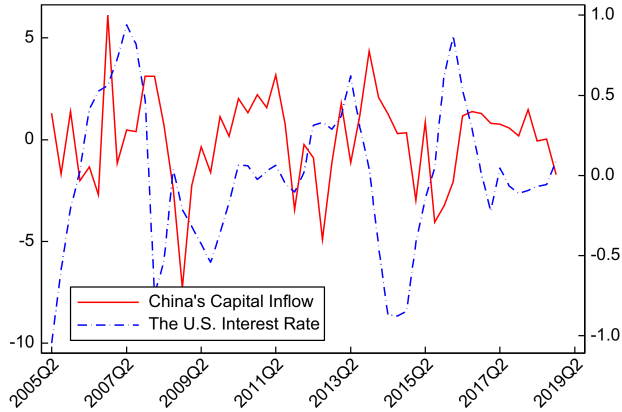

Figure 2. Co-movement between China's capital inflow and the U.S. interest rate. The data sample covers the period from 2005 Q2 to 2018 Q4. The U.S. interest rate is given by the quarterly average of the U.S. shadow interest rate. China's capital inflow is expressed as the net value of China's non-reserve financial liabilities and is divided by the nominal gross domestic product (GDP) for standardization. China's non-reserve financial liabilities data are sourced from www.safe.gov.cn, while the U.S. shadow interest rate and China's nominal GDP data are sourced from www.frbatlanta.org. The red solid line is calibrated with the ordinate left axis and the blue dotted line is calibrated with the ordinate right axis.

from the quantitative easing monetary policy, China's capital inflow began to decline sharply again and reached its lowest historical level at the end of 2015.

Figure 2 demonstrates the existence of a reverse synergetic movement between China's international capital inflow and the U.S. nominal interest rate. That is, the decline in the U.S. nominal interest rate is accompanied by an increase in China's international capital inflow, while an increase in the U.S. nominal interest rate is accompanied by a decline in China's international capital inflow.

Some literatures have studied the spillover effect of U.S. monetary policy on China's international capital flow, such as Wu et al. (2021), Yan and He (2021). However, these literatures only focus on the perspective of interest rate spread, or exchange rate to study the impact of U.S. monetary policy shock on China's international capital flows, and pay little attention to the transmission effect of international risk index. Bekaert et al. (2013) based on the international risk index VIX, propose that U.S. monetary policy loose can reduce risk aversion and uncertainty, and the effect of risk aversion is stronger, the risk aversion coefficient of international investment institutions to different types of countries is heterogeneous due to the trade index, financial openness, political risk, debt proportion.

We propose that U.S. monetary policy shock causes the change in the interest rate spread and the bilateral exchange rate between two countries as well as the international risk index. All these changes affect the volatility of China's international capital flow, resulting in a spillover impact on China's macro-economies through capital flow channel. In this study, we first build an open country theoretical model with financial frictions to analyse the spillover impact of the U.S. monetary policy shock on China's economy through the international capital flow channel.

We then adopt the time-varying parameter vector autoregressive (TVP-VAR) empirical model to verify the spillover effect of the U.S. monetary policy shock on

China and whether has time-varying characteristics. Based on the result of the model, we obtain three main results. First, the increase in the U.S. nominal interest rate causes an increase in interest rate differentials, the international risk index, and the bilateral nominal exchange rate, resulting in a decline in China's capital inflow, which leads to a decline in China's real output. Second, the negative spillover impact of the increase in the U.S. nominal interest rate shock on China's economy is larger in the short term than in the medium and long term. However, it exhibits no structural time-varying characteristics. Third, the pass-through effect from international capital flow to China's real output is greater than that of international capital inflow under the U.S. monetary shock.

The remainder of the paper proceeds as follows: Section 2 reviews the relevant literature. Section 3 constructs an open country theoretical model with financial frictions to analyse the spillover impacts of the U.S. monetary policy shock on China's economy through the international capital flow channel. Section 4 presents the TVP-VAR empirical model, describes the data used for estimation, and their sources. Section 5 provides the main findings of the TVP-VAR empirical model. Section 6 presents a robustness check. Finally, Section 7 concludes the paper.

2. Literature review

Two strands of literatures exist on the spillover impact of central countries' monetary policy shocks on peripheral countries' economies through the international capital flow channel. The first captures the international credit and portfolio transmission mechanisms. Bruno and Shin (2015) introduce international banks into the research framework and propose that international banks play a key role in the flow of credit capital. The change in monetary policy in central countries leads to fluctuations in the interest rate difference, which drives international banks to contract or expand the credit disbursed through their branches in peripheral countries, resulting in the fluctuation of financial conditions and credit rationing in peripheral countries (Auer et al., 2019; Schmidt et al., 2018). At the same time, monetary policy shocks in central countries not only cause fluctuations in domestic financial markets but also transmit the fluctuations to the financial markets of peripheral countries through international banks (Gajewski et al., 2019). Gilchrist et al. (2019) contend that the U.S. monetary policy shock had a spillover effect on foreign bond yields.

The second strand considers the risk-taking transmission mechanism. Some studies include the risk perception of international financial institutions into the framework and suggest that in the real world, the financial markets of developed countries are perfect. By contrast, the financial markets of emerging market countries have frictions and need to be improved. A 'wedge' exists between economies with perfect and imperfect financial markets, which reflects the risk premium of international capital. Therefore, central countries' monetary policy shocks induce a change in not only the interest rate differential but also the risk perception of international institutions, leading to large fluctuations in international capital flow in emerging market countries (Aizenman et al., 2016; Bekaert et al., 2013; Cerutti et al., 2019; Dedola et al., 2017; Gabaix & Maggiori, 2015; Ghosh et al., 2014; Kalemli-Özcan, 2019).

Ghosh et al. (2014) used the international net capital flow data of 56 emerging markets covering the period from 1980 to 2011 and found that the U.S. interest rate and international investors' risk aversion are the main factors causing capital volatility in emerging markets. Bekaert et al. (2013) argue that a loose monetary policy in central countries reduce international risk aversion and uncertainty. Devereux and Yetman (2010) propose that with the decline in asset value, net assets of international financial institutions with high leverage ratios contracted sharply and force them to divest their assets to avoid unacceptable bankruptcy risk. Asset selling cause the value of assets to fall further, which negatively impact the balance sheets of other institutions, resulting in a vicious circle of deterioration of their balance sheets and asset selling, as well as the worsening of financial and economic conditions.

However, monetary policy shocks in central countries cause not only changes in the interest rate differential and risk perception of international investment institutions, but also a change in the bilateral nominal exchange rate. All these changes affect the capital market and cause volatility in international capital flows in emerging market countries, having a spillover impact on the macro-economies of these countries. Therefore, in the empirical part of this study, we include the international risk, the interest rate differential, and the bilateral nominal exchange rate into the research framework to analyse the spillover impact of the U.S. monetary policy shock on China's macro-economy.

3. Theoretical model

As an emerging market country, China's domestic financial market has frictions and is not perfect. Hence, following Clarida et al. (2002), Galí and Monacelli (2005), Schmitt-Grohé and Uribe (2017), and Kalemli-Özcan (2019), we build an open country theoretical model with financial frictions to analyse the spillover impact of the U.S. monetary policy on China's economy through the international capital flow channel. In the following model, China is referred to as the domestic country.

We assume that numerous identical households and firms exist in the domestic country. Households can obtain rental income by providing physical capital to the capital market and can borrow from domestic financial intermediaries. They choose to consume, invest, and borrow to maximize their lifetime utility. The economy has tradable and non-tradable goods. Tradable goods are exogenous endowments and fixed, while non-tradable goods are produced by domestic manufacturers. Firms take material capital as the only input factor to produce non-tradable goods and maximize their profits. The non-tradable goods market has perfect competition. For convenience, we standardize the total number of households in the domestic country as 1.

3.1. Households

Assume that the lifetime utility of households is the total consumption discounted to period t. We use the equal elasticity utility function to describe households' utility. Further, assume that the period utility function U is strictly increasing and strictly concave.

$$U_t = E_t \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} \right\} \tag{1}$$

Where E_t denotes the mathematical expectation operator conditional on the available information in period t. The parameter $\beta \in (0,1)$ is the subjective discount factor. C_t represents the consumption of domestic residents in period t and $\sigma > 0$ denotes the intertemporal substitution elasticity of consumption.

The real consumption of households is composed of tradable goods consumption c_t^T and non-tradable goods consumption c_t^N. The composition of the real consumption follows Equation (2).

$$C_t = A(c_t^T, c_t^N) = \left[\omega (c_t^T)^{1-\frac{1}{\xi}} + (1-\omega)(c_t^N)^{1-\frac{1}{\xi}} \right]^{\frac{1}{1-\frac{1}{\xi}}} \tag{2}$$

where $0 < \omega < 1$. Furthermore, we assume that $\xi = 1/\sigma$. Then, the real consumption mix can be rewritten as Equation (2.1).

$$C_t = A(c_t^T, c_t^N) = \left[\omega (c_t^T)^{1-\sigma} + (1-\omega)(c_t^N)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{2.1}$$

Households obtain rental income by providing physical capital to firms producing non-tradable goods. Profits from firms and financial intermediaries belong to households, who can also borrow from domestic financial intermediaries. The households' budget constraints are described as follows.

$$D_t^H + c_t^T + p_t c_t^N + I_t = \frac{D_{t+1}^H}{1+R_t} + y_t^T + u_t K_t + \Phi_t \tag{3}$$

where D_t^H denotes the amount of debt that households borrow from financial intermediaries in period t-1 and need to repay in period t and p_t denotes the price of non-tradable goods in terms of tradable goods. We assume that physical capital does not depreciate. I_t denotes the investment of households in period t and $I_t = K_{t+1}$ - K_t. K_{t+1}, where K_t represent the physical capital owned by residents in period $t+1$ and t, respectively. u_t is the rent of physical capital. D_{t+1}^H denotes the amount of debt that households borrow from financial intermediaries in period t and need to repay in period $t+1$. R_t denotes the nominal lending rate in the domestic financial market between periods t and $t+1$. y_t^T means the endowment of tradable goods. Φ_t is the household profit income. The debt of households is subject to the non-Ponzi constraint condition described in Equation (4).

$$E_t \lim_{j \to \infty} \frac{D_{t+j+1}^H}{\prod_{s=0}^{j} 1 + R_{t+s}} \leq 0 \tag{4}$$

Given Φ_t, R_t, u_t, p_t, and y_t^T, households choose c_t^T, c_t^N, K_{t+1}, and D_{t+1}^H to maximize their utilities depicted in Equation (1) with the budget constraint given by Equation (3) and the non-Ponzi constraint represented by Equation (4).

$$\lambda_t = \omega(c_t^T)^{-\sigma} \tag{5}$$

$$p_t\lambda_t = (1-\omega)(c_t^N)^{-\sigma} \tag{6}$$

$$\lambda_t = \beta(u_{t+1} + 1)E_t\lambda_{t+1} \tag{7}$$

$$\lambda_t = \beta(1 + R_t)E_t\lambda_{t+1} \tag{8}$$

where λ_t denotes the Lagrange multiplier related to the budget constraint equation. Combining Equations (5) and (6), we obtain the price of non-tradable goods relative to tradable goods.

$$p_t = \frac{1-\omega}{\omega}(\frac{c_t^N}{c_t^T})^{-\sigma} \tag{9}$$

Combining Equations (7) and (8) yields Equation (10).

$$E_t u_{t+1} = R_t \tag{10}$$

3.2. Firms

We assume that firms producing non-tradable goods employ physical capital as the only input factor to produce non-tradable goods. The production function of non-tradable goods is subject to the Cobb–Douglas form and is strictly increasing and strictly concave.

$$y_t^N = A_t K_t^\alpha \tag{11}$$

Where y_t^N denotes the output of non-tradable goods in period t and the parameter α ranges in the interval (0, 1).

Suppose that firms have working capital constraints—that is, firms need to hold the proportion η to pay the rent for physical capital without earning any interest. Therefore, the working capital constraints are expressed by Equation (12).

$$M_t \geq \eta u_t K_t \tag{12}$$

Where M_t is the amount of working capital held by firms in period t. Firms can borrow from domestic financial intermediaries at a nominal lending rate R_t. The firms' budget constraints are subject to Equation (13).

$$\frac{D_{t+1}^F}{(1 + R_t)} = D_t^F + (M_t - M_{t-1}) + \Phi_t^F + u_t K_t - A_t K_t^\alpha \tag{13}$$

Where D_t^F represents the amount of debt firms borrow from financial intermediaries in period $t-1$ and need to repay in period t. Φ_t^F denotes the profits in period t.

The debt of firms is subject to the non-Ponzi constraint condition.

$$E_t \lim_{j\to\infty} \frac{D^F_{t+j+1} - M_{t+j+1}}{\prod_{s=0}^{j} 1 + R_{t+s}} \leq 0 \tag{14}$$

Given A_t, R_t, and u_t, firms choose K, D^F_{t+1}, and M_t to maximize their profits.

$$L = E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \left[\frac{D^F_{t+1}}{(1+R_t)} + A_t K_t^{\alpha} + M_{t-1} - D^F_t - M_t - u_t K_t + \mu_t (M_t - \eta u_t K_t) \right] \tag{15}$$

where $\beta^t \lambda_t \mu_t$ denotes the Lagrange multiplier related to the firms' budget constraint equation and μ_t is the shadow price of working capital.

$$\alpha A_t K_t^{\alpha-1} = (1 + \eta \mu_t) u_t \tag{16}$$

$$\lambda_t = \beta (1 + R_t) E_t \lambda_{t+1} \tag{17}$$

$$\beta E_t \lambda_{t+1} = (1 - \mu_t) \lambda_t \tag{18}$$

Combining Equations (17) and (18) yields Equation (19).

$$\mu_t = \frac{R_t}{1 + R_t} \tag{19}$$

Then, combining Equations (19) (16), and (10), we obtain Equation (20).

$$K_t = \left[\frac{R_{t-1}}{\alpha A_t} (1 + \frac{\eta R_t}{1 + R_t}) \right]^{\frac{1}{\alpha - 1}} \tag{20}$$

3.3. Financial intermediaries

Assume that the domestic competitive financial market has several identical intermediaries, who borrow money from the international financial market and lend to domestic households and firms. The budget constraint of financial intermediaries is expressed by Equation (21).

$$\frac{D^H_{t+1} + D^F_{t+1}}{1 + R_t} = \frac{D_{t+1}}{1 + R_t} + M_t \tag{21}$$

Where D_{t+1} denotes the amount of debt borrowed by financial intermediaries from international financial markets in period t and needs to be repaid in period $t+1$.

$$\Phi_t^B = D_t^H + D_t^F - D_t - M_{t-1} \tag{22}$$

3.4. Equilibrium

As described above, the profits from both enterprises and financial intermediaries belong to households, which is expressed by the following equation.

$$\Phi_t = \Phi_t^F + \Phi_t^B \tag{23}$$

Following Schmitt-Grohé and Uribe (2017), when the market is in equilibrium, the supply of physical capital is always greater than zero, that is, $k > 0$. At the same time, the market for non-tradable goods is in a clearing state, that is, $c_t^N = y_t^N$.

Combining the equations for budget constraint, Equation (3), firms' production function, Equation (11), firms' debt, Equation (13), and Equations (21) - (23), we obtain the resource constraint of the domestic economy as Equation (24).

$$c_t^T + D_t = \frac{D_{t+1}}{1 + R_t} + y_t^T \tag{24}$$

We rewrite the market equilibrium conditions as Equations (25) - (30).

$$\lambda_t = \omega (c_t^T)^{-\sigma} \tag{25}$$

$$\lambda_t = \beta(1 + R_t) E_t \lambda_{t+1} \tag{26}$$

$$p_t = \frac{1-\omega}{\omega} \left(\frac{c_t^N}{c_t^T}\right)^{-\sigma} \tag{27}$$

$$y_t^N = A_t K_t^\alpha \tag{28}$$

$$K_t = \left[\frac{R_{t-1}}{\alpha A_t}\left(1 + \frac{\eta R_t}{1 + R_t}\right)\right]^{\frac{1}{\alpha-1}} \tag{29}$$

$$c_t^T + D_t = \frac{D_{t+1}}{1 + R_t} + y_t^T \tag{30}$$

3.5. Foreign nominal interest rate shocks

According to the above descriptions, the foreign country's financial market is perfect, with no financial frictions. Therefore, the nominal interest rate R_t^* of the foreign financial market is equal to its policy rate R_t^{*p}.

$$R_t^* = R_t^{*p} \tag{31}$$

The domestic country's financial market has financial frictions and is not perfect. Hence, following Kalemli-Özcan (2019), we assume that the nominal lending rate in the domestic financial market is the sum of the domestic policy rate R_t^p and domestic risk premium γ_t.

$$R_t = R_t^p + \gamma_t \tag{32}$$

The domestic risk premium is mainly affected by the international risk premium under a foreign monetary policy shock. We assume that the domestic risk premium is equal to the international risk premium, which is a linear function of the foreign nominal interest rate, as in Equation (33), where $0 < \phi < 1$.

$$\gamma_t = \phi R_t^* \tag{33}$$

Combining Equations (31) and (33) yields Equation (34).

$$R_t = R_t^p + \phi R_t^{*p} \tag{34}$$

We assume that the domestic policy rate remains unchanged at R^p. The foreign policy rate is R^{p*} in period $t-1$ and before, implying that $R = R^p + \phi R^{p*} > 0$. Simultaneously, we assume $\beta(1{+}R) = 1$. The foreign policy rate has a temporary rise in $\bar{R}^{p*} > R^{p*}$ period t and then returns to the initial interest rate level R^{p*} from period $t+1$ onward. Combining Equations (25) (26), and (34), we obtain the following equations.

$$c_{t+1}^T = \left[\beta(1 + R^p + \phi\bar{R}^{p*})\right]^{\frac{1}{\sigma}} c_t^T \tag{35}$$

$$c_{t+n}^T = c_{t+1}^T \tag{36}$$

where $n > 1$.

For convenience, we assume that the external debt in period t and before is equal to 0, that is, $D_t = 0$. Further, the external debt is always equal to D_{t+1} from period $t+1$ onward. Combining Equations (30) (34), and (36) yields Equations (37) and (38).

$$c_t^T = \frac{D_{t+1}}{1 + R^p + \phi\bar{R}^{p*}} + y^T \tag{37}$$

$$c_{t+1}^T + D_{t+1} = \frac{D_{t+1}}{1 + R^p + \phi R^{p*}} + y^T \tag{38}$$

Then, combining Equations (35) (37), and (38) yields Equations (39) and (40).

$$c_t^T = y^T\left(\frac{1}{1+R^p+\phi\bar{R}^{p*}}+\frac{R^p+\phi R^{p*}}{1+R^p+\phi R^{p*}}\right)\Big/\left(\frac{(1+R^p+\phi\bar{R}^{p*})^{\frac{1-\sigma}{\sigma}}}{(1+R^p+\phi R^{p*})^{\frac{1}{\sigma}}}+\frac{R^p+\phi R^{p*}}{1+R^p+\phi R^{p*}}\right) \tag{39}$$

$$D_{t+1} = (1+R^p+\phi\bar{R}^{p*})(c_t^T - y^T) \tag{40}$$

As the foreign policy rate rises to $\bar{R}^{p*} > R^{p*}$ in period t, according to Equations (39), we find that the consumption of domestic tradable goods in period t is less than its endowment, that is, $c_t^T < y^T$. Then, according to Equation (40), if there is a surplus of domestic tradable goods, the domestic debt (international capital inflow) will decrease.

Combining Equations (28) (29), and (34), we obtain Equations (41).

$$y_t^N = A_t\left[\frac{R^p+\phi R^{p*}}{\alpha A_t}\left(1+\frac{\eta R^p+\phi\eta\bar{R}^{p*}}{1+R^p+\phi\bar{R}^{p*}}\right)\right]^{\frac{\alpha}{\alpha-1}} \tag{41}$$

After deriving $y_t^N$and R_t^{*p} from Equation (41), we obtain the following equation.

$$\frac{dy_t^N}{d\bar{R}^{p*}} = \frac{\alpha}{\alpha-1}\frac{\phi\eta A_t}{(1+R^p+\phi\bar{R}^{p*})^2})\left(\frac{R^p+\phi R^{p*}}{\alpha A_t}\right)^{\frac{\alpha}{\alpha-1}}\left(1+\frac{\eta R^p+\phi\eta\bar{R}^{p*}}{1+R^p+\phi\bar{R}^{p*}}\right)^{\frac{1}{\alpha-1}} < 0 \tag{42}$$

Equation (42) illustrates that if the foreign policy rate rises while the domestic policy rate and production technology remain unchanged, the domestic real output of non-tradable goods will decrease.

According to the above analysis, we find that when other factors remain unchanged, an increase in foreign policy rate shock causes an increase in international risk and interest rate differential, which results in an increase in the lending rate in the domestic financial market. This leads to a decline in domestic international capital inflow and real output in China. Therefore, a foreign monetary policy shock has a negative spillover impact on the domestic economy through the international capital flow channel.

4. The empirical model

As there may be structural mutations in the spillover effects of the U.S. monetary policy shock on China's economy in different periods, we adopt the TVP-VAR (Time-varying Parameter vector autoregressive) model to conduct empirical tests related to Nakajima (2011) to analyze the impact of the U.S. monetary policy shock on China's economy on the one hand and verify whether the spillover effect has time-varying characteristics on the other hand.

TVP-VAR model was first constructed by Primiceri (2005) and then widely used in macroeconomic research, such as Antonakakis et al. (2020). TVP-VAR model combines the idea of randomness and VAR (vector autoregressive) model to study the nonlinear impact of exogenous shocks on macroeconomic variables. Hence, the model incorporates random volatility into estimation can significantly improve the estimation performance and avoid the heteroscedasticity problem in parameter estimation, at the same time it can effectively describe whether the influence of exogenous factors on endogenous variables has structural change.

4.1. TVP-VAR model

The standard structural VAR model can be expressed by Equation (4-1),

$$Ay_t = F_1 y_{t-1} + F_2 y_{t-2} + \ldots + F_s y_{t-s} + u_t \; t = s+1 \ldots\ldots n \tag{4-1}$$

Where y_t denotes the $k \times 1$ matrix vector of observable variables, A, $F_1 \ldots \ldots F_s$ are all $k \times k$ coefficient matrices, and u_t denotes the $k \times 1$ matrix vector of exogenous shocks.

Assume that u_t is subject to$(0, \Sigma\Sigma)$distribution as follows.

$$\Sigma = \begin{pmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \ddots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_k \end{pmatrix}$$

Further, suppose that A is a lower triangular matrix.

$$A = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ a_{21} & \ddots & \ddots & \vdots \\ \ddots & \ddots & \ddots & 0 \\ a_{k1} & \cdots & a_{k,k-1} & 1 \end{pmatrix}$$

Then, we use the reduced-form VAR model depicted in Equation (4-2) to express the structural VAR model of Equation (4-1).

$$y_t = B_1 y_{t-1} + B_2 y_{t-2} + \ldots + B_s y_{t-s} + A^{-}\Sigma\varepsilon_t \; \varepsilon_t \sim N(0, I_k) \tag{4-2}$$

Where $B_i = A^{-}F_i$, $i = 1, \ldots, s$. The $k^2 s \times 1$ dimensional coefficient matrix β_t is obtained by arranging B_i in rows. We can rewrite Equation (4-2) as Equation (4-3).

$$y_t = X_t \beta + A^{-}\Sigma\varepsilon_t \quad \varepsilon_t \sim N(0, I_k) \tag{4-3}$$

Where $X_t = I_k \otimes (y'_{t-1}, \ldots, y'_{t-s})$, and $\otimes$ denotes the Kronecker product.

As the coefficient matrices β, A^{-}, and $\sum$ in Equation (4-3) are all time invariant, we extend the VAR model to the TVP-VAR model using the following Equation (4-4).

$$y_t = X_t\beta_t + A_t^{-}\Sigma_t\varepsilon_t \; t = s+1......n \tag{4-4}$$

Unlike the traditional VAR model, $\beta_t A_t^{-}$ and $\sum_t$ in Equation (4-4) are all time-varying coefficient matrices. Let $a_t = (a_{21}, a_{31}, a_{32}, a_{41}, ..., a_{k,k-1})'$ be the vector of the lower triangular matrix A_t, $h_t = (h_{1t}, ..., h_{kt})'$ and $h_{jt} = log\sigma_{jt}^2$, $j = 1, \dots, k$, $t = s+1, \dots, n$. At the same time, we assume that all parameters in Equation (4-4) follow the random walk process.

$$\beta_{t+1} = \beta_t + u_{\beta t} \; a_{t+1} = a_t + u_{at} \; h_{t+1} = h_t + u_{ht}$$

$$\begin{pmatrix} \varepsilon_t \\ u_{\beta t} \\ u_{at} \\ u_{ht} \end{pmatrix} = N\left(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_a & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix}\right) t = s+1, ..., n$$

Where $\beta_{s+1} \sim N(\mu_{\beta_0}, \Sigma_{\beta_0})$, $a_{s+1} \sim N(\mu_{a_0}, \Sigma_{a_0})$, $h_{s+1} \sim N(\mu_{h_0}, \Sigma_{h_0})$. Furthermore, we assume that Σ_β, Σ_a, and Σ_h are all diagonal matrices.

4.2. The data

As proposed in the introduction, the U.S. monetary policy shock causes the change in the interest rate spread and the bilateral exchange rate between two countries as well as the international risk index, which affect the fluctuation of china's international capital flow, resulting in a spillover impact on china's macro-economies through capital flow channel. There have six endogenous variables of our TVP-VAR empirical model. The six endogenous variables are the change in the U.S. nominal interest rate, the change in the nominal interest rate differential between China and the United States, the change in the international risk index, the change in the bilateral nominal exchange rate (RMB price of one U.S. dollar), the growth rate of China's international capital inflow, and the growth rate of China's real output.

The estimation uses quarterly data cover the period from 2005Q2 to 2018Q4. The U.S. nominal interest rate is represented by the U.S. shadow rate. The interest rate differential uses the logarithm of the U.S. shadow rate minus China's 7-day repo rate, which is sourced from www.frbatlanta.org. The international risk index adopts the logarithm of the VIX related to Bekaert et al. (2013), and the VIX is sourced from www.federalreserve.gov. The bilateral nominal exchange rate is expressed as the logarithm of the nominal exchange rate (RMB price of one U.S. dollar) and is sourced from the IMF's IFS database. China's international capital inflow is given by the net value of China's non-reserve international capital liabilities and is sourced from www.safe.gov.cn. China's real output is given by seasonally adjusted value-added GDP and is sourced from www.frbatlanta.org.

We use the augmented Dickey–Fuller (ADF) test to check the presence of a unit root in the six endogenous variables. The results (see Table 1) demonstrate that the hypothesis of the presence of a unit root in the change in the U.S. nominal interest rate can be rejected at the 5% significance level. At the same time, the hypothesis of the presence of a unit root in the change in the nominal interest rate differential, the

Table 1. ADF test results.

Variable	ADF Stat.
Change in the U.S. nominal interest rate	−3.849**
Change in the interest rate differential	−5.825***
Change in the international risk index	−7.872***
Change in the nominal exchange rate	−4.661***
Growth rate of China's capital inflow	−7.221***
Growth rate of China's real output	−4.163***

Note: **denotes 5% significance level, ***denotes 1% significance level.
Source: ourselves.

Table 2. Lag order tests.

Lag Order	Akaike information criterion	Hannan–Quinn information criterion	Schwarz's Bayesian information criterion
0	−4.3314	−4.2440	−4.1019*
1	−4.8855*	−4.2739*	−3.2794
2	−4.6681	−3.5322	−1.6853
3	−4.1784	−2.5183	0.1811
4	−4.1957	−2.0114	1.5404

Source: ourselves.

change in the international risk index, the change in the bilateral nominal exchange rate, the growth rate of China's international capital inflow, and the growth rate of China's real output can be rejected at the 1% significance level.

We use the VAR lag order test to validate the lag order of the model. According to the results (see Table 2), the Akaike information criterion and the Hannan–Quinn information criterion both show that the lag order is one period. Schwarz's Bayesian information criterion shows that the lag order is zero period. Therefore, we set the lag order of the model as one period.

Following Nakajima (2011), we assume that Σ_β, Σ_a, and Σ_h are diagonal matrices and the prior mean and standard deviation of parameters are set as follows.

$$\mu_{\beta_0} = \mu_{a_0} = \mu_{h_0} = 0$$

$$\Sigma_{\beta_0} = \Sigma_{a_0} = \Sigma_{h_0} = 10 \times I$$

$$(\Sigma_\beta)_i^{-2} \sim Gamma(40, 0.02)$$

$$(\Sigma_a)_i^{-2} \sim Gamma(40, 0.02)$$

$$(\Sigma_h)_i^{-2} \sim Gamma(40, 0.02)$$

where $(\Sigma_\beta)_i$, $(\Sigma_a)_i$, and $(\Sigma_h)_i$ represent the i element on the diagonal of the diagonal matrix Σ_β, Σ_a, and Σ_h, respectively. We use the Monte Carlo Markov chain sampling method to draw 10,000 data and burn out the first 1000 data, and then obtain the posterior distribution of parameters. The Ineff. values are all less than 100 (see Table 3), indicating that the parameter estimation is effective and robust (Geweke, 1991).

Table 3. Estimation results.

Variables	Mean	Std.	95% Up	95% Down	CD	Ineff.
sb_1	0.002 3	0.000 3	0.001 8	0.002 9	0.873	5.13
sb_2	0.002 3	0.000 3	0.001 8	0.002 9	0.192	4.21
sa_1	0.005 5	0.001 6	0.003 4	0.009 4	0.173	19.86
sh_1	0.005 3	0.001 7	0.002 6	0.009 6	0.010	67.33
sh_2	0.005 5	0.001 6	0.003 3	0.009 4	0.187	14.27

Source: ourselves.

5. Impulse response analysis

Based on the adjustment cycle of conventional and unconventional monetary policy in the United States, we select three time points when the shadow interest rate rises. The first time point is 2005Q4 when the federal funds rate is raised; it is also the time point when the floating flexibility of the exchange rate increases after the reform of China's exchange rate system. The second time point is 2012Q1 when the second round of quantitative easing monetary policy ended in the United States, and both the U.S. federal funds rate and the shadow rate increased. The third time point is 2014Q4 when both the federal funds rate and the shadow rate rose after the complete withdrawal of quantitative easing. At the same time, we selected equal time intervals of two, four, and eight periods.

5.1. Time point impulse response analysis

According to Figure 3, in 2005Q4, 2012Q1, and 2014Q4, the U.S. monetary policy shock causes the U.S. nominal interest rate to rise by about 0.38% immediately, then gradually declines and returns to the initial nominal interest rate level after 12 periods of the shock. The impulse response trend at the three time points is consistent, and there is no structural change. The response degree of the interest rate differential to the U.S. interest rate shock is strongest. Facing the U.S. nominal interest rate shock, the interest rate differential rises by approximately 0.23% immediately, the international risk index rises rapidly, and reach about 0.05% higher than the initial level after the first period of the shock. At the same time, the bilateral nominal exchange rate rises by approximately 0.002% in the shock period.

Turning to the response of China's capital inflows which is the key variable of this paper. We find that the U.S. tightening monetary policy shock decreases China's international capital inflow as the interest rate differential, the nominal exchange rate, and the international risk index all increases under the shock. This result is consistent with Wang and Wu (2021) who take 15 emerging market countries such as China into the empirical test sample and came to the conclusion that the U.S. tightening monetary policy shock caused the decline of capital inflows in these countries. Specifically, we find that China's international capital inflow reaches the trough, about 0.15% lower than the initial level after two periods. The decline degree of China's international capital inflow of our result is a little bit lower than 0.18% under the result of Dahlhaus and Vasishtha (2020) who took the U.S. Monetary policy news as the shock.

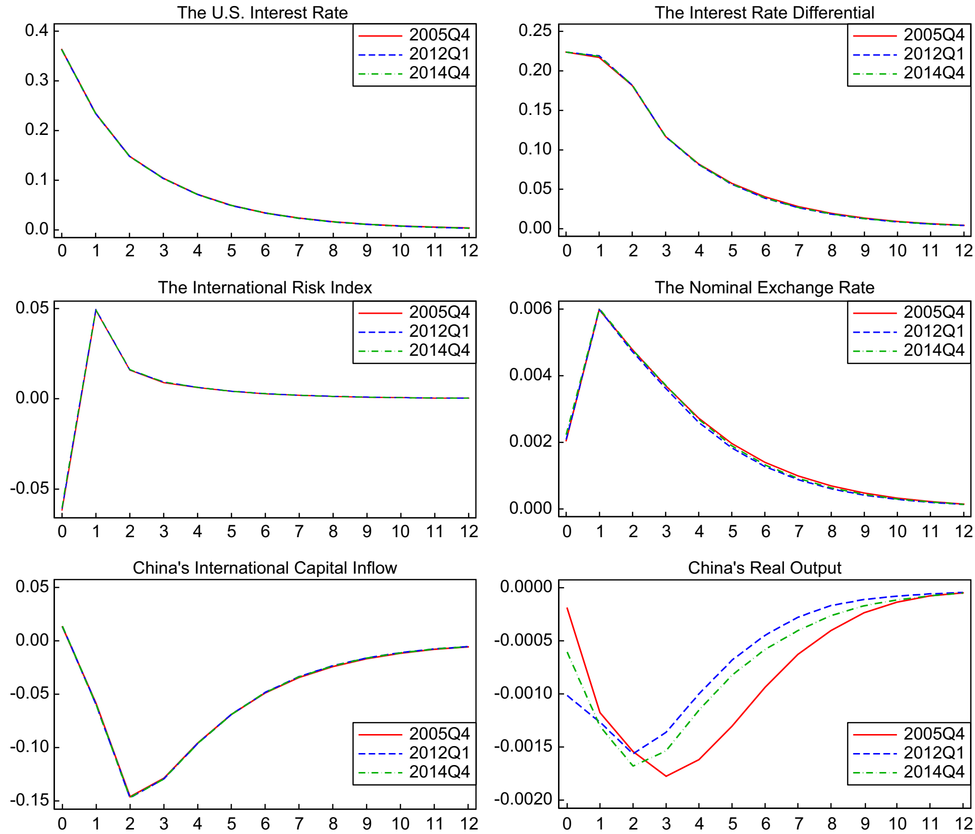

Figure 3. Time point impulse responses to the shock of increase in the U.S. interest rate.
Source: ourselves.

China's real output declines as China's capital inflows decreases under the U.S. monetary policy shock. However, there are differences in the decline range at the three time points. In 2005Q4, an increase in the U.S. nominal interest rate causes China's real output to drop by about 0.0002% immediately. After three periods, China's real output reaches the trough, approximately 0.0017% lower than the initial level, and then recovers to its initial level in the long run. In 2012Q1, an increase in the U.S. nominal interest rate causes China's real output to decline by approximately 0.001% in the shock period. China's real output is lower than the initial level by approximately 0.0016% after two periods. In 2014Q4, an increase in the U.S. nominal interest rate leads to the decline in China's real output by approximately 0.0006% in the shock period. China's real output is lower than its initial level by approximately 0.0016%–0.0017% after three periods of the shock.

In summary, we find that an increase in the U.S. nominal interest rate leads to an increase in the nominal interest rate differential, the international risk index, and the nominal exchange rate in the short term, resulting in a decline in China's international capital inflow and real output. The increase in the nominal interest rate in the United States has a negative spillover effect on China's economy through international capital flow channel, and this negative spillover effect has no structural time-varying characteristics.

5.2. Equal time interval impulse response

Figure 4 shows the interval impulse responses of the six endogenous variables under the U.S. monetary policy shock. We select two, four, and eight equal time intervals to track the changes. The U.S. nominal interest rate rises two periods ahead, causing the nominal interest rate differential, the international risk index, and the nominal exchange rate to increase to a higher level in the four and eight periods ahead,

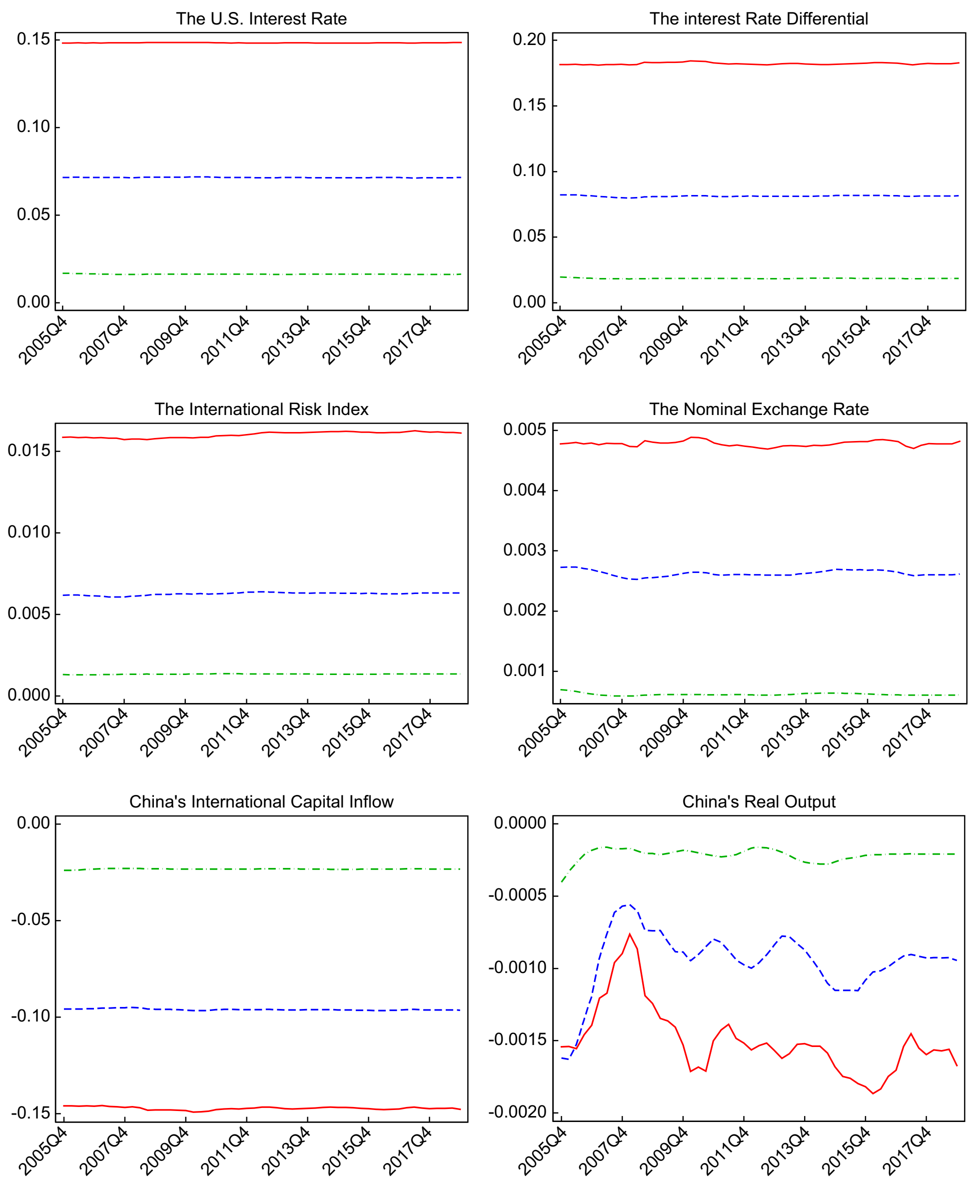

Figure 4. Equal interval impulse responses to the shock of increase in the U.S. interest rate. The red solid line indicates two periods ahead, the blue dashed line indicates four periods ahead, and the green dash–dot line indicates two periods ahead.
Source: ourselves.

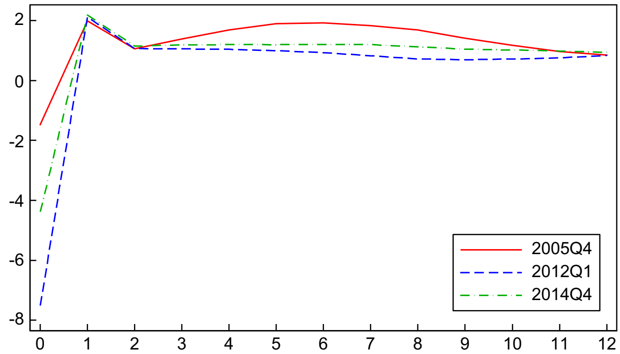

Figure 5. Pass-through effect from China's international capital inflow to China's real output.
Source: ourselves.

Table 4. Estimation results - robustness check.

Variables	Mean	Std.	95% Up	95% Down	CD	Ineff.
sb_1	0.002 3	0.000 3	0.001 8	0.002 9	0.879	2.77
sb_2	0.002 3	0.000 3	0.001 8	0.002 9	0.498	4.05
sa_1	0.005 5	0.001 5	0.003 4	0.009 1	0.007	12.32
sh_1	0.005 5	0.001 5	0.003 3	0.009 1	0.135	17.28
sh_2	0.005 7	0.001 7	0.003 5	0.010 0	0.748	15.37

Source: ourselves.

resulting in a larger decline in China's international capital inflow and China's real output. Therefore, the negative spillover effect of the increase in the U.S. nominal interest rate on China's economy is greater in the short term and weaker in the medium and long term.

5.3. Pass-through effect

We refer to Forbes et al. (2018) to analyse the pass-through effect from China's international capital inflow to China's real output under the U.S. monetary policy shock. The pass-through index is calculated by the response range of China's real output to shocks divided by the response range of the international capital inflow. As evident from Figure 5, we find that the pass-through from China's international capital inflow to China's real output has time lags, as the pass-through index is negative initially after the shock and then begins to rise and goes up to 2 after one period. In the medium and long term, the pass-through index remains at the level of 1.5–2, which indicates that the fluctuation of international capital flow expands macroeconomic cycles.

5.4. Robustness check

We use China's foreign direct investment to replace China's international capital inflow to conduct a robustness check. China's foreign direct investment is taken as quarterly net value and in logarithmic form, and the data is sourced from www.safe.gov.cn. Table 4 presents the estimation results of the TVP-VAR model.

From Figure 6, we find that the negative spillover effect of the U.S. monetary policy shock is robust. The increase in the U.S. nominal interest rate leads to an increase

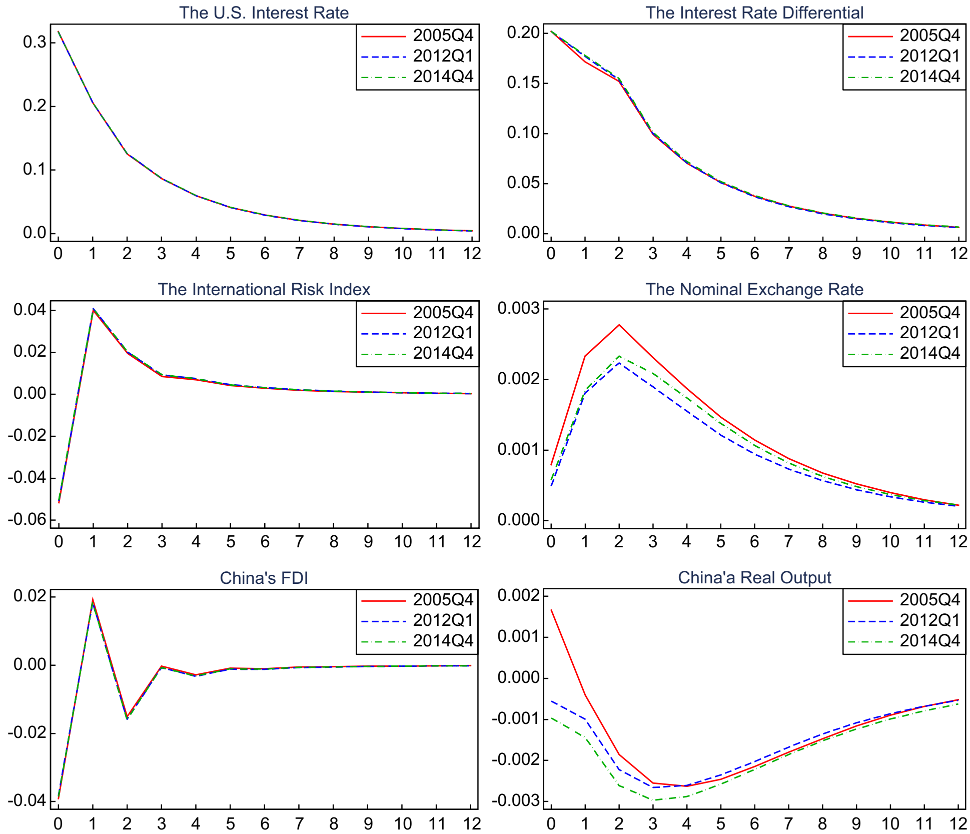

Figure 6. Time point impulse responses to the shock of increase in the U.S. interest rate: Robustness check.
Source: ourselves.

in the nominal interest rate differential, the international risk index, and the nominal exchange rate in the short term, which results in a decline in China's international capital inflow and real output. At the same time, this negative spillover effect has no structural time-varying characteristics. From Figure 7, we find that the negative spillover effect of an increase in the U.S. nominal interest rate on China's economy is greater in the short term and gradually weakens in the long term.

6. Conclusion

In this study, we build a small open theoretical model with financial frictions to analyse the spillover impact of the U.S. monetary policy shock on China's economy through the international capital flow channel. Then TVP-VAR model is employed for the empirical test and obtained three main results. First, the time point impulse response demonstrated that an increase in the U.S. nominal interest rate leads to a rise in the nominal interest rate differential, the international risk index, and the bilateral nominal exchange rate in the short term, resulting in a decline in China's

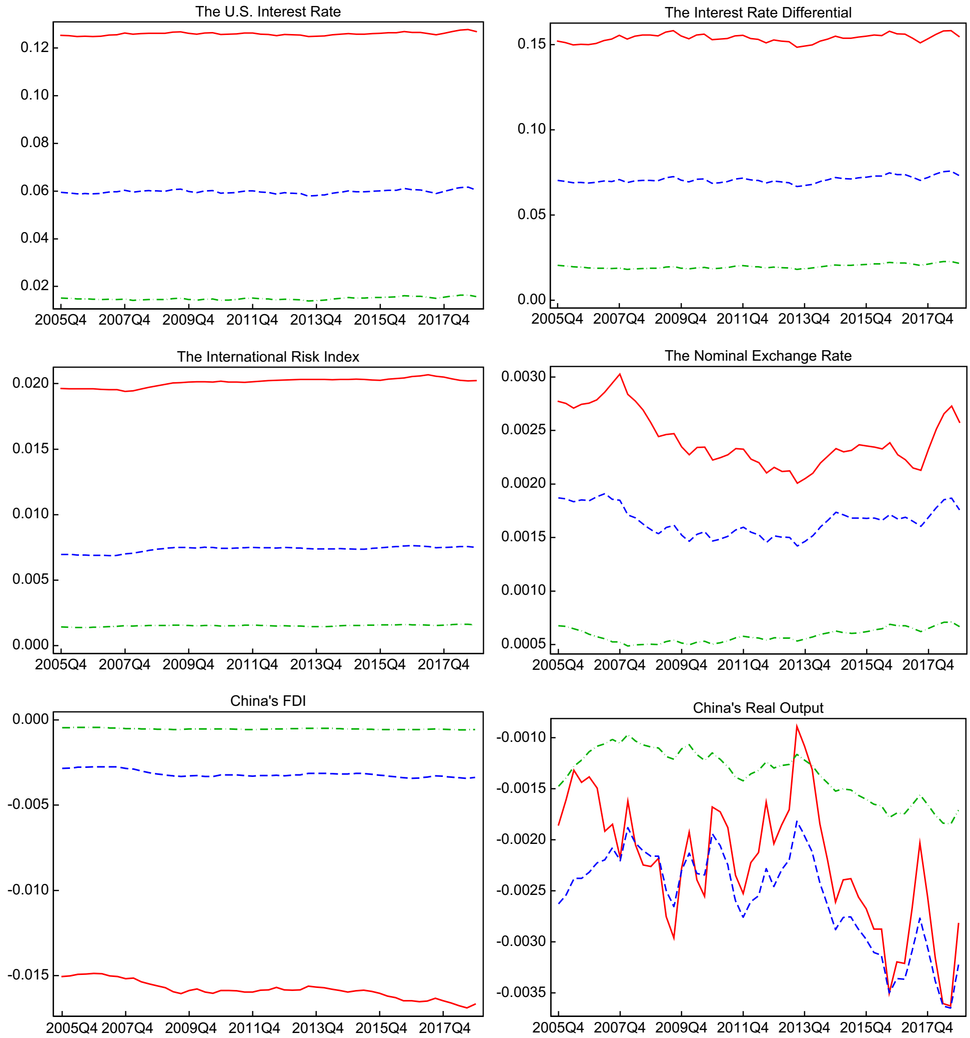

Figure 7. Equal interval impulse responses to the shock of increase in the U.S. interest rate: Robustness check. The red solid line indicates two periods ahead, the blue dashed line indicates four periods ahead, and the green dashed line indicates two periods ahead.
Source: ourselves.

international capital inflow and real output. Therefore, an increase in the U.S. nominal interest rate has a negative spillover impact on China's economy through the international capital flow channel.

Second, the equal time interval impulse response illustrated that the negative spillover impact of the U.S. monetary shocks is greater in the short term than in the medium and long term, and does not have time-varying characteristics. Third, according to the analysis of the pass-through effect from China's international capital inflow to China's real output, the pass-through effect has time lags. The response range of China's real output to international capital inflow is higher than that of international capital inflow itself, indicating that the fluctuation in international capital flow expands macroeconomic cycles.

Just as Daehler et al. (2020) and Acharya and Vij (2020) demonstrate that after the Federal Reserve announced to reduce the scale of quantitative easing in 2013, the economic growth of emerging countries generally slowed down. Facing the gradual withdrawal of quantitative easing monetary policy from the United States, China needs to be vigilant the sharp outflow of international capital and the negative spillover impact on China's macro-economy through international capital flow channel. The research results of this paper provide empirical support for the capital control policy suggestions after the financial crisis, such as Wang and Wu (2021), that is, in the case of large capital fluctuations, counter cyclical capital flow management needs to be used to improve the impact of external shocks, so as to alleviate the expansion effect of large capital inflows and outflows on the economic cycle. However, there are potential costs in capital control, which need to be further analyzed. This paper aims to provide early warning for policymakers to the U.S. monetary policy shocks.

In addition, this paper only considers the spillover effect of U.S. monetary policy shock on China's economy through capital flow channels, but does not consider the reverse effect of China on the U.S. macro-economy. This is because the US dollar is still the leading international currency. The US dollar accounts for 60% of the world's foreign exchange reserves, while the RMB accounts for less than 3%. At the same time, China's capital market is still not perfect and there exist financial frictions. The spillover impact of China's policy changes on the U.S. economy is relatively small, just as Yang et al. (2018) verify that the spillover effect of the U.S. monetary policy on some Chinese economic variables is greater than that on the U.S. economic variables.

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