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RMB Internationalization and the Effectiveness of Exchange Rate Intervention

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This paper constructs a DSGE model of asymmetric two-country open economy, and compares and analyzes the economic effects of both sterilized and unsterilized interventions. Moreover, we explore the impact of RMB internationalization on the spillover effect of foreign monetary policy and the effectiveness of exchange rate intervention. We identify that both sterilized and unsterilized interventions can slow down exchange rate fluctuations. However, unsterilized intervention will weaken the stability of China's monetary policy on output and inflation, resulting in policy objectives conflict and higher real economic stability costs. The promotion of RMB internationalization will have a significant impact on the spillover effect of foreign monetary policy, thus reducing the necessity for unsterilized intervention to stabilize the exchange rate. Meanwhile, we should also moderately reduce the regulation of sterilized intervention. According to the conclusion of the study, the Chinese monetary authority should prioritize the reform of the RMB exchange rate regime. While promoting the internationalization of RMB, we should gradually reduce the frequency and intensity of exchange rate intervention, and speed up the reform of exchange rate marketization.

Key Words: RMB Internationalization; Sterilized Intervention; Unsterilized Intervention; Spillover Effect of Monetary Policy.
JEL Classification Numbers: F31, E52, E41.

1. INTRODUCTION

In recent decades, the frequent occurrence of international financial crises has led to sharp exchange rate fluctuations in many countries. To eliminate its negative effects, exchange rate intervention has become one of the most important macroeconomic policy tools in developing countries. After 2019, the global economy had a poor prospect for development, and the

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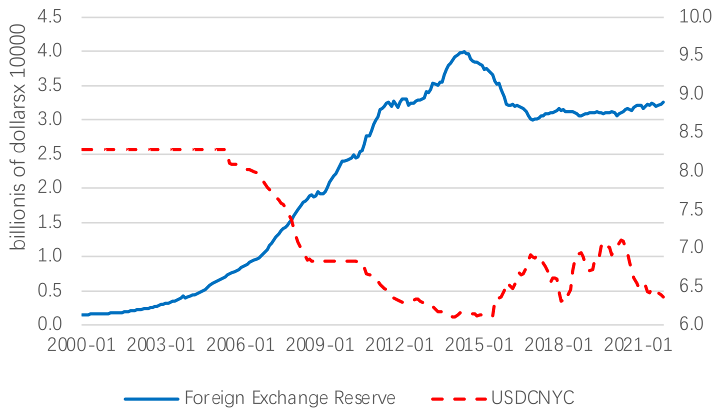
intensifying trade conflict between China and the United States further increased the uncertainty of the world economy. The Federal Reserve began to conduct interest rate reduction policy in the post-financial crisis period, and the expectations of the foreign exchange market also changed. Since August 2019, various currencies have depreciated against the dollar, the onshore and offshore exchange rate of RMB against the dollar both broke 7. Complex international financial situation and RMB depreciation pressure put forward severe challenges to China's financial stability and macroeconomic control; therefore, it is important to strengthen the research of exchange rate intervention tools and their effectiveness.

Since the "7.21" exchange rate reform in 2005, the RMB began real managed floating exchange rate arrangements. Since then, there has been a significant negative correlation between foreign exchange reserves and the nominal exchange rate of RMB, as shown in Figure 1. This indicates that the monetary authority has been regulating the exchange rate through foreign exchange interventions to achieve the purpose of maintaining import and export, and realizing the stability of macro-economy and financial markets.

However, with the deepening of reform and opening up and promotion of RMB internationalization, the reform of RMB exchange rate formation mechanism urgently requires the Chinese Central Bank to adjust the goal and way of intervention in its exchange rate. On August 6, 2019, China was listed as a "currency manipulator" by the United States, which means that China may face severe penalties from the US. Changes in the external economic environment force the monetary authority to take the study of exchange rate intervention adjustment as the highest priority of its current work.

FIG. 1. China's foreign exchange reserve and RMB exchange rate



There are two main kinds of exchange rate interventions: sterilized intervention and unsterilized intervention. Sterilized intervention refers to the reverse operation in the domestic bond market while buying or selling foreign currency assets in the foreign exchange market. This is carried out to ensure the stability of the domestic currency supply without directly affecting the domestic interest rate. On the contrary, unsterilized intervention does not conduct reverse operations in the domestic bond market, which will have a direct impact on the domestic interest rate. Some scholars such as Zhang (2015), Wang and Deng (2016) conduct normative theoretical research on China's exchange rate intervention policies; but in these models, the differences between sterilized and unsterilized interventions are not discussed, meaning that the theoretical framework analysis does not depict accurate features of the Chinese economy. Devereux and Yetman (2014) reveal the features of unsterilized intervention policy by letting the interest rate pegged on the exchange rate fluctuations. We adopt their method to introduce unsterilized intervention, and choose foreign exchange intervention, which is studied by some scholars such as Wang and Deng (2016), as the sterilized intervention tool; so that we can compare the mechanism of the two intervention tools and their influence on the economy.

With the rapid development of China's economy and its deepening financial market, the internationalization of RMB is stepping forward on the international arena. The most direct and important impact of internationalization is to enhance the priority of RMB in international pricing and settlement. The proportion of RMB settlement in China's foreign trade rose rapidly from less than 10% in 2012 to approximately 35% in 2015. On October 1, 2016, RMB was officially included in the Special Drawing Rights (SDR) currency basket by IMF; which became a milestone in the process of RMB internationalization. However, compared to some main international currencies, the RMB internationalization level is still relatively low. Gopinath (2016) find that the share of RMB settlement in China's exports trade is only 4.5%. Following Engel (2011), a low domestic currency settlement ratio in exporting countries will directly reduce the degree of exchange rate pass-through. Allowing free exchange rate fluctuations will cause serious currency and resource mismatch, and then bring loss to social welfare. Therefore, the internationalization of RMB will not only influence the economic effect of exchange rate intervention, but also directly affect its welfare effect.

This paper initially builds an open economy DSGE model to compare and analyze the impact mechanism and economic effect of two different exchange rate intervention methods. Then, we discuss the influence of RMB internationalization on the effectiveness of exchange rate intervention and its welfare effects, and attempt to provide some meaningful suggestions for China's macroeconomic regulation. We find that the share of local currency settlement has a significant impact on the spillover effects of foreign monetary policy, and the enhancement of RMB internationalization can attenuate the adverse impact of spillovers. Although both sterilized and unsterilized interventions can moderate exchange rate fluctuations, sterilized intervention will cause a hysteresis quality of exchange rate adjustment, so its effectiveness is quite limited. Under the shock of foreign monetary policy, unsterilized intervention will impair the function of domestic monetary policy aimed at stabilizing inflation fluctuations, thus incurring lower domestic demand and severer deflation; which consequently means a higher cost to stabilize economic oscillations. On the other side, sterilized intervention alters the foreign asset holdings of domestic residents, but also has a noteworthy impact on domestic credit markets with an increase in real investment, offsetting some of the negative effects of falling exports. We must also point out the weaker ability of sterilized intervention to stabilize the exchange rate, but its relatively lower real economic costs. However, the increased internationalization of currency will promote the costs of stabilizing the fluctuations in the real economy since sterilized intervention will lead to further declines in net exports and net short-term capital inflows, resulting in larger fluctuations in inflation. Finally, through optimal policy analysis, it is concluded that the monetary authority should adopt sterilized intervention to stabilize the exchange rate with a low level of currency internationalization, and the interest rate policy ought not respond to exchange rate fluctuations excessively. With the improvement of currency internationalization, the authority is supposed to tone down the intensity of sterilized intervention, and fully abandon unsterilized intervention.

The innovative aspects of this paper are as follows: Firstly, we use the share of domestic currency in exports pricing to reflect the typical characteristics of RMB internationalization and analyze the different effects of sterilized and unsterilized interventions in the process of RMB internationalization. Secondly, this paper utilizes an asymmetric economy DSGE model to simulate the economy of China and the United States, and discusses the mechanism and macro-influence of exchange rate intervention by introducing factors such as RMB internationalization and capital control. Finally, we explore the optimal policy mix of the two exchange rate intervention methods under the standard welfare loss function, and provide the monetary authority with theoretical evidence and reform suggestion.

The rest of the paper includes the following: Section 2 critically reviews the related empirical literature. Section 3 constructs the basic theoretical model. Section 4 discusses the parameter calibration and the results of simulations. Section 5 presents the research results and attempts to provide a number of suggestions.

2. LITERATURE REVIEW

In recent years, research work on exchange rate intervention has mainly focused on the effectiveness of intervention policy. Most empirical studies have explored the depth and duration of the impact on the exchange rate level, or its volatility caused by intervention policy. Adler and Tovar (2011) study intervention tools and their corresponding effectiveness in 15 economies covering 2004-2010. They find that foreign exchange intervention can slow the pace of currency appreciation, and can be more effective when capital control exists or the exchange rate is overvalued. Kuersteiner et.al (2018) also find that interventions have significant effects on the exchange rate, and capital controls can amplify the effect of intervention in Colombia through regression discontinuity methods. Blanchard et al. (2015) investigate whether foreign exchange intervention can curb capital inflows to influence the exchange rates, and by studying transnational changes and exchange rate responses, successfully demonstrate that foreign exchange intervention is an effective policy tool of macro-economic management. Daude et al. (2016) analyze the effectiveness of intervention in 18 emerging market economies from 2003 to 2011. Their study verifies that foreign exchange intervention plays an effective role in exchange rate change, fundamentals controlling, and imbalance of global financial variables. Deng and Dong (2017) use the panel instrumental variable to test the effectiveness of foreign exchange intervention in 23 countries and regions. They find that intervention by the central bank plays a significant role in slowing down exchange rate fluctuations. Si et al. (2016) demonstrate that the foreign exchange intervention of the central bank has significant asymmetric effects on RMB exchange rate, both in the short-term and long-term.

The development of empirical research tools such as the DSGE model has promoted some theoretical discoveries that focus on the mechanism and macro-effects of intervention policies. Benes et al. (2015) and Kumhof (2010) discuss the impact of foreign exchange interventions via portfolio balance channel. Devereux and Yetman (2014) study the economic effects of various intervention methods in an open-economy New Keynesian model, arguing that implementing sterilized intervention policies in Asian countries can maximize welfare, but the improvement of financial market integration will reduce the overall effectiveness. Cun and Li (2017) study the influence of interventions on liquidity in the financial sector. Prasad (2018) combines sterilized intervention policy with capital control in a small open-economy, proving that the joint implementation of sterilized intervention and capital control can mitigate inflation and real exchange fluctuations, and improve domestic welfare.

Several recent papers scrutinize the Chinese exchange rate intervention policy. Chang et al. (2015) study the choice of optimal exchange rate and foreign exchange sterilization tools in China under limited capital control and risk-sharing. Zhang (2015) establishes a New Keynesian DSGE model including capital control and central bank balance sheet to study the relationship among hot money inflow, exchange rate intervention, and foreign exchange sterilization. They find that capital control is the premise of exchange rate intervention, which plays a key role in demand expansion, but also leads to the excessive accumulation of foreign exchange reserves. Wang and Deng (2016) incorporate foreign exchange intervention and monetary policy transformation into the DSGE model and add capital control to the uncovered interest rate parity to study the macro-economic responses under multiple shocks, including foreign exchange intervention.

To sum up, most of the aforementioned studies discuss the impact of exchange rate intervention policy from an empirical perspective; whereas studies which focus on the pass-through mechanism and economic impact of exchange rate intervention policy are scarce; let alone the exchange rate intervention tools and their effectiveness. Under the background of RMB internationalization, exchange rate intervention may have a profound influence on capital flow, asset prices, investment, and output; thus affecting the overall effectiveness of such intervention policies. All the issues above are worthy of attention.

3. THE MODEL

This paper constructs a theoretical framework, which refers to Davis and Presno (2017) and Liu (2018), and introduces the influence of currency internationalization on the transmission mechanism. We compare the differences between sterilized intervention and unsterilized intervention, which is rather similar to the study conducted by Devereux and Yetman (2014). However, their model is based on the analysis of the symmetric two-country model without introducing the capital factor, and does not take into account the significance of capital control for exchange rate intervention policies.

This paper develops an asymmetric two-country New Keynesian DSGE model. Domestic residents are divided into two groups: patient households and impatient entrepreneurs. The entrepreneurs have a lower discount rate than the patient households, so the two groups serve respectively as the debtor and creditor of the domestic capital market. Only the patient households can engage in international borrowing activities. Both groups consume the final goods, but only the patient households provide labor, while the entrepreneurs have capital and hire labor for production.

Considering that the most direct impact of currency internationalization is to increase the share of cross-border settlement, retail enterprises that adopt a pricing-to-market strategy are introduced in the model. The difference in currency internationalization is reflected by adjusting the share of the two categories of Exporters, Producer Currency Pricing (PCP), and Local Currency Pricing (LCP).

3.1. Patient Households

Since there is no heterogeneity among the individuals in the patient households, only the optimal decision problem of the representative is taken into account. The representative patient households do not have capital. They provide funds to entrepreneurs and central banks through buying domestic bonds B_t^h and B_t^g, respectively, and smooth their intertemporal consumption through buying and selling foreign bonds in international markets. The utility function of the representative patient households is:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t - \nu C_{t-1}) - \frac{1}{1+\sigma_H^{-1}} N_t^{1+\sigma_H^{-1}} \right], \tag{1}$$

where β is the subjective discount factor, C_t and N_t represent the consumption and labor supply of patient households, respectively, ν shows the size of consumption inertia preference, and σ_H is the Frisch elasticity of labor. The budget constraint is as follows:

$$P_t C_t + B_t^h + S_t B_t^f + B_t^g = W_t N_t + R_{t-1} B_{t-1}^h + (1-\tau_{t-1}) R_{t-1}^f S_t B_{t-1}^f + R_{t-1} B_{t-1}^g, \tag{2}$$

where P_t is the general price index, W_t is the nominal salary of domestic patient residents, respectively, R_t and R_t^f represent the nominal return rate of national bonds and international bonds, and S_t is the nominal exchange rate.

To maintain the model stationary, this paper refers to Davis and Presno (2017) to introduce the risk premium factor for foreign bond returns; $R_t^f = R_t^* \exp(-\xi \tilde{B}_t^f)$. In this formula, $\tilde{B}_t^f = \int_0^1 B_t^f dh$ is the total nominal amount of foreign bonds held by domestic households, which means that households ignore the impact of their own portfolio decisions on asset returns. R_t^* is the exogenous foreign risk-free interest rate. The first-order conditions for the households are as follows:

$$\Lambda_t = \frac{1}{C_t - \nu C_{t-1}} - \beta E_t \frac{\nu}{C_{t+1} - \nu C_t}, \quad (3)$$

$$\Lambda_t = R_t \beta E_t (\Lambda_{t+1} P_t / P_{t+1}), \quad (4)$$

$$\Lambda_t = (1-\tau_t) R_t^f \beta E_t \left(\frac{\Lambda_{t+1} P_t S_{t+1}}{P_{t+1} S_t} \right), \quad (5)$$

$$N_t^{1/\sigma_H} = \Lambda_t W_t / P_t, \quad (6)$$

where, Λ_t is the multiplier of the budget constraint formula (2), formula (4) is the Euler equation for consumption, and formula (6) is the determining equation of labor supply.

Previous studies, such as Benes (2015) and Wang and Deng (2016), assume that the size of foreign exchange reserves will directly affect the deviation of uncovered rate parity. So, domestic and foreign bonds are not completely substituted; thus, unsterilized intervention is effective. However, these assumptions lack a rigorous micro-foundation, thus failing to adequately describe the theoretical mechanism of foreign exchange sterilized intervention policy.

In this paper, capital control implemented by the monetary authority is the core precondition for the effectiveness of sterilized intervention. Specifically, when the central bank adjusts the scale of foreign exchange reserves and domestic bond issuance, the allocation of households' asset portfolio will also be adjusted accordingly under the pressure of external balance and budget constraints. Quantitative capital controls tax rate $\tau(\tilde{B}_t^f)$ changes when the total amount of foreign bonds $\tilde{B}_t^f$ held by residents fluctuates, which in turn affects the deviation degree of uncovered interest rate parity, and bring about the incomplete substitution of domestic and foreign risk-free bond and the effectiveness of sterilized intervention.

3.2. Entrepreneur Group

As in Liu et al. (2013), the preference of the representative entrepreneur depends only on their consumption C_t^e, and the utility function is:

$$E_0 \sum_{t=0}^{\infty} (\beta^e)^t [\ln(C_t^e - \nu C_{t-1}^e)]. \quad (7)$$

Since the representative entrepreneur is more impatient than households, they have a smaller discount factor, which ensures that the entrepreneur is the borrower in the steady state. The entrepreneur has capital returns and profits because they own capital. Meanwhile, they participate in investment activities in the capital market. Their budget constraint is as follows:

$$P_tC_t^e + P_t^I I_t + R_{t-1}b_{t-1} + P_tP_t^k\Delta_t = R_t^k K_{t-1} + b_t + div_t, \tag{8}$$

where I_t denotes the actual investment of the representative entrepreneur, K_t denotes the predetermined amount of capital goods, P_t^k denotes the actual price of capital goods, b_t denotes domestic financing scale, and div_t represents the profit dividends of the entrepreneur by holding shares. Following Christiano et al. (2010), we also assume that the representative entrepreneur can accumulate capital goods in two ways: the first is to obtain capital goods through investment I_t, which has quadratic adjustment costs; the second is to directly purchase capital goods Δ_t in the market. To sum up, the capital accumulation equation of the entrepreneur is:

$$K_t = (1-\delta)K_{t-1} + \left[1 + \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t + \Delta_t. \tag{9}$$

As in Liu et al. (2013), the entrepreneur faces borrowing constraints due to financial market imperfections. In particular, they have limited commitment and contract enforcement, which means creditors can only retain the proportion of θ assets in liquidation. Thus, the borrowing constraint for the entrepreneurs is:

$$\theta E_t(P_{t+1}P_{t+1}^k)K_t \geq R_t b_t, \tag{10}$$

where the actual market price P_t^k of capital goods directly affects the value of the entrepreneur's collateral. Based on the above utility functions and constraints, the optimal decision of the representative entrepreneur can be expressed as the following first-order conditions:

$$\Lambda_t^e = \frac{1}{C_t^e - \nu C_{t-1}^e} - \beta^e E_t \frac{\nu}{C_{t+1}^e - \nu C_t^e}, \tag{11}$$

$$\Lambda_t^e - R_t\mu_t = R_t\beta^e E_t(\Lambda_{t+1}^e P_t/P_{t+1}), \tag{12}$$

$$\begin{aligned} P_t^I = & \left[\left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) - \kappa\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] P_t^k \\ & + \beta^e\kappa E_t\left[P_{t+1}^k\left(\frac{\Lambda_{t+1}^e}{\Lambda_t^e}\right)\left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right], \end{aligned} \tag{13}$$

$$P_t^k\Lambda_t^e - \mu_t\theta E_t(P_{t+1}^k P_{t+1}/P_t) = \beta^e E_t[\Lambda_{t+1}^e(R_{t+1}^k + (1-\delta)P_{t+1}^k)], \tag{14}$$

where, Λ_t^e and μ_t are the multiplier of the budget and borrowing constraints, respectively. We can prove that when $\beta^e < \beta$, the borrowing constraint (10) satisfies the equation condition, which is a binding constraint.

3.3. Producer of Final Goods

Assuming that the producers of final goods are entirely competitive, they will produce domestic and export goods: Y_t^d and Y_t^x. Both final goods are aggregated by the intermediate goods produced by intermediate manufacturers. To introduce a generalized pricing currency share setting, we assume that there are two types of intermediate manufacturers, namely $\{i_P, i_L\}$, in the market using the PCP and LCP methods. For domestic goods Y_t^d, its relationship among the intermediate goods of the two types of intermediate manufacturers satisfies:

$$Y_t^d = \left[\kappa_h^{1/\sigma} \int_0^{\kappa_h} \kappa_h^{-1/\sigma} y_t^d(i_P)^{\frac{\sigma-1}{\sigma}} di_P + (1-\kappa_h)^{1/\sigma} \int_{\kappa_h}^1 (1-\kappa_h)^{-1/\sigma} y_t^d(i_L)^{\frac{\sigma-1}{\sigma}} di_L\right]^{\frac{\sigma}{\sigma-1}}, \tag{15}$$

where σ represents the substitution elasticity among different intermediate goods, and κ_h is the share of the PCP intermediate goods. We can define the final export goods as:

$$Y_t^x = \left[\kappa_h^{1/\sigma} \int_0^{\kappa_h} \kappa_h^{-1/\sigma} y_t^x(i_P)^{\frac{\sigma-1}{\sigma}} di_P + (1-\kappa_h)^{1/\sigma} \int_{\kappa_h}^1 (1-\kappa_h)^{-1/\sigma} y_t^x(i_L)^{\frac{\sigma-1}{\sigma}} di_L\right]^{\frac{\sigma}{\sigma-1}}. \tag{16}$$

Based on the assumptions above, the demand function of intermediate manufacturers can be obtained via:

$$y_t^d(i) + y_t^x(i) = \left(\frac{P_t(i)}{P_t^d}\right)^{-\sigma} Y_t^d + \left(\frac{P_t^{x^*}(i)}{P_t^{x^*}}\right)^{-\sigma} Y_t^x, \tag{17}$$

where the price index of domestic final goods is $P_t^d = \left[\int_0^1 (P_t(i))^{1-\sigma} di\right]^{1/1-\sigma}$, the price index of export goods Y_t^x is $P_t^{x^*} = \left[\int_0^1 (P_t^{x^*}(i))^{1-\sigma} di\right]^{1/1-\sigma}$, and the target price with an asterisk means expressed in foreign currency. Because export manufacturers adopt LCP, the one-price law for LCP manufacturers is no longer valid.

3.4. Producer of Intermediate Goods

The market is a monopoly competitive market due to the heterogeneity of intermediate goods produced by different manufacturers. Assuming that each intermediate manufacturer i has the same constant returns to scale production function:

$$y_t(i) = y_t^d(i) + y_t^x(i) = A_t(N_t(i))^{1-\alpha}(K_{t-1}(i))^{\alpha}, \tag{18}$$

where $N(i)$ is the labor demand for patient households, α is the amount of capital share, and A_t is the productivity level. Given a certain wage and return on capital, and by solving the cost minimization problem, we can obtain the demand for each production factor:

$$W_t N_t(i) = (1-\alpha)(y_t^d(i) + y_t^x(i))MC_t, \quad R_t^k K_{t-1}(i) = \alpha(y_t^d(i) + y_t^x(i))MC_t, \tag{19}$$

Where MC_t represents the marginal production cost of intermediate manufacturers. It is expressed as follows:

$$MC_t = A_t^{-1}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t^k}{\alpha}\right)^{\alpha}. \tag{20}$$

We assume that all intermediate manufacturers set prices in a staggered fashion, which means any individual manufacturer will reset the optimal price periodically with an independent probability $1-\theta_P$. As we need to use the generalized pricing and settlement share of domestic currency to describe the degree of currency internationalization, it is assumed that there are intermediate manufacturers in the market adopting both the PCP strategy and the LCP strategy. For the intermediate manufacturer i_P who adopts PCP, they only need to set the optimal price $\tilde{P}_{P,t}^d$ marked by domestic currency, so the export price of such intermediate goods accords with the law of one price$S_t\tilde{P}_{P,t}^{x^*} = \tilde{P}_{P,t}^d$, and the exchange rate is fully passed through. Since the individual manufacturer can not adjust the price for each period with an independent probability θ_P, the relevant profit function is:

$$\sum_{j=0}^{\infty}(\beta\Theta_P)^j\nu_{t,t+j}[y_{t+j}^d(i_P)(P_t^d(i_P)-(1-\tau_d)MC_{t+j})+y_{t+j}^x(i_P)(P_t^d(i_P)-(1-\tau_x)MC_{t+j})].$$

To eliminate the monopoly distortions in the steady-state, we assume that government subsidizes $\tau_x = \tau_d = 1/\sigma$ to manufacturers' production costs. Under the constraint of market demand function, the intermediate manufacturer i_P chooses the optimal price $\tilde{P}_t^d(i^P)$ to pursue its profit maximization. We can obtain the first-order condition of the price decision via:

$$\tilde{P}_{P,t}^d = \frac{E_t\sum_{j=0}^{\infty}(\beta\theta_P)^j\nu_{t,t+j}\left(y_{t+j}^d + \left(\frac{P_{P,t+j}^d}{S_tP_{t+j}^{x^*}}\right)^{-\sigma}y_{t+j}^x\right)(P_{P,t+j}^d)^{\sigma}MC_{t+j}}{E_t\sum_{j=0}^{\infty}(\beta\theta_P)^j\nu_{t,t+j}\left(y_{t+j}^d + \left(\frac{P_{P,t+j}^d}{S_tP_{t+j}^{x^*}}\right)^{-\sigma}y_{t+j}^x\right)(P_{P,t+j}^d)^{\sigma}}. \tag{21}$$

Since all the intermediate manufacturers who can adjust the price, set the same optimal price of $\tilde{P}^d_{P,t}$, by the definition of price, we can obtain: ${P^d_{P,t}}^{1-\sigma} = (1-\theta_P){\tilde{P}^d_{P,t}}^{1-\sigma} + \theta_P {P^d_{P,t-1}}^{1-\sigma}$.

Individual intermediate manufacturer i_L adopting the LCP strategy has the same production function as manufacturer i_P, but their optimal prices are different: one is the domestic price $\tilde{P}^d_{L,t}$ settled by the domestic currency, and the other is the export price $\tilde{P}^{x^*}_{L,t}$ settled by the foreign currency. When the price is sticky, the law of one price is not satisfied regarding the export and domestic intermediate goods of LCP manufacturers, so the exchange rate cannot entirely pass through. Assuming that LCP manufacturers cannot adjust the price for each period with the same independent probability θ_P, the pricing decision strategy of their domestic goods is identical with PCP manufacturers, so $\tilde{P}^d_{L,t} = \tilde{P}^d_{P,t}$. For export intermediate goods, the profit function of the LCP manufacturer is:

$$\sum_{j=0}^{\infty}(\beta\theta_P)^j \nu_{t,t+j}[y^x_{t+j}(i_L)(S_{t+j}P^{x^*}_t(i_L) - (1-\tau_x)MC_{t+j})].$$

Thus, the optimal export price of the manufacturer i_L can be obtained via:

$$\tilde{P}^{x^*}_{L,t} = \frac{E_t \sum_{j=0}^{\infty}(\beta\theta_P)^j \nu_{t,t+j}\left(\frac{P^{x^*}_{L,t+j}}{P^{x^*}_{t+j}}\right)^{-\sigma} y^x_{t+j}(P^{x^*}_{L,t+j})^{\sigma} MC_{t+j}}{E_t \sum_{j=0}^{\infty}(\beta\theta_P)^j \nu_{t,t+j}\left(\frac{P^{x^*}_{L,t+j}}{P^{x^*}_{t+j}}\right)^{-\sigma} y^x_{t+j}(P^{x^*}_{L,t+j})^{\sigma} S_{t+j}}. \quad (22)$$

Deriving out of the definition of aggregate price, we can obtain: ${P^{x^*}_{L,t}}^{1-\sigma} = (1-\theta_P){\tilde{P}^{x^*}_{L,t}}^{1-\sigma} + \theta_P {P^{x^*}_{L,t-1}}^{1-\sigma}$.

3.5. Monetary Authority and Relevant Policies

We assume that the central bank's interest rate regulations are pegged to the exchange rate, and we use it to represent the unsterilized intervention policy. Its expression is as follows:

$$\log(R_t) = (1-\theta_R)(\theta_\pi \pi_t + \theta_S \log(S_t/S_{t-1}) + \theta_{gdp}\log(gdp_i/gdp)) + \theta_R \log(R_{t-1}) + \varepsilon^R_t, \quad (23)$$

where ε^R_t is the white noise interest rate impact with zero mean, $gdp_t = y^d_t + y^x_t$ represents the total domestic output, and gdp is its steady-state. Following Chen et al. (2015), we also use θ_S to reflect the change of the interest rate in response to the exchange rate, and it can also represent a managed floating exchange rate regime.

Referring to Benes et al. (2015), the central bank formulates the foreign exchange policy in the following manner, which represents the sterilized intervention policy:

$$\log\left(\frac{F_t}{P_t}\right) = \rho_f \log\left(\frac{F_{t-1}}{P_{t-1}}\right) + (1-\rho_f)\left(\log\left(\frac{F}{P}\right) - \rho_s \log\left(\frac{S_t}{S_{t-1}}\right)\right), \quad (24)$$

where $\rho_s > 0$ reflects the adjustment of foreign exchange reserve to the exchange rate fluctuations. The central bank reduces the holding of foreign exchange reserves when the domestic currency depreciates, which also conforms to the typical characteristics of China's economy in Figure 1. The size of the adjustment represents the strength of sterilized intervention.

Determined by the discussion above, there are two exchange rate intervention methods: one is unsterilized intervention (to adjust the exchange rate fluctuations by expansionary interest rate policy), and the other is sterilized intervention (to control the exchange rate through foreign exchange trading). When the monetary authority implements the foreign exchange intervention policy, it should subject to the following budget constraint to achieve its goal of sterilized intervention:

$$S_t F_t + R_{t-1} B^g_{t-1} = R^*_t S_t F_{t-1} + B^g_t. \quad (25)$$

The left side is the expenditure of authority with income on the right. Referring to Davis and Presno (2017), we assume that the degree of capital control is represented by the tax rate levied on foreign bonds, so that the central government can control the net flow of international capital through the tax rate adjustment, given by:

$$\tau_t = \chi\left(\frac{\tilde{B}^f_t}{gdp_t} - \frac{\tilde{B}^f}{gdp}\right), \quad (26)$$

where $\chi > 0$ represents that when domestic residents invest in more foreign bonds, the monetary authority will increase the income tax to reduce residents' investment motivation. This matter reflects the intensity of capital flow management.

3.6. Foreign Sector

When building a DSGE model in an open economy, we usually assume that the home country is a small country, i.e., domestic economic fluctuations do not have any impacts on foreign output and inflation. Yet, due to the considerable scale of the Chinese economy, such an assumption may not be utterly consistent with the current situation. To respond to the above consideration, we have introduced an endogenous foreign sector to represent the rest of world. On the other hand, in order to avoid any unnecessary complexities, financial friction is not considered in the foreign economy.

Firstly, we discuss the decision-making problem of foreign households. Foreign households can issue and buy bonds on the international capital market, and can obtain income by investing in foreign capital K_t^* and providing labor N_t^*. The objective function of foreign households is as follows:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t^* - \nu^* C_{t-1}^*) - \frac{N_t^{*1+1/\sigma_H^*}}{1+1/\sigma_H^*} \right]. \tag{27}$$

Under budget constraints and capital movement rate, foreign households choose the optimal option $\{C_t^*, N_t^*, B_t^*, B_t^{f^*}, I_t^*, K_t^*\}$ to maximize their target function:

$$C_t^* P_t^* + B_t^* + I_t^* P_t^* + B_t^{f^*}/S_t = W_t^* N_t^* + R_t^{k^*} K_{t-1}^* + R_{t-1}^* B_{t-1}^* + R_{t-1}^{f^*} B_{t-1}^{f^*}/S_t + T_t^*, \tag{28}$$

$$K_t^* = (1-\delta^*) K_{t-1}^* + \left[1 - \frac{\kappa}{2} \left(\frac{I_t^*}{I_{t-1}^*} - 1 \right)^2 \right] I_t^*. \tag{29}$$

In the above constraints, $B_t^{f^*}$ and B_t^* are the risk-free domestic and foreign bonds purchased by foreign residents, while $R_t^{f^*}$ is the return of domestic bonds held by foreign residents and satisfies $R_t^{f^*} = R_t \exp(-\xi \tilde{B}_t^{f^*})$. We assume that the two countries have symmetrical risk premiums.

Secondly, we consider the foreign producer sector. The setting of foreign final goods is similar to domestic goods, and is given by:

$$Y_t^* = \left[\Omega^{*1/\rho^*} Y_t^{d^* \, \frac{\rho^*-1}{\rho^*}} + Y_t^{m^* \, \frac{\rho^*-1}{\rho^*}} \right]^{\frac{\rho^*}{\rho^*-1}}, \tag{30}$$

where Ω^* and ρ^* respectively represent the domestic share of foreign final goods and the substitution elasticity between domestic and imported goods. From the discussion above, the demand for domestic and imported goods of foreign final manufacturers satisfies:

$$Y_t^{d^*} = \Omega^* [\Omega^* + (1-\Omega^*) T_t^{*1-\rho^*}]^{\frac{\rho^*}{1-\rho^*}} Y_t^*, \quad Y_t^{m^*} = (1-\Omega^*) [\Omega^* T_t^{*\rho^*-1} + 1 - \Omega^*]^{\frac{\rho^*}{1-\rho^*}} Y_t^*. \tag{31}$$

The price inflation of foreign final goods is given by:

$$\pi_t^* = \left(\frac{\Omega^* + (1-\Omega^*) T_t^{*1-\rho^*}}{\Omega^* \pi_t^{d^* \rho^* - 1} + (1-\Omega^*) \pi_t^{d^* \rho^* - 1} T_{t-1}^{*\;1-\rho^*}} \right)^{\frac{1}{1-\rho^*}}. \tag{32}$$

Similar to domestic producers, the production function of the foreign individual intermediate manufacturers is $y_i^*(i^*) = A_t^* [K_t^*(i^*)]^{\alpha^*} [N_t^*(i^*)]^{1-\alpha^*}$.

They produce both export and domestic goods $y_t^{d^*}, y_t^{x^*}$, so the production constraint is: $y_t^*(i^*) = y_t^{d^*}(i^*) + y_t^{x^*}(i^*)$. Also, we assume that monopoly competition and price stickiness exist, the relationship between intermediate goods and final goods satisfies:

$$Y_t^{d/x^*} = \left(\int_0^1 [y_t^{d/x^*}(i^*)]^{\frac{\sigma^*-1}{\sigma^*}} di^*\right)^{\frac{\sigma^*}{\sigma^*-1}}. \tag{33}$$

Under the above condition, the demand function of foreign intermediate goods is: $y_t^{d^*}(i^*) = (P_t^*(i^*)/P_t^*)^{-\sigma} Y_t^{d^*}$. The marginal production cost of foreign intermediate manufacturers satisfies: $MC_t^* = A_t^{*-1}(W_t^*/(1-\alpha^*))^{1-\alpha^*}(R_t^{k^*}/\alpha^*)^{\alpha^*}$.

The optimal pricing problem of foreign intermediate manufacturers is to choose the optimal price $\tilde{P}_t^{d^*}$ under the constraint of intermediate good demand, and to maximize the following target function:

$$\tilde{p}_t^{d^*} = \arg\max_{P_t^*(i^*)} E_0 \sum_{t=0}^{\infty} (\beta^*\theta^*)^t \Lambda_t^* [(y_t^{d^*}(i^*) + y_t^{x^*}(i^*))(P_t^*(i^*) - MC_t^*)].$$

The first-order conditions for the above optimal price decision do not need to be discussed. According to the definition of price aggregation, the relationship between the inflation of foreign goods $\pi_t^{d^*}$ and optimal price $\tilde{p}_t^{d^*}$ can be given by:

$$(1-\theta^*)\tilde{p}_t^{d^*1-\sigma^*} = 1 - \theta^* \pi_t^{d^*\sigma^*-1}. \tag{34}$$

Finally, it is assumed that foreign monetary policy will conform to interest rate rules that pegged on output and inflation:

$$\log(R^*/\overline{R}^*) = (1-\theta_R^*)[\theta_\pi^* \log(\pi_t^{d^*}/\overline{\pi}) + \theta_{gdp}^* \log(gdp_t^*/\overline{gdp})] + \theta_R^* \log(R_{t-1}^*/\overline{R}^*) + \varepsilon_t^{R^*}. \tag{35}$$

It should be noted that the above foreign interest rate rule assumes that foreign monetary authorities will not stabilize exchange rate fluctuations.

3.7. Market Clearing

First of all, market-clearing in the domestic labor and capital markets requires that manufacturers' factor demand equals supply, which are:

$$\int_0^1 N_t(i)di = N_t, \quad \int_0^1 K_t(i)di = K_t. \tag{36}$$

Under the market clearing of factor and aggregate production constraints of manufacturers, domestic output, domestic and export goods satisfy the relationship below:

$$Y_t = A_t(N_t)^{1-\alpha}(K_{t-1}^{\alpha}) = Y_t^d + Y_t^x. \tag{37}$$

Further, under the conditions of market clearing, domestic goods are produced for domestic consumption and investment by domestic manufacturers. The total export goods, produced by two kinds of domestic intermediate manufacturers, is equal to total imports, so the condition below must be satisfied:

$$Y_t^d = C_t^d + I_t^d, \quad Y_t^x = \left[\kappa_h^{1/\sigma} {Y_{P,t}^x}^{\frac{\sigma-1}{\sigma}} + (1-\kappa_h)^{1/\sigma} {Y_{L,t}^x}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} = Y_t^{m^*}, \tag{38}$$

where $Y_{P,t}^x Y_{L,t}^x$ represent the aggregation of export intermediate goods of PCP and LCP manufacturers. Under the market clearing condition, domestic imports consumption, investment goods, and foreign export goods are subject to:

$$Y_t^m = Y_t^{x^*}, \quad Y_t^m = C_t^m + I_t^m. \tag{39}$$

The domestic sales and import goods in the above conditions can be regarded as supply, and the optimal decision conditions of domestic residents and entrepreneurs for the aggregate consumer goods represent demand; which can be expressed as:

$$C_t^d = \Omega_C^d \left(\frac{P_t^d}{P_t}\right)^{-\rho_C} (C_t + C_t^e), \; C_t^m = (1-\Omega_C^d) \left(\frac{P_t^m}{P_t}\right)^{-\rho_C} (C_t + C_t^e). \tag{40}$$

Similarly, the total investment demand of domestic entrepreneurs is I_t. When there is an optimal portfolio decision, we can get domestic and imported investment goods:

$$I_t^d = \Omega_I^d \left(\frac{P_t^d}{P_t}\right)^{-\rho_I} I_t, \quad I_t^m = (1-\Omega_I^d) \left(\frac{P_t^m}{P_t}\right)^{-\rho_I} I_t, \tag{41}$$

where Ω_C^d and Ω_I^d respectively represent the share of domestic consumption goods in total consumption, and domestic investment goods in the total investment; ρ_C and ρ_I indicate the substitution elasticity between domestic and foreign consumption goods, and investment goods.

On the other hand, the domestic lending market clearing must satisfy: $B_t^h = b_t$, which means the capital supply of patient households is equal to the capital need of the entrepreneur. As entrepreneurs and households are not discriminated against in the foreign sector, foreign bond market clearing requires: $B_t^* = 0, B_t^{f^*} + B_t^f = 0$. Finally, the market clearing of foreign production and final goods implies that:

$$A_t^*(K_{t-1}^*)^{\alpha^*}(N_t^*)^{1-\alpha^*} = Y_t^{d^*} + Y_t^{x^*}, \quad Y_t^* = C_t^* + I_t^*. \tag{42}$$

4. PARAMETER CALIBRATION AND DATA SIMULATION

4.1. Parameter Calibration

The model is calibrated at quarterly intervals. Some parameters of the domestic country are set as follows: the households time discount rate is: $\beta = 0.993$, which means the steady-state quarterly risk-free interest rate is: 1.00705. Referring to Davis and Presno (2017), we set the entrepreneur time discount rate as: $\beta^e = 0.98$. Following Chang et al. (2015), we also set the Frisch elastic reciprocal value of the labor to 2, which means $\sigma_h = 0.5$. The depreciation rate of capital and the capital production share parameter are set on a regular basis as: $\delta = 0.05, \alpha = 0.54$, respectively. Based on Chen (2018), we set the domestic consumer goods, and the share of investment goods as: $\Omega_C^d = 0.75, \Omega_I^d = 0.84$. According to the data published by China National Balance Sheet and compiled by the CASS, the collateral rate θ is 0.6. Referring to Christiano et al. (2010), we assume that the substitution elastic parameter ρ_C of import and export goods is 1.5. Following statistical results on the share of currency used for China's exports in Gopinath (2016), the value of κ_h is set as 5%. Considering the general value of price stickiness regarding domestic retailers, the price stickiness coefficient θ_P, with PCP and LCP in the terms of export, is 0.75. An important parameter in the interest rate rule is the exchange rate change pegged on the coefficient. We value θ_S as 0.5, referring to Chen (2015), and Wang and Deng (2016). There is limited research on the foreign exchange intervention coefficient. Referring to Benes et al. (2015), we assume that ρ_S is 2.5, while contemplating the comparability of the two exchange rate intervention methods.

The foreign parameters are mainly calibrated with reference to US data. As in Christiano (2010), we set the foreign price inflation ϕ_π^*, and output peg coefficient ϕ_y^*, to 1.43 and 0.07, respectively; the interest rate lag coefficient ρ_R^* is set to 0.87; the intermediate goods substitution elasticity is $\sigma = 11$; and the consumption inertia ν^* is 0.77. The parameter σ_h^* implies the inverse of Frisch elasticity of foreign households. We adopt the value of 4.5 based on the estimates made by Justiniano et al. (2010); the parameter of capital share α^*, investment adjustment cost κ^*, and depreciation rate δ^* are set as 0.287, 3.14, and 0.025, severally; and the price viscosity parameter θ^* to 0.8. Referring to Christiano (2010), the foreign consumption substitution elasticity is $\rho_c^* = 1.5$. In addition, based on the CEIC database, we estimate the proportion of the total imports from China to

America in the American GDP from 2000 to present, which fluctuates from 2.8% to 3.5%. Accordingly, the Ω_C^* value is set to 0.97.

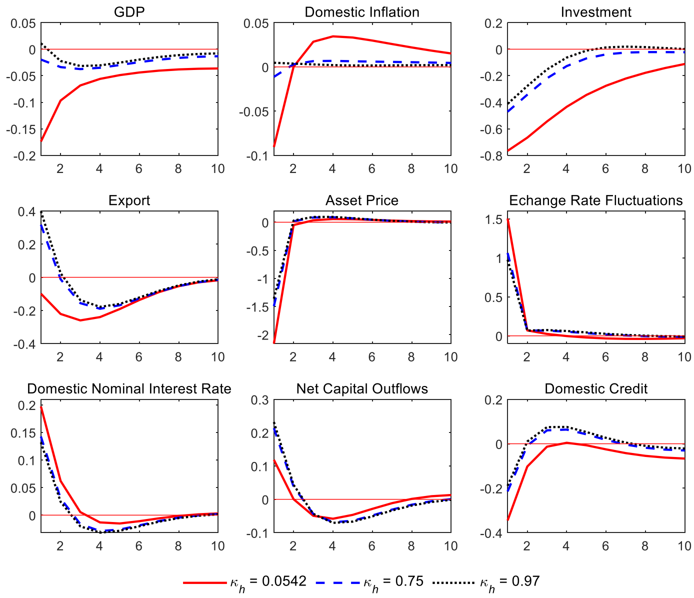
4.2. Currency Internationalization and Economic Fluctuation

Previous studies have often used the share of the domestic currency in pricing, i.e., the proportion of firms adopting PCP, to represent the degree of currency internationalization. For instance, Devereux et al. (2007) investigate the optimal policy in the context of dollarization based on the above measure. Wang and Liao (2017) apply the same to study the impact of RMB internationalization on the exchange rate volatility. Therefore, we also consider the above shares as a proxy for currency internationalization. Moreover, to reveal how currency internationalization affects the effectiveness of exchange rate intervention policy, we further consider the following three scenarios, the first of which is known as the low currency internationalization scenario, and the proportion of domestic exporters using PCP is only 5% in this case, i.e., $\kappa_h = 0.05$. The above PCP shares mainly refer to the work of Gopinath (2016), who counts the PCP shares of developing countries' exports. The second scenario is the one with a high degree of currency internationalization, in which the share of domestic exporters using PCP is set to 75%. This ratio mainly represents the case of export pricing in European countries. The latter is the case of a very high degree of currency internationalization, in which we assume that $\kappa_h = 0.97$; a scenario that corresponds to the share of U.S. exports denominated by dollars.

It should be noted that Dotsey (2017) finds a very weak effect regarding the choice of export pricing currency on the dynamics of domestic productivity shocks and price markup shocks, but a relatively large effect on that of the risk premium shocks. Our model has similar features. On the other hand, by comparing different shocks, we observe the significant impact of currency internationalization on the foreign monetary policy shock, which will be explained in due course. Furthermore, a large number of theoretical and empirical research have studied the foreign monetary policy shock in recent years; for instance, Davis & Presno (2017) deeply study the theoretical mechanism of this shock; Dedola et al. (2017) and Iacoviello & Navarro (2019) emphasize the significance of the US monetary policy shock on developed and emerging economies. Some researches on foreign exchange intervention policies, such as Benes et al. (2015), only consider the external interest rate shock. In conclusion, our theoretical analysis mainly focuses on the impact of foreign monetary policy shock, and the optimal policy.

Figure 2 shows the results of the impulse responses to a contractionary monetary policy shock abroad for three different degrees of currency internationalization. The results indicate that domestic currency international-

FIG. 2. Currency internationalization and foreign monetary policy shock



ization exerts a noticeable influence on the volatility of various variables, suggesting that with higher (greater) degrees of currency internationalization, GDP, inflation, real investment, and asset prices are less vulnerable to the shock. Simultaneously, and very importantly, the gross domestic export rise from -0.1% to approximately 0.4% since the higher share of PCP improves the degree of exchange rate pass-through. The shock to the foreign interest rate leads to a positive spread among domestic and foreign interest rates, and it further induces depreciation of the domestic currency. When the exchange rate pass-through increases, a sufficient decline in domestic export price could effectively improve the demand for domestic exports. Therefore, the internationalization of currency leads to added exports in the domestic country. When exports improve, domestic net exports also rise, so the domestic net capital outflow displays larger fluctuations under the external balance. On the other hand, the higher level of net exports also implies the improved aggregate demand in the home country, thus shrinking the fluctuation of domestic GDP, investment, and consumption. In addition, the rise in aggregate demand will reduce the volatility of the marginal cost of domestic production. Finally, fluctuations regarding inflation also drop significantly. Moreover, it is noteworthy that the decreases in the extent of investment fluctuation also bring to the stabilizer asset price, which leads to entrepreneurs having a stronger borrowing capacity. Therefore, domestic credit increases significantly.

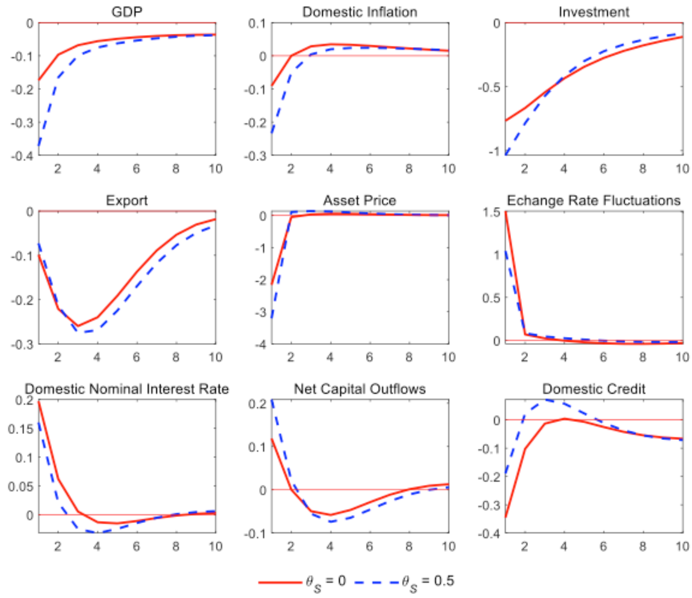
In short, an increased degree of currency internationalization would entail an enhanced expenditure switching effects for the exchange rate, which renders it possible for the contractionary foreign monetary policy shock to generate an improvement in net exports, and ultimately reduce the extent of contraction in domestic economic activity. Dedola et al. (2017), Iacoviello and Navarro (2019) also find that Fed's interest rate raising policy can cause more negative effects on developing countries; whereas Gopinath (2016) points out that developing countries tend to have a lower producer currency pricing share of exports. Our findings may provide an explanation for the above connection between currency internationalization, and the impact of foreign interest rate shock.

4.3. The Analysis of Sterilized Intervention and Unsterilized Intervention

Following Engel (2011), when a country's export goods are all priced by LCP, the exchange rate fluctuation caused by exogenous shocks can lead to an inefficient adjustment concerning term of trade, and the misallocation of resources. For this reason, a free-floating exchange rate may induce additional welfare loss, whereas the main purpose of exchange rate intervention is to reduce the aforementioned losses by lowering volatility. Nevertheless, in face of some specific circumstances, the central bank's intervention may also incur unexpected costs to the economy. Moreover, there are multiple selections regarding policy instruments for the central bank to realize a stability in the exchange rate, e.g., sterilized or unsterilized intervention, and different approaches could possess diverged costs and benefits. For such considerations, we then examine the consequences of the above two intervention policies under the foreign contractionary monetary policy shock. Specifically, we will consider using counterfactual simulation to investigate the impact due to policy design. Regarding sterilized intervention, one should realize that only when domestic and foreign assets are incompletely substituted, the implementation of such a policy can exert a significant effect on the exchange rate, and thus the real economy. We continue with the analysis of the unsterilized intervention policy, and following the work of Benes et al. (2015), we also adopt the policy parameter θ_S to represent the strength of sterilized intervention.

Figure 3 depicts the impulse response results of foreign monetary policy shocks under unsterilized intervention. It can be observed at first glance that there is a significant decline in the volatility of the exchange rate π_t^S when the domestic nominal interest rate R_t responds actively to its changes. However, since the exchange rate moves in the opposite direction to that of the domestic inflation as well as GDP, it leads to a stabilization conflict

FIG. 3. Unsterilized intervention and foreign monetary policy shock

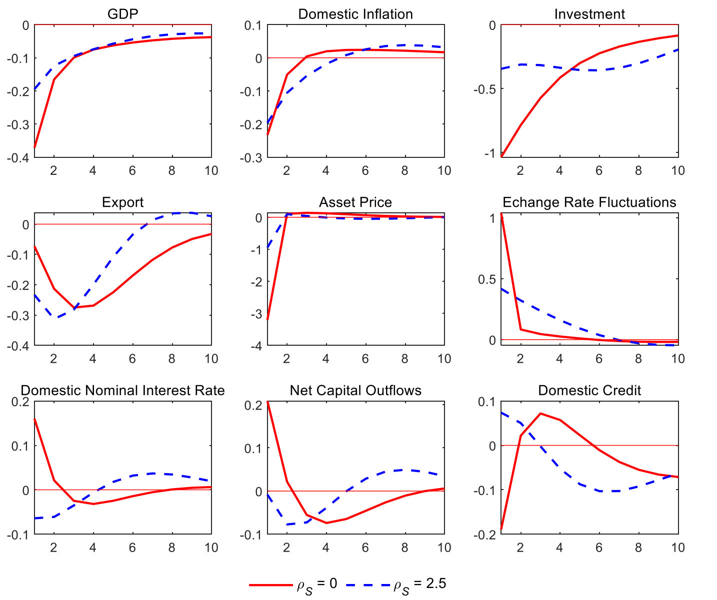


among the targeted variables of the central bank's monetary policy; thus weakening its capacity in stabilizing the real economy. As a result, both real GDP and inflation in the home country fall by a larger magnitude under unsterilized intervention.

Remarkably, one might argue that under the intervention scenario, the exchange rate depreciation should lead to a contractionary monetary policy passively implemented by the domestic central bank, which induces a rise in the nominal interest rates. Instead, the impulse results indicate a lower nominal interest rate, which is at odds with the above theoretical intuition. Indeed, even though the nominal interest rate falls, the real interest rate in the home country remains elevated. This is due to a larger drop in domestic inflation. More specifically, after a dramatic fall in the inflation rate, the spread between real yields on risk-free bonds both at home and abroad will shrink and then, the volatility of the nominal exchange rate will drop by improving the demand for the domestic currency; which in turn mitigates the contraction of the monetary policy. On the other hand, the decline in domestic inflation and GDP also prompts the central bank to cut the nominal interest rates, which will eventually result in a reduction, rather than an increase, in the nominal interest rates. In summary, unsterilized intervention, while effective in stabilizing exchange rate volatility, can also create a severe policy stabilization conflict and amplify economic recession.

The empirical evidence put forth by Iacoviello and Navarro (2019) confirm our findings. After examining the international spillover effects of hiking U.S. interest rates, they identified that output is more severely affected in developing countries with more controlled exchange rates.

FIG. 4. Sterilized intervention policy and foreign monetary policy shock



We next consider the sterilized interventions that are implemented by adjusting foreign exchange reserves. Figure 4 compares impulse responses with the foreign interest rate shock under different scenarios of intervention policies. One could observe that the economic dynamics under sterilized intervention policy show several distinctions compared with that of the unsterilized case; in which the most significant difference lies in the financial variables, e.g., assets price and credits. In our model, the central bank implements a certain degree of capital control. Therefore, the changes in foreign exchange reserve will indirectly affect households' holding of foreign bond B_t^f, then form the gap of uncovered interest rate parity via capital control tax rate $\tau(B_t^f)$, and finally achieve exchange rate stability. In Figure 4, net capital outflow indicates that when the central bank sells foreign exchange reserves due to the depreciation of the domestic currency, the net capital outflows decline sharply in the initial stage as a result of the incomplete substitution of domestic and foreign assets caused by capital control[1]. In other words, adjusting foreign exchange reserves can effectively influence the overall holding scale of foreign assets. This implies a shrinking demand for foreign currency, and arising demand regarding domestic currency; so the depreciation of domestic currency drops significantly in the initial stage. In contrast, unsterilized intervention does not directly affect the amount of foreign assets held by domestic households. It attains exchange rate stability only via adjusting the nominal interest rate.

Sterilized intervention can not only affect the total foreign assets held by domestic households, but also has a significant impact on the domestic credit market. As shown in the Figure 4, domestic credit appears to indicate a reversed adjustment during the first period. This is due to the fact that the changes in foreign exchange reserves simultaneously affect the amount of domestic central bank bond issuance. When implementing sterilized intervention by selling foreign exchange reserves, although the amount of foreign bond assets held by households has a slight increase, the central bank bond assets decrease more significantly. Thus, households are more inclined to invest in the bonds issued by entrepreneurs. Entrepreneurs can enlarge their actual investment after borrowing more funds. Doing so has a positive effect on asset prices. Moreover, the rise of asset prices improves the value of entrepreneurs' collateral, and brings about a stronger borrowing ability in order to expand investment. This trend forms a positive financial amplification effect. Eventually, growth in real investment compensates for the negative effects on the output caused by net exports decline.

Although sterilized intervention can initially stabilize the exchange rate fluctuations effectively, it leads to a more persistent exchange rate adjustment. This means that in the long-term perspective, the ability to stabilize the exchange rate of sterilized intervention is relatively weaker than that of unsterilized intervention. On the other hand, since sterilized intervention induces a long-lasting stimulus over investment, the supply of fixed assets rises and marginal product of capital declines constantly. Eventually, this trend causes a stronger lag of actual marginal costs fluctuation, and causes domestic inflation to experience a slower adjustment and more severe fluctuations. Overall, sterilized intervention has lower actual economic stability costs compared to unsterilized intervention, but is relatively less effective on exchange rate stabilization.

By comparing the two intervention methods mentioned above, it is not difficult to conclude that the sterilization intervention can keep the domestic interest rate relatively stable, so as to alleviate the impact of decline

[1]Capital Control is a necessary condition for effective foreign exchange intervention. Due to limitations regarding the length of the paper, readers can contact us to acquire additional specific graphic analysis.

in investment. Thus, its negative impact on the real economy is relatively limited. However, unsterilized intervention does not need to focus on the stability of the domestic interest rate, and eventually leads to the domestic interest rate being forced to follow the foreign interest rate increase. Accordingly, its actual economic stability cost is higher. Under the effect of positive foreign interest rate shock, unsterilized intervention will lead to the increase of domestic nominal interest rate, and negatively affect domestic GDP, investment, and asset prices. More essentially, a rise in domestic interest rates would trigger an amplifier of financial frictions, further freezing up domestic credit markets, and ultimately leading to a deeper recession. Note that unsterilized intervention can be more effective in stabilizing exchange rates. By contrast, sterilized intervention avoids the passive adjustment of domestic interest rates. Consequently, there is no interest rate price effect and the amplifying effect of financial frictions as mentioned above, which is the first advantage. Another advantage of sterilized intervention is that such policies indirectly stimulate supply in the corporate credit market, and can therefore be seen as a positive domestic credit shock. Under the above mechanism, sterilization intervention not only reduces the fluctuation of GDP, investment, and other real economic variables, but also alleviates the negative adjustment of asset prices and credit scale. However, sterilized intervention would be less effective in stabilizing the exchange rate than unsterilized intervention, thus sacrificing exchange rate stability.

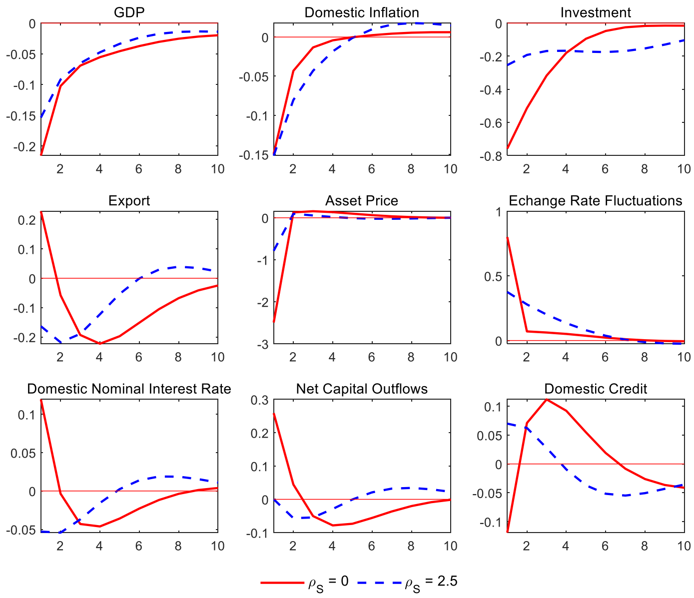
To sum up, unsterilized intervention has a strong stability potential on the exchange rate, but a poor ability to stabilize the real economy. In other words, sterilized intervention in exchange rate stability ability is weak, but its economic and financial stability potentials are strong. It is precisely because of the differences in the advantages and disadvantages of the two types of intervention policies that we will see different optimal intervention coefficients in the subsequent optimal policy analysis. It is important to emphasize that there is no situation where one intervention policy is utterly superior to the other.

When the US entered its interest rate hike cycle in 2015, many developing countries were forced to raise the interest rates in order to avoid the depreciation of their currencies, which caused an alarming negative impact on their real economies. China, as the country with the most abundant foreign exchange reserves, adopted sterilized intervention to keep the interest rate relatively stable and alleviate the adverse impact of the Fed's interest rate hike on China's real economy. Our analysis here provides a possible theoretical explanation for the actual economic situation described above.

4.4. Currency Internationalization and Sterilized Intervention

Based on the analysis above, we deduce that the increasing degree of currency internationalization can protect the domestic economy from the negative impact of foreign monetary policies to some extent; so it has an important impact on the economic stability cost of sterilized intervention. To clarify, we present the impulse response results of sterilized intervention under the situation of higher currency internationalization ($\kappa_h = 0.75$).

FIG. 5. Currency internationalization and the effectiveness of sterilized intervention



By comparing the impulse results in Figure 4 and 5, we can observe that when currency internationalization is high, sterilized intervention leads to greater fluctuations in domestic inflation; which means the cost of stabilizing the economy increases largely. There are two main reasons: firstly, the higher share of domestic currency settlement reduces fluctuations in the actual economy, and when sterilized intervention is implemented, it produces unnecessary stimulation on the domestic credit market. Secondly, when the exchange rate pass-through is transmitted to a higher extent, the expenditure switching effect brought about by the devaluation of the local currency will help the country's exports; thus slowing down the cost of stabilizing the real economy. Therefore, the exchange rate stability brought about by sterilized intervention will weaken the previous expenditure switching effect, leading to higher economic costs. In this way, the decline in the actual production costs of domestic manufacturers is superimposed on the weak export demand, resulting in the continuous decline of domestic price inflation. In summary, when the degree of monetary internationalization rises, the actual cost to maintain the economic stability of sterilized intervention also increases accordingly.

At present, developed countries such as Japan have basically abandoned exchange rate control and intervention. The conclusion of this paper can provide a theoretical explanation, that is, the degree of currency internationalization in these developed countries is relatively high. At this time, both sterilized and unsterilized interventions will bring higher economic costs. This can also provide some theoretical guidance for the reform and implementation of the exchange rate intervention policy in the process of RMB internationalization.

4.5. Optimal Policy Analysis

As in Davis and Presno (2017), we assume that the monetary authority's loss function takes a quadratic form with respect to the targeted variables, and use it to study the optimal foreign exchange intervention policy. We can numerically solve the minimization problem regarding the loss function in decentralized equilibrium to obtain the optimal coefficients of intervention policies. Previous studies generally selected the domestic output gap and price inflation as the targeted variables of the monetary authority. This is because in the benchmark framework of the New Keynesian model, the above assumed target function is precisely consistent with the social welfare loss function derived from the household utility function; thus, it is backed by a strict micro-foundation. If we consider a more general model, the welfare loss function will have both linear and quadratic terms. Correspondingly, it will be insufficient to accurately assess the welfare loss if we only consider the solution under the first-order approximation. To avoid this complexity, we assume that the loss function still takes a simple quadratic form. In addition, Wang and Zhou (2018) proved that when there exist some exporters using the LCP pricing strategy, the social welfare loss function will contain the currency misalignment cm_t. Considering all the above, the authority loss function is given by:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \left((\pi_t - \overline{\pi})^2 + \psi_y (y_t - \overline{y})^2 + \psi_{cm} (cm_t^{agg} - \overline{cm}^{agg})^2 \right),$$

Where cm_t^{agg} represents the overall currency mismatch between aggregated export goods and the PCP goods. According to price aggregate, it obviously satisfies:

$$cm_t^{agg} = S_t P_t^{x^*} / P_{P,t}^x = \left(\kappa_h + (1 - \kappa_h) cm_t^{1-\sigma} \right)^{1/(1-\sigma)}.$$

When there are only PCP intermediary manufacturers, the overall currency mismatch satisfies $cm_t^{agg}(\kappa_h = 1) = 0$; which means there is no extra welfare loss caused by pricing-to-market, so monetary authorities do not need to peg to the currency mismatch. In addition, when considering the first-order approximation solution, currency mismatch cm_t is only determined by the intertemporal change of the exchange rate π_t^S; so the essence of stabilizing currency mismatch is to stabilize exchange rate fluctuations. The parameter φ_i $(i = y, cm)$ in the above function represents the relative weight set by the central bank on different target variables during policy decisions. This paper sets the output weight as $\psi_y = 0.1$ referring to Woodford (2013) Davis & Presno (2017); and the currency mismatch weight is $\psi_{cm} = 0.05$ following Wang and Zhou (2018). Furthermore, the optimal policy rules in three cases $\kappa_h = \{0.05, 0.75, 0.97\}$ are shown in Table 1.

TABLE 1.

Optimal policy rules and exchange rate intervention policies

	Benchmark	Optimal Policy		
	$\kappa_h = 5\%$	$\kappa_h = 5\%$	$\kappa_h = 75\%$	$\kappa_h = 97\%$
Optimal Policy Coefficients				
Pegged exchange rate θ_S	0	0.1037	0	0
Sterilized intervention ρ_S	0	4.3407	0.9910	0.2999
Fluctuation of Major Economic Variables				
Domestic real GDP gdp_t	2.941	1.772	1.001	0.698
Domestic price inflation π_t^d	1.227	1.839	0.374	0.118
Exchange rate intertemporal fluctuation π_t^S	15.31	6.711	8.415	9.148
Currency mismatch cm_t^{agg}	17.30	9.331	2.878	0.343
Asset price P_t^k	21.61	11.69	7.241	11.50

The above optimal policy coefficients indicate that with the increase of currency internationalization, the optimal coefficients of both types of intervention policies decrease significantly; where the coefficient of exchange rate targeting even reaches a value of zero when the share of PCP is above 75%. The above results imply that, on the one hand, as currency internationalization rises, the central bank should reduce the degree of exchange rate intervention, and on the other hand, the central bank should rely more on unsterilized intervention to maintain exchange rate stability. The optimal policy results here are consistent with what we found in the impulse response analysis. To be more specific, the main purpose of foreign exchange intervention is to maintain exchange rate stability, but this comes at the sacrifice of economic stability. In particular, the volatility of currency misalignment, cm_t^{agg}, decreases significantly when the domestic currency is more internationalized; which directly reduces the welfare gains from the stabilization of the exchange rate. Meanwhile, stabilizing the exchange rate also restricts its expenditure switching effects, leading to more volatile inflation and output. Therefore, as the PCP ratio κ_h rises, the optimal magnitude of foreign exchange intervention should be reduced.

Further, the higher coefficients of sterilized intervention in Table 1 are results of its relatively lower cost of economic stabilization, as well as the fact that this policy instrument also contributes to the stability of domestic financial markets to some extent. In spite of this, as the currency internationalizes, a stronger negative effect of unsterilized intervention on domestic inflation stabilization causes the optimal coefficient of this policy, ρ_S, to decrease to approximately 0.3 at a PCP share (κ_h) of 0.97.

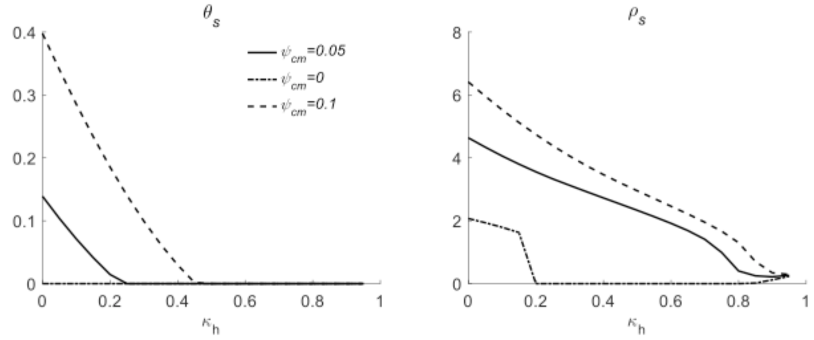
On the right-hand side of Table 1, the variables under the optimal policy column indicate that output, currency mismatch, and exchange rate fluctuations decrease after implementing the optimal combination of exchange rate intervention policy. This is due to the fact that sterilized interventions can simultaneously reduce both the exchange rate and output fluctuations. However, both intervention policies can amplify inflation fluctuations, which increases domestic inflation volatility. A comparison of various currency internationalization scenarios indicates that a higher degree of internationalization reduces real GDP and inflation volatility, which is consistent with Figure 2. This matter suggests that stronger export exchange rate transmissions reduce foreign contractionary monetary policy shocks, resulting in lower fluctuations. The intertemporal fluctuation of the exchange rate displays an inverse direction compared with real GDP and inflation, because the rise in pricing share of domestic currency reduces the need to moderate the exchange rate and currency misalignment, so a weaker sterilized intervention enlarges the exchange rate fluctuations.

From the optimal policy analysis, we find that the currency misalignment in the loss function is important for the optimal intervention policy. This is owing to the fact that currency misalignment depends mainly on the intertemporal changes in the exchange rate, and the main role of an intervention policy is to stabilize the exchange rate. Thus, the relative weight of the currency misalignment in the loss function should have a strong impact on the optimal intervention policy. To specify this relationship, Figure 6 presents the optimal intervention policy coefficients in the cases of $\kappa_h \in [0, 1]$, and $\psi_{cm} \in [0, 0.05, 0.1]$[2].

When exchange rate stability is not considered, i.e., the welfare loss weight of currency misalignment ψ_{cm} is set to zero, the optimal coefficient of unsterilized intervention, θ_S, is always equal to zero for any scenario of

[2]The parameters ψ_{cm}, taken as 0 and 0.1, represent two cases respectively: (i) the monetary authority ignores the stability of the exchange rate; (ii) the monetary authority considers exchange rate stability as important as the stability of the output gap.

FIG. 6. The optimal sterilized intervention coefficient



currency internationalization; owing to its stability cost to the real economy. This implies that the interest rate policy only needs to consider the stability of real GDP and inflation, rather than that of the exchange rate. Likewise, the optimal policy coefficient for sterilized intervention also falls considerably when the welfare losses from currency misalignment are ignored. This situation arises from the disappearance of exchange rate stabilization gains, and the extra volatility in inflation associated with foreign exchange interventions. In general, a greater relative weight of currency misalignment, and a lower level of currency internationalization can both lead to a stronger motive for stabilizing the exchange rate. Furthermore, considering the current low degree of RMB internationalization, the numerical results from the optimal policy analysis imply that it may be reasonable for monetary authorities to use a combination of stronger sterilized intervention, and weaker unsterilized intervention policies to stabilize the exchange rate. In other words, the findings of this paper provide a theoretical interpretation for the Chinese foreign exchange intervention policy in the past.

5. CONCLUSION

This paper builds a DSGE model of asymmetric two-country open economy, while focusing on the different effects of sterilized and unsterilized interventions, and discusses the influence of RMB internationalization on the spillover effect of foreign monetary policy, and the effectiveness of exchange rate intervention policy. The main conclusions derived from this study are as follows:

First, as an important measurement of currency internationalization, the share of pricing and settlement in the domestic currency has an obvious impact on the spillover effect of foreign monetary policy. The improvement of currency internationalization can attenuate the influence of foreign monetary policy on the domestic economy. Secondly, although both sterilized and unsterilized intervention approaches can moderate exchange rate fluctuations, sterilized intervention will cause a lag of exchange rate adjustment, so its effectiveness is relatively limited. However, it has lower costs regarding the stabilization of the economy; even though currency internationalization can increase the costs. Unsterilized intervention can fade the ability of the domestic interest rate policy to stabilize output and inflation under the shock of foreign monetary policy, resulting in policy conflict with the high costs of actual economic stability. Finally, through optimal policy analysis, we come to the conclusion that in a low currency internationalization circumstance, monetary authorities should adopt sterilized intervention to stabilize the exchange rate. The interest rate policy should not respond to exchange rate fluctuations excessively; currency internationalization is the key factor to determine the optimal intervention policy. With the advancement of currency internationalization, the intensity of sterilized intervention policy should be moderately reduced, and unsterilized intervention should not be practiced.

These conclusions reveal an important policy connotation: with the development of economic globalization, economic dependence and mutual influence between countries are becoming more and more profound. RMB internationalization will significantly influence the spillover effect of foreign monetary policy on China; sterilized intervention has a more desirable effect on stabilizing the economy than unsterilized intervention. Chinese monetary authorities should give priority to reforming an RMB exchange rate regime. Considering the effectiveness of sterilized intervention policy, the Chinese government should carefully implement the capital account opening policy and gradually reduce the frequency and intensity of exchange rate intervention, while promoting the internationalization of RMB and accelerating the marketization of the exchange rate; thus extricating from the accusations of "exchange rate manipulator" judged by some developed countries.

An important assumption in this paper to compare the merits of the two intervention policies is capital controls. Imposing taxes on international bond transactions is a simple way to introduce capital controls, which is a requirement for sterilized intervention. Meanwhile, this also points out the deficiency of this paper. There are many ways of capital control in the real economy, so the conclusion of this paper may be altered due to varying international capital control settings. In addition, this paper does not consider the banking sector. As the real subject of international financing, its financial frictions and operational controls will also have a significant impact on the exchange rate intervention policy, which is also a feasible outline for future research and discussion.

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