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Exchange Rate of the Ruble Modeling: Macroeconomic Level

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Abstract: As underlying determinants of the author's model are used capital flows, import and export operations, elasticities of cross-country trade, terms of foreign trade, indexes of real GDP, indexes of domestic and export prices, solutions of microagents. The model was verified on data from the crisis period in Russia 2013-2015. The simulation results are applied to the analysis of contemporary monetary policy of Russia.

Keywords: Exchange rate of the ruble, modelling, balance of payments, currency crisis.

1. INTRODUCTION

The monetary approach to exchange rate modeling is important: the models of Frenkel [1], Mussa [2, 3], Hooper-Morton [4] and others. Model with sticky prices was created by Dornbush [5, 6]. The two-country model with maximization of individual preferences was created by Stockman [7]. Representative of another class of dynamic stochastic general equilibrium (DSGE) models is the monopolistic competition model Obstfeld-Rogoff [8] of exchange rate of two open economies. It should be noted that Economic Fundamentals takes an important place both in these models and in the model Clark-MacDonald [9, 10].

A number of researches was devoted to the dynamics of the ruble: Strizhkova [11], Mirkin [12] and others. However, to construct a mathematical fundamental determinants model of the Russian ruble new developments are necessary. We have to base on the study of the fund movements of the Russian balance of payments. We also need to engage in modeling the terms of foreign trade as one of the most important fundamental determinants. As a result, it's necessary to investigate the equilibrium medium-term dynamics of the ruble in the context of the currency crisis in 2013-15.

In this paper the proposed dynamic model of the equilibrium exchange rate of Russian ruble is a development of previous author's research [13, 14]. It takes into account in the medium-term period capital flows, import and export operations, elasticity of cross-country trade, terms of foreign trade, indexes of real GDP, indexes of export and domestic prices, solutions of micro agents. The constructed exchange rate will balance the balance of payments. As a consequence, it will balance the offer of national and foreign currencies on the cross-country monetary market.

The main objective of the modeling was to identify the dynamics of the ruble exchange rate from the system of major macroeconomic factors. This system must necessarily include the factors of the monetary sector, as well as the factors of the real sector. Modeling will be based on the principles of the International Flows Equilibrium Exchange Rate (IFEER), developed in the works of the author. But in this article we will present a new model.

2. A DYNAMIC MODEL OF THE EXCHANGE RATE OF THE RUBLE

The exchange rate policy of the Bank of Russia is the regime of independent floating according to the classification of the International Monetary Fund. Russia is also characterized by special public attention to the dynamics of the nominal exchange rate of the national currency. As a result, the importance of the Bank of Russia's exchange rate policy is typical in modern conditions.

Initially, we consider all real market transactions at nominal exchange rates $e_i, i \in (1, N)$ on the domestic currency market that occurred in a certain period of time.

Then e_i, D_i, R_i in *i-th* transaction are: the nominal exchange rate, the amount in the determined foreign currency and the amount in the national currency respectively.

These variables are linked by ratios:

$e_i D_i = R_i$, and therefore, $e_i = R_i / D_i$.

In the Russian foreign exchange market, a significant part of transactions takes place in US dollars. Transactions in other currencies, such as the Euro, the British pound are directly linked to these prevailing rates through the system of cross-rates in the international and local market. Thus, we further consider the US dollar as a foreign currency and the direct quotes of US dollar to Russian ruble.

It should be noted that the contribution of each market transaction is different. It depends on the volume of the transaction.

Therefore, we define the synthetic value of the exchange rate for the certain period as the sum of exchange rates, weighted by amounts in determined foreign currencies:

$$e \equiv \sum_{i=1}^{N} \frac{D_i}{\sum_{j=1}^{N} D_j} \times e_i \,, \tag{2.1}$$

Using the definition of the exchange rate in *i-th* transaction, we get from (2.1):

$$e = \sum_{i=1}^{N} \frac{D_i}{\sum_{j=1}^{N} D_j} \times \frac{R_i}{D_i} = \sum_{i=1}^{N} R_i \Big/ \sum_{j=1}^{N} D_j$$

So, on a conceptual level, we can disaggregate the country's balance of payments flows:

$$e = \frac{\sum R^{CA} + \sum R^{K} + \sum R^{CB}}{\sum D^{CA} + \sum D^{K} + \sum D^{CB}} \tag{2.2}$$

In this formula (2.2) we consider flows in the respective currencies that came to the domestic currency market:

- as the supply of the foreign and national currencies in accordance with current account operations - amount of funds with index *CA*,

- as the supply of the foreign and national currencies in accordance with capital operations - amount of funds with index *K*,

- as a result of currency interventions of the Bank of Russia - amount of funds with index *CB*.

This formula takes into account such important components as export revenue, demand for imports, demand for foreign assets and so on.

Conceptually, formula (2.2) can be applied not necessarily to analyze the dynamics of the Russian ruble, but in other cases as well. In the work of the author [6], its adapted version was used to model the dynamics of equilibrium exchange rates under the equality of economies.

However, in this paper we will conduct a modeling of the ruble exchange rate in the conditions “open economy - rest of the world”.

Further two-period model will be considered in periods *t, t-1*.

It should be noted that Russian exports affect the economic situation in the country. Of course, the dynamics of actual export prices will directly determine the state of the domestic foreign exchange market. Amount of foreign currency in the market at period *t* will be determined by the volume of exports decisions of exporters at period *t-1*. And the most important factor in increasing the physical volume of exports is the real terms of international trade. We define these conditions in this situation as the division of exports and domestic prices adjusted to the nominal exchange rate:

$$e^{R}{}_{t-1} = e_{t-1} \, P^{*}_{t-1} \big/ P_{t-1} \, ,$$

where P_t - the internal price index (e.g., CPI), P^{*}_{t-1} - the actual export price index.

Here the terms of international trade can be structurally correlated with the real exchange rate, used in the author's work [13].

Thus, the amount in foreign currency at period *t* that came to the domestic foreign exchange market as part k_E of export earnings in actual export prices P^{*}_{t} is equal to

$$\sum D^{CA} = P^{*}_{t} k_E \left(Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}}\right)^{1+\delta} \left(e^{R}_{t-1}\right)^{z} \tag{2.3}$$

where $k_E = const,$ Q_t - the index of total real output (e.g., real GDP).

Let’s give some explanations to the formula (2.3). Index *z* values response to the state of the terms of international trade at period *t-1*. The part $k_E \left(Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}}\right)^{1+\delta}$ reflects that the physical export is a part of averaged total real output not only in current period, but also in the previous time. At the same time averaging method in $k_E \left(Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}}\right)^{1+\delta}$ shall not have a significant influence on the final result from economic positions. This is due to the insignificance in the real output changes, compared to possible fluctuations of price indices in the medium term.

Rate δ shows a "slightly higher" non-negative growth of national exports in relation to imports as a function of real output. The main reason is the restriction of domestic demand and thus the need to realize the growing domestic output due to the growth of exports. The parameter $x=(z-y)$ associates parameters *y* and *z* in the dependencies (2.3) and (2.4).

Next, make an assumption about the import dependencies: the consumption of imports at time *t* by residents with proportion k_I of their income $P_t \left(Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}}\right)$ is represented both current income and income in the previous period as follows

$$\sum R^{CA} = k_I P_t \left(Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}}\right) \left(e^{R}_{t-1}\right)^{y} \tag{2.4}$$

The parameter *y* also values response to the state of the real terms of international trade.

Of course, as it can be seen from formula (2.2), capital flows directly determine the dynamics of the exchange rate. At the same time, a significant number of exchange rate models ignore this problem, while remaining at the level of the trade balance.

However, within the framework of the proposed IFEER modeling the capital flows can be involved in the process. We accept the hypothesis for the functional dependence of capital outflows: this is the demand for international assets of Russian residents for savings purposes and it is part of total income in domestic prices:

$$(\sum R^K + \sum R^{CB}) = \\ = P_t \, k_{K^-} (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})(e_{t-1}^R)^y, \tag{2.5}$$

where $k_{K^-} = const$.

It will also assumes that in (2.5) and further in (2.6) transactions of the Bank of Russia are considered.

For the functional dependence of capital inflows, we accept that it reflects the inflows of portfolio and direct investments. According to this international speculators and investors want to buy a part of the real national product in international prices. Another important factor is the terms of international trade because the changes in them will certainly affect the investment climate:

$$(\sum D^K + \sum D^{CB}) = \\ = P_t^* k_{K^+} (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{1+\theta} (e_{t-1}^R)^z \tag{2.6}$$

where $k_{K^+} = const$, $\theta \geq 0$.

Dependence (2.6) suggests that the impact of national product growth is increased more than proportionally due to psychological factors and the implemented policy of import substitution, which is carried out by the Government of the Russian Federation in recent years. In this dependence it is expressed by the parameter θ in part $k_{K^+} (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{1+\theta}$.

We will directly substitute dependencies (2.3) - (2.6) into the formula (2.2):

$$e_t = \Big[k_I P_t (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})(e_{t-1}^R)^y + \\ + k_{K^-} P_t (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})(e_{t-1}^R)^y \Big] \times \\ \Big[k_E P_t^* (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{1+\delta} (e_{t-1}^R)^z + \\ + k_{K^+} P_t^* (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{1+\theta} (e_{t-1}^R)^z \Big]^{-1} =$$

$$= \left[P_t (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})(e_{t-1}^R)^y (k_I + k_{K^-}) \right] \times$$
$$\left[P_t^* (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{1+\theta} (e_{t-1}^R)^z \times \right. \quad (2.7)$$
$$\left. \times (k_E (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{\delta-\theta} + k_{K^+}) \right]^{-1}.$$

Based on economic logic, we can assume that $(\delta - \theta) \approx 0$ and the part $(Q_{t-1}^{\tilde{o}/\tilde{o}+} Q_t^{1/\tilde{o}+1})$ is stable, comparing to other model variables in the medium term. This makes it possible to consider the component as a constant in (2.7):

$$\frac{(k_I + k_{K^-})}{(k_E (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{\delta-\theta} + k_{K^+})} = (k')^{x+1} = const.$$

Thus as you can see, this component k' is the more stable, the smaller the contribution of the current balance flows compared to the capital flows.

Formula (2.7):

$$e_t = \frac{(k')^{x+1} P_t}{P_t^* (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{\theta} (e_{t-1}^R)^{\tilde{o}}} =$$

$$= \frac{(k')^{x+1} P_t}{P_t^* (Q_t^{\frac{1}{x+1}} Q_{t-1}^{\frac{x}{x+1}})^{\theta} (e_{t-1} P_{t-1}^* / P_{t-1})^{\tilde{o}}}.$$

Then:

$$e_t (e_{t-1})^x = \left(k' \frac{P_t}{P_t^*} Q_t^{-\theta/x+1} \right) \left(k' \frac{P_{t-1}}{P_{t-1}^*} Q_{t-1}^{-\theta/x+1} \right)^x \quad (2.8)$$

And then after intertemporary separation of variables and notation $\theta' = \theta/x+1$:

$$e_t = k' \frac{P_t}{P_t^*} Q_t^{-\theta/x+1} = k' \frac{P_t}{P_t^*} Q_t^{-\theta'}. \quad (2.9)$$

3. VERIFICATION OF THE MODEL

Of course, to verify the model most appropriate would be the crisis period 2013 - 2015, associated primarily with the significant depreciation of the ruble.

The starting point of the research period is December 2013. At the moment, both the domestic macroeconomic situation and the international environment were characterized by stability. The exchange rate of the ruble according to the Bank of Russia at that time was *32,73* to the US dollar.

We used the CPI (Consumer Price Index) as the model variable *P* [15], the prices of blend crude oil as the model variable *P** (US dollars per brent-mix barrel, Intercontinental Exchange, [16]), the index of the real GDP as the model variable *Q* [17].
Our setting used the least squares method with normalization of the investigated variables. Thus, parametric minimization problem

$$\min_{\theta'} \sum_t \left(\frac{e_t(\theta') - e(\text{nominal})_t}{e(\text{nominal})_t} \right)^2 \tag{3.1}$$

was solved here under the conditions $\theta' \geq 0$.
The exchange rate *e(nominal)* is the nominal exchange rate USD/RUR [17], according to the Bank of Russia calculations monthly at the end of the each period.
Solution of parametric optimization (3.1) in accordance with numerical simulation is $\theta' = 0{,}5$.
Here we use the updated data compared with the data of work [14].
In Figure 3.1 (author's calculations, monthly updated data) presents the dynamics of the exchange rate of the Russian ruble against the US dollar in accordance with the result formula of our research (2.9) *e(Theor)* and the nominal exchange rate *e(nominal).*

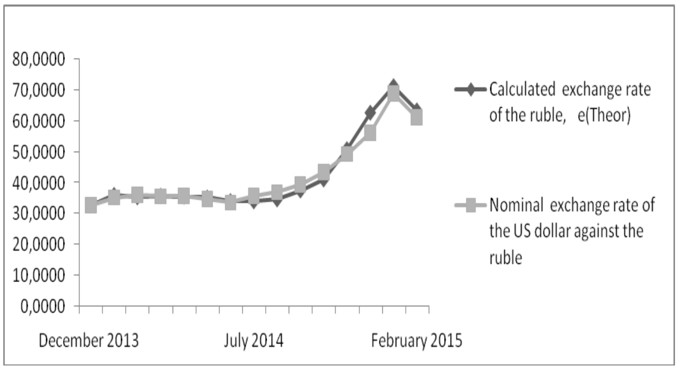

Fig. 3.1. The nominal and calculated exchange rates of Russian ruble USD/RUR (2013 - 2015, monthly updated data).

As results, the average of absolute normalized deviations of the calculated and nominal exchange rates is 0.3% and average of normalized deviations is 3%. This allows us to speak about the high quality of the developed mathematical model.

4. CONCLUSION

The results of the modeling generally confirm the conclusions made in the media about the causes of the currency crisis in this period.
A serious drop in oil prices and closely correlated the prices of natural gas and processed products was the main reason for the actual double devaluation of the ruble. However, it should be noted that the internal situation in the form of accelerated inflation and GDP decline has made a serious contribution to this process.
Of course, a statement of this fact cannot say about the adequacy of the situation. In the transition to a floating exchange rate such a rigid dependence of the ruble exchange rate from the foreign economic environment requires increasing degrees of intervention by the Bank of Russia on the domestic FOREX market.

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