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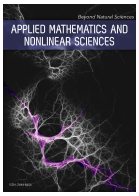

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Nonlinear Relationship based on Range Quadratic Loss Function

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Abstract This paper uses the interval quadratic preference loss function to establish the threshold model of exchange rate volatility by Taylor series expansion, and GMM method to study the intervention behavior of exchange rate. It found that the central bank has asymmetric intervention preference for exchange rate, discontinuous and nonlinear intervention for exchange rate, and there is an intervention threshold, and the central bank has a certain degree of "fear of appreciation" trend. To some extent, asymmetric interval intervention preference has resulted in the rapid growth of China's foreign exchange reserves.

Keywords: Central zone of intervention preferences; The threshold of exchange rate fluctuation; GMM
AMS 2010 codes: 41A58.

1 Foreword

That the central bank intervenes in the foreign exchange market to reduce larger exchange rate fluctuations is always one of the targets of macro-financial policy of each country. The action that China's central bank intervened in the foreign exchange market in the process of the reform of exchange rate of RMB was quite obvious. On Jul. 21^{st}, 2005, RMB began to implement a managed floating exchange rate system based on market supply and demand and adjusted with reference to a basket of currencies. The RMB exchange rate was no longer pegged to the single dollar. However, the floating range of RMB against US dollar in the inter-bank spot foreign exchange market remained within 3‰. On May 21^{st}, 2007, the central bank decided to expand the floating range from 3‰ to 5‰, and on Apr. 16^{th}, 2012, the floating range was expanded from 5‰ to 1%. However, they are always unanswered questions for the central bank about the weight of basket of currencies, the way it intervened in the currency market and the existence of foreign exchange intervention targets. What is the intervention preference of China's central bank in the foreign exchange market? Is there a target range of RMB exchange rate, or is there a threshold for RMB exchange rate volatility? Does the intervention preference of the central bank cause a sharp increase of foreign exchange reserves?

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This paper initially introduces range quadratic loss function to study the behavioral preference of the intervention of China's central bank in the foreign exchange market and the target range of RMB exchange rate. Its study conclusions are of stronger theoretical and practical significance to the reform of RMB exchange rate, the export-import management as well as the investments in foreign countries and the control of foreign exchange risks.

The structure of this paper is: the second part is literature review, the third part is theoretical models, the fourth part is metrical results and analysis and the fifth part is conclusion. The main innovation of this paper is that it is the first time to use the interval quadratic preference loss function to study the central bank's intervention on the exchange rate, and establish the threshold model of RMB exchange rate fluctuation by Taylor series expansion.

2 Literature review

The study on the intervention of the central bank in the foreign exchange market has been always one of the hot spots. Dornbush [1] expounded the necessity of the intervention of the central bank in the foreign exchange market in theory for the first time. He pointed out that the rigidity which the goods had in the short term might result in the overshoot of exchange rate and then intervened in the economic operation. His study has provided a theoretical basis for the invention of the central bank in the foreign exchange.The study involving the exchange rate range of Krugman [2], as the founder of the range target of exchange rate, on the basis of a continuous time expression for the flexible-price monetary model, represented the exchange rate as an expected linear combination of basic economic factors and the rate of change of instantaneous exchange rate and pointed out that only when the exchange rate touched the margin of the target range would the central bank intervene in the foreign exchange market. The scholar found that the central bank might intervene within the margin of the range, not only when the exchange rate touched the margin of the target range. Delgado and Dumas [3] found that the marginal intervention of the central bank in the target range would happen successively from considering the angular correction Krugman model of the marginal intervention in the target range. Bertola and Caballero [4] introduced the exogenous readjustment risk into modelling, and the characteristics of the model was that the central bank took different intervention policies according to different probabilities of readjustment and the intervention of the central bank was a jumping and discrete intervention.

There were two circumstances that the central bank intervened in the foreign exchange market: (1) symmetric intervention in the foreign exchange market. The symmetric bilateral intervention in the exchange rate of the central bank aimed at eliminating the drastic fluctuation of exchange rate thus to remain the stability of exchange rate or to pursue a target inflation via stable exchange rate; (2) asymmetric intervention, that is to say, to intervene in the asymmetric appreciation or depreciation of the foreign exchange market. The reason why to intervene in the depreciation of exchange rate of the domestic currency was afraid of capital flight or admission and inflation, and the appreciation of exchange rate of the domestic currency was to remain the export competitiveness of domestic goods [5]. The study of Calvo and Reinhart [6] found that there was a phenomenon of "fear of floating" in the developing economic entities in the process of economic development. Levy-Yeyati and Sturzenegger [7] pointed out that most developing economic entities had "fear of floating", that is to say, the foreign exchange authority were not as sensitive to the appreciation and depreciation of the domestic currency, the authority tended to maintain the export competitiveness by the depreciation of the domestic currency and such asymmetric intervention would bring in a massive accumulation of foreign exchange reserves. Ramachandran and Srinivasan [8] applied a dummy variable into the buffer inventory model of Frenkel to study on actions that India's central bank intervened in the foreign exchange market. The study found that India had a stronger asymmetric intervention and actively bought foreign currencies to intervene in the appreciation of Rupee. Pontines and Rajan [9] improved the loss function of the central bank, introduced cube items to measure the asymmetric intervention actions of Japan's, Korea's, Singapore's, India's and China's central banks, and studied the intervention action of Asia's central bank under the foreign exchange intervention and restriction

actions. And their study results showed that central bank of each country in Asia was more sensitive to the appreciation of domestic currency than to the depreciation. Pontines and Siregar [10] studied the intervention action of Indonesia's, Philippines', Korea's and Taiwan's central bank by applying Markov switching models. And the results showed that not only there was appreciation intervention in US dollar, along with the economic development in mainland of China, and there was also a stronger appreciation intervention of its central bank in RMB exchange rate.

Studies on the intervention of the central bank in the foreign exchange market by domestic scholars were focused on metrical study. Zhang et al. [11] carried out a modification on the basis of Weymark model and studied the dynamic intervention margin of the central bank under the managed floating exchange rate system. And their studies found that there were asymmetric intervention margin in the central bank. Huang and Chen [12] assessed the reasonableness of flexible space of RMB exchange rate. And their studies found it reasonable and necessary to expand the fluctuation range from 0.3% to 0.5% on the exchange rate date. And some scholars studied the effectiveness of the intervention of the central bank in the foreign exchange market [13–15]. Huang and Chen [16] carried out studies on the correlation of RMB exchange rate, appreciation expectation and foreign exchange reserves. And their studies found that there was no co-integration relationship between whether RMB nominal effective exchange rate or real effective exchange rate and the foreign exchange reserves, while the RMB appreciation expectation would accelerate the increase of the foreign exchange rate. Chen and Huang [17] found that both the nominal effective exchange rate and the real effective exchange rate had obvious negative effects on the change of foreign exchange reserves.

At present, studies on the relationship among the intervention preferences of the central bank, the exchange fluctuation and the foreign exchange reserves haven't been found and most of the literature applied the range intervention preference to the research on the inflation target and economic growth of the central bank [21–24]. There were intervention costs in the intervention of the central bank in the foreign exchange market, such as the intervention of foreign exchange asset conversion and sterilization in the currency market influenced the exchange rate level and the adjustment of exchange rate influenced the domestic economic operation through the overflow effect [18], there were also some political costs [19,20], so the central bank would analyze the costs and earnings when intervening in the foreign exchange market, and only when the earnings of the intervened foreign exchange market exceeded the earnings, would the central bank actively intervene in the foreign exchange market. On this basis, there might be a nonintervention range in the central bank, and in this range, loss of the central bank was 0. This paper initially applied it in the studies on the mechanism and methods to the intervention of China's central bank in the foreign exchange market to explain the action preference of the intervention of China's central bank in the exchange rate market and the target range of RMB exchange rate.

3 Theoretical models

3.1 Derivation of range intervention function model by Central Bank

At present, most of the frequently - used literature applies standard quadratic loss function:

$$L_t = \frac{1}{2}(R_t - R^*)^2 + \frac{\lambda}{2}(e_t - e^*)^2 \tag{1}$$

This standard quadratic loss function can only describe the linear target of the central bank but it cannot describe the nonlinear target and range preference of the central bank in the foreign exchange market. Continuous linear intervention of the central bank brings large policy costs and political costs [25,26], so there is nonlinear intervention range in the central bank in theory.

Consulting the studies of Surico [23] and Pontines [12], the nonlinear intervention function of the central

bank is set as:

$$L_t = \frac{1}{2}(R_t - R^*)^2 + \frac{\lambda (e_t - e^*)^2}{1 + \exp\left\{-\gamma\left[(e_t - e^*)^2 - \eta\right]\right\}} \tag{2}$$

Where: R_t denotes the policy tools of the intervention of the central bank in the foreign exchange market and R^* means the target foreign reserves of the central bank. *et* is the fluctuation rate of nominal exchange rate or nominal effective exchange rate of direct quotation and e^* denotes the target range or the expected exchange rate range of the central bank. λ is the policy operation weight of the central bank, and η refers to the parameter of asymmetric intervention of the central bank, and its size determines the intervention function slope, that is to say, policy sensitivity. $\gamma > 0$ is the influence coefficient of the target range preference of exchange rate of the central bank.

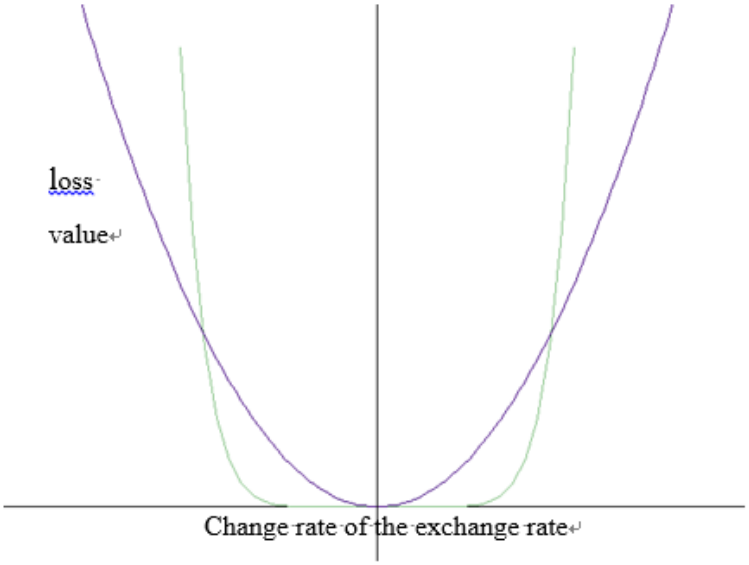

Fig. 1 Range Quadratic Preference Function and Quadratic Preference Function

Figure 1 and 2 are function figures after modification. Assuming that $\gamma = 10$, $\eta = 6$, it can be seen the standard quadratic loss function, the continuous interventions of the central bank when exchange rate changes, the modified range quadratic loss function and 0 loss range of the central bank, which indicates that the loss in the nonintervention threshold range of the central bank is 0, namely, it will not intervene in the foreign exchange market.

Assume that the constrained path of the intervention of the central bank in the foreign exchange market is:

$$e_t - e^* = \alpha_0 + \alpha_1 R_t + \varepsilon_t \tag{3}$$

Considering R_t as the variable of policy control, minimize (2) under the constrained condition (3), it can obtain its first order condition:

$$(R_t - R^*) + \frac{\lambda\left\{2\alpha_1 e_t\left(1 + \exp\left(-\gamma\left(e_t^2 - \eta\right)\right) + 2\gamma\alpha_1 e_t^3 \exp\left(-\gamma\left(e_t^2 - \eta\right)\right)\right)\right\}}{\left(1 + \exp\left\{-\gamma\left[(e_t - e^*)^2 - \eta\right]\right\}\right)^2} = 0 \tag{4}$$

Let

$$f(\gamma) = \frac{\lambda\left\{2\alpha_1 e_t\left(1 + \exp\left(-\gamma\left(e_t^2 - \eta\right)\right) + 2\gamma\alpha_1 e_t^3 \exp\left(-\gamma\left(e_t^2 - \eta\right)\right)\right)\right\}}{\left(1 + \exp\left\{-\gamma\left[(e_t - e^*)^2 - \eta\right]\right\}\right)^2} \tag{5}$$

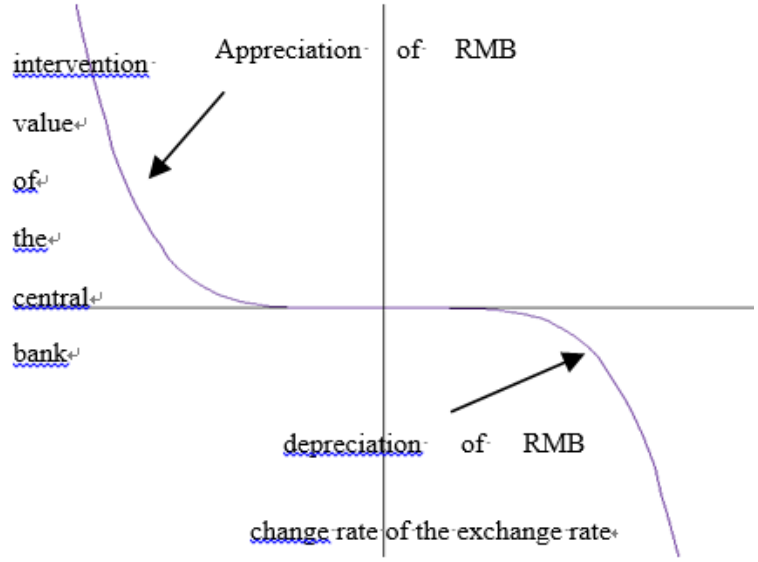

Fig. 2 The Intervention of the Central Bank under the Range Quadratic Preference Model

Put (5) in the place of $\gamma = 0$, it can be obtained after spreading the first order Taylor:

$$f(\gamma) = f(0) + f'(0) * \gamma \tag{6}$$

Where: $f(0) = \lambda\alpha_1, \quad f'(0) = \lambda e_t^3 - \lambda\alpha_1\eta e_t/2$ It can be obtained from (4) (6):

$$R_t = \beta_0 + \beta_1 e_t + \beta_2 e_t^3 \tag{7}$$

Where: $\beta_0 = R^*, \quad \beta = \lambda\alpha_1(2 - m/2), \quad \beta_2 = -\lambda\gamma\alpha_1$

Where: ε_t is a disturbing term, independent identically distributed.

In (7), β_2 includes the information of exchange rate target range of the central bank, if β_2 is estimated obviously different from 0, that is, $\gamma \neq 0$, it is explained that there is target range of exchange rate in the central bank but a point target. Figure 2 shows that in a certain target range, that is to say, in a certain threshold value, the central bank will not employ the foreign exchange reserves to intervene in the foreign exchange market.

3.2 Intervention threshold model of the central bank

If $\gamma \neq 0$, it is indicated that there is no intervention range in the central bank, that is to say, there is a certain intervention threshold in the policy target of the central bank, and in the threshold range, the central bank will not intervene in the foreign exchange market. Consulting the method of work by Boinet and Martiny [27] as well as Naraidoo and Raputsoane [24], establishing an intervention threshold model of the central bank.

Assume that the change of foreign exchange reserves ε_t and the change of RMB exchange rate have the linear relation, namely:

$$R_t = \theta_0 + \theta_1 e_t + \mu_t \tag{8}$$

Where: $\theta_0 = R^*, |\theta_1 = \lambda\alpha_1(2 - \gamma\eta/2)$, μ_t means error term. There is no intervention threshold of the central bank under this equation, and the central bank continuously intervenes in the foreign exchange market.

The intervention threshold of the central bank (namely, the target range of the central bank) is introduced to the relaxation assumption to build the intervention threshold model of the central bank and to allow different θ value, which depends on the size of different exchange rate range. Complied with the method of work of introducing a dummy variable by Minoru Tachibana [21, 22], Boinet and Martiny [27]as well as Naraidoo and Raputsoane [24] , it explained the change of policies of the equation in and out of the threshold with the dummy variable.

$$R_t = \theta_0 + \theta_1^0 e_t + \left(\theta_1^* - \theta_1^0\right) D_t e_t + \omega_t(10) \tag{9}$$

where: $D_t = \begin{cases} 1, e_t \in [\zeta_1, \zeta_2] \\ 0, e_t \notin [\zeta_1 \zeta_2] \end{cases}$ D_t denotes a dummy variable, ζ_1 and ζ_2 mean the top and bottom threshold values. θ_1^0 refers to a policy coefficient of the central bank out of the threshold value, θ_1^* is a policy coefficient in the threshold range. if the exchange rate range exceeds the threshold range, it can be expected that $\left|\theta_1^0\right| > |\theta_1^*|$, and if $\theta_1^0 = \theta_1^*| = \theta_1$, the equation (9) will become linear function (8), so (9) can estimate the nonlinear intervention characteristics of the central bank.

4 Metrical results

4.1 Explanation of data and variables

Data sample is from Jan. 1994 to Jun. 2012. Data of RMB nominal effective exchange rate comes from the Bank of International Settlement (BIS) (2010=100), and the foreign exchange reserves come from the website of the People's Bank of China.

Due to the unavailability of real intervention data of China's exchange rate and the foreign exchange market transaction in the proportion that the accrual of foreign exchange reserves account in the foreign exchange market transaction is also a state secret, the foreign exchange intervention variable replaces the variable, that is to say,$R_t = (\Delta \log I_t) * 100$, where, I_t means foreign exchange reserves (excluding gold and special drawing rights) , for example, Guo and Chen [28], Srinivasan [29], Sheng and Wu [30] and Lin [31] adopted the variable quantity of foreign exchange reserves as the substitute variable of real intervention amount. The change rate of RMB exchange rate e_t , and $e_t = (\Delta \log q_t)^* 100$, where, is direct-quotation nominal effective exchange rate.

4.2 Estimation methods and metrical results

There exist endogenous problems in equations (8), (9). Referring to existing similar study results and adopting GMM (generalized method of moment), GMM does not have too many requirements on the disturbing term of equation. In the process of estimation, (1) apply the second-order lag of c, e_t and e_t^3 as tool variables; (2) in order to control the heteroscedasticity and serial correlation in the error term, use Newey-West method to estimate the co-variance matrix; (3) utilize J-statistic method to verify if there is over-identifying, that is to say, whether tool variable selection is suitable or not.

Table 1 Estimated Results of Equation (8)

parameter	Coefficient value	T-value	Standard deviation	P value
β_0	0.356***	6.245	0.057	0.00
β_1	-0.158	-0.151	0.829	0.41
β_2	-0.932***	-4.571	0.203	0.00

Notes: (1) *** is 1% significant level,(2) J-statistics=24.157, p=0.994

Table 2 Estimated Results of Equation (9)

parameter	Coefficient value	T-value	Standard deviation	P value
θ_0	0.316***	8.145	0.0387	0.00
θ_1	-0.258**	-2.03	0.127	0.04

Notes: (1) *** is 1% significant level, ** is 5% significant level, (2) J-statistics=26.457, p=0.99

Table 3 Estimated Results of Equation (10)

parameter	Coefficient value	T-value	Standard deviation	P value
θ_0	0.348***	12.065	0.0285	0.00
θ_1^0	-0.687***	-5.251	0.130	0.00
θ_1^*	-0.348	-1.164	0.299	0.213

Notes: (1) *** is 1% significant level, (2) J-statistics=28.954, p=0.99, (3) LR statistics (H_0: $\theta_1^0 = \theta_1^*$) = 3.67

Since this paper doesn't know the target range of exchange rate of the central bank, indirect estimation which Tachibana [21, 22], have used is adopted to equation (9):

1. Establishing the target range of RMB exchange rate, RMB fluctuation range in the sample range [-3.58%, 5.10%], 95 depreciation data in the range account for 43% in the total data, with its maximum depreciation of 3.58% and the maximum appreciation of 5.1%, and assuming that the target range of RMB exchange rate is [-3.6%,5.2%]. Provided that the target range of the central bank is in [-3.6%,5.2%], there will be no intervention in the sample range; provided that target range width of the central bank is 0, that is to say, the exchange rate target of the central bank is point target, and the central bank will intervene in the foreign exchange market uninterruptedly, so the exchange rate target of the central bank is in the range of [-3.6%,5.2%].

2. Each time the range width is changed by 0.5%, each range is repeatedly estimated, and the maximum LR statistic is considered as the range target of exchange rate of the central bank. The estimated results show that the target range of the central bank in the sample range is [-1.6%,0.9%], that is in the sample range, and China' s central bank is able to tolerate a depreciation of 1.6%, but an appreciation of 0.9%, which indicates that there is asymmetric intervention range in the central bank.

3. The estimated display range in the sub range from Jul. 2005 to Jun. 2012 is [-1.7%,1.2%], which indicates the increase of tolerance range of the central bank.

4.3 Metrical analysis

1. The estimated results in Table 1 indicates that j-statistic statistic shows that there is no overestimation, namely, there is no ineffective tool variable; β_2 in 1% obvious level differs from 0, explaining $\gamma \neq 0$, and indicating that there is no discontinuous and nonlinear intervention action of the central bank in the foreign exchange market, that is to say, there is a target range of exchange rate in the central bank.

2. Equation (7) is a special form of equation (8), and its estimated results are Table 2 and Table 3. J-statistics statistic and P value in Table 2 and Table 3 show that there is no overestimation and the setting of tool variables is valid.

3. That θ_1^* is not obviously different from 0 indicating that there the exchange rate of the central bank is in the target range, so it will not intervene in the foreign exchange market; θ_1^0 differs from 0 under 1% obvious level indicates that RMB exchange rate fluctuation exceeds its threshold value, so the central bank will actively intervene in the foreign exchange market.

4. From the view of estimated range target threshold value of RMB exchange rate of the central bank, the central bank has a stronger asymmetric intervention in the foreign exchange market and is more sensitive to RMB appreciation than RMB depreciation, which is keeping up with China's economic policy orientation. Over 30 years of China' s reform and opening up, the foreign trade export strategy has made undeniable contributions to the economical development. It has been a policy orientation for a long time to focus on the competitiveness of export commodities.

5. The estimated results of the sub sample indicate that the target range of RMB exchange rate has become larger since Jul. 2005, which shows that the flexible range of RMB exchange rate is becoming larger. However, the operation of "fear of appreciation" policy is weakening, which is keeping up with the reform orientation of RMB exchange rate and shows that RMB reform increases the floating range of exchange rate and actively

implements a two-way floating.

5 Conclusions

This paper establishes a threshold model of RMB exchange rate fluctuation by applying range quadratic preference loss functions and via formula of expanded Taylor series and studies intervention actions of the central bank in RMB exchange rate from Jan. 1994 to Jun. 2012. Studies found:

1. There is asymmetric intervention preference of the central bank in RMB exchange rate, and the central bank carries out discontinuous and nonlinear interventions in RMB exchange rate, existing an intervention threshold [-1.6%, 0.9%], and the central bank has the trend of "fear of appreciation" to some extent.

2. The asymmetric range intervention preference of the central bank causes a rapid growth of our foreign exchange reserves to some extent.

3. RMB intervention threshold range has become larger since Jul. 2005, which indicates that the flexible range of RMB exchange rate is becoming larger.The operation of "fear of appreciation" policy is weakening.

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