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Toward the modeling of Russia's monetary system

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The paper explains the dynamics of monetary aggregates in Russia with the help of country's trade balance, the creation of deposits by commercial banks and cross-border flows of rubles and (foreign) currency. The volumes of deposits and flows, in turn, depend on changes the currency/ruble exchange rate and favorable external economic conditions. The model was estimated by the Kalman filter, the adequacy was confirmed by stimulation. Monthly money supply forecasts have an accuracy of ~ 1%. It was found that the volume of additional deposits created per month is ~ 300 billion RUB (this leads to real inflation of 9.5% per annum), money flows that are not related to payments for goods: rubles inflow from abroad ~ 100 billion RUB, currency goes abroad ~ $ 15 billion. With the growth / fall of the dollar exchange rate by 1 RUB per month, during the same month, the creation of additional ruble deposits and the arrival of rubles from outside decreases / increases by $ 0.114 billion. The increase of the Currency Reserve Assets of Russia is accompanied by going abroad ~ 5% of the increase.

Keywords: broad money supply, currency outflow, money creation, exchange rate, Kalman filter

INTRODUCTION

The economy and finances of modern Russia are deeply integrated into the global system, when rubles and currency, on equal terms, perform the function of money. However, for correct decisions in the monetary sphere, it is necessary to clearly understand their roles, the corresponding volumes and mutual transitions. From the Central Bank of Russia statistics [1] of the payments balance, it is difficult to understand how much of what money is involved in cross-border transfer when acquiring assets or accepting liabilities. The existing global macroeconomic models of the Russian economy, see, for example, [2, 3] have not yet reached the required level of detailed description.

The objective of this work: to build a model of the monetary subsystem of the Russian economy, covering the most important cash flows and suitable for further clarification. The basic principles of the model: rubles and currency in the accounts of residents change under the influence of foreign trade, other incomes from outside / creation of rubles by banks [4] and currency outflows abroad. It is generally recognized that it is difficult to predict exchange rates, since information shocks and political decisions have a decisive influence on them. But the changes in the exchange rate that have occurred have a significant impact on the Russian monetary system and should be used as explanatory variables in the model, as well as the amount of replenishment of the Currency Reserve Assets of Russia, for example, at favorable oil prices.

MODEL AND DATA

Observed system's output in moments (the beginning of the subsequent months) $t = 0,1,...,T$ are

$$y^t = \begin{pmatrix} M2^t \\ M4^t \end{pmatrix},$$

where $M2^t$ is the money supply (monetary aggregate) consists of ruble cash and deposits, held by the non-bank residents of Russia. $M4^t$ is the broad money supply (consisting of $M2^t$ and deposits in currency placed in the banking system by residents of Russia), billion RUB.

We introduce variables: R^t - ruble cash and deposits (residents), D^t - currency deposits (residents) in the moment *t*. ex^t, im^t - export and import of goods, RA^t - creation of additional ruble deposits by commercial banks + inflow of rubles from abroad (for example, to purchase Russian stocks, bonds), DA^t - currency outflow abroad - for the month from *t* to *t* +1. All in billions USD. The last 2 indicators are not connected with ex^t, im^t, and can be negative with changing the direction of the flow of the related money. ΔS^t - the change in the dollar-to-ruble exchange rate S^t during the same period (RUB for 1 USD). Compared with the 1st version of this work [5], the equations of the system are somewhat modified to obtain a completely observable and controllable (according to Kalman's criterion) system. System dynamics

$$R^{t+1} = \frac{S^t}{S^{t+1}} R^t + 0.144 ex^t - 0.31 im^t + RA^t + \delta_0^t, \quad (1)$$

$$D^{t+1} = D^t + 0.856 ex^t - 0.69 im^t - DA^t + \beta_0 \Delta RES0^t + \delta_1^t, \quad (2)$$

$$RA^t = RA^{t-1} - \beta_1 \Delta S^t + \delta_2^t, \quad (3)$$

$$DA^t = DA^{t-1} + \beta_2 \Delta RES0^t + \delta_3^t. \quad (4)$$

The first coefficient on the right-hand side of (1) provides a conversion to the currency of ruble deposits passing from the previous month. The coefficients for export and import are taken from [6]: “if Russia receives only 14.4% in rubles for export, then it pays 31% of import in its own currency”. It is possible to take the actual data for each month on rubles and currency in exports and imports for clarification.

We assume (3), that the change in variable RA^t against the same month ago is proportional ΔS^t. Since, firstly, the creation of ruble deposits is largely carried out for the purchase of a depreciating currency. This is confirmed by an estimate of the correlation coefficient of monthly changes in the dollar / ruble exchange rate and monthly changes in ruble deposits (expressed in $). According to data from 01.02.2012 to 01.01.2020 it is negative and equal to - 0.889, the significance level (sl) according to the t-criterion is 0.00000 ... Data on ruble deposits “Funds on accounts of organizations, bank deposits (deposits) and other funds of legal entities and individuals in rubles (for the whole of the Russian Federation)” are taken from the website of the Central Bank of Russia [7]. That is, when the exchange rate decreases, the creation of deposits is accelerated. Secondly, the arrival of non-resident rubles falls when the price of ruble exchange-traded assets increases with the growth of the dollar. The latter relationship is evidenced by the estimate of the correlation coefficient of the dollar rate *S* and the Moscow Exchange index IMOEX. According to monthly data from 01.01.1998 to 01.08.2019, it is 0.692, the significance level (sl) by *t*-criterion is equal to 0.00000 .... And, when the index lags from the rate, the connection is stronger than in reverse lag (see Fig. 1), i.e., a change in rate precedes an index change.

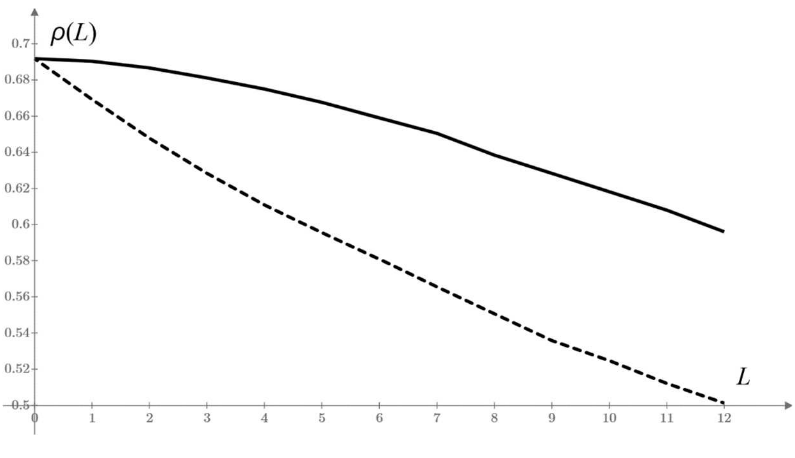

Figure 1. Estimates of the correlations of the dollar exchange rate *S* and IMOEX ρ (*L*) at different *L* (months) – delays of the index from the rate (continuous curve) and advances (dashed curve) of the index.

$\Delta RES0^t = \max(\Delta RES^t, 0)$, $\Delta RES^t = RES^{t+1} - RES^t$, RES^t - Currency Reserve Assets of Russia at time *t* in billion USD. The meaning of the term $\beta_0 \Delta RES0^t$ and $\beta_2 \Delta RES0^t$ is that when the accumulation of reserves took place, then these were also favorable months for the build-up D^t and DA^t. An attempt to directly include the known increase / decrease of reserves in the accounts (1) and (2) worsened the description, which means that reserves are not replenished from them. δ_i^t - mutually independent errors. The purchase and sale of currency for rubles from abroad under normal conditions is relatively small (see the 1st version of the work) and is not included in (1) - (2). Purchase and sale of currency within the country, obviously, does not affect ruble and currency deposits.

We introduce the directly unobservable state vector of the system $x^t = \begin{pmatrix} R^t & D^t & RA^{t-1} & DA^{t-1} \end{pmatrix}^T$, and the control vector

$$u^t = \begin{pmatrix} ex^t & im^t & \Delta S^t & \Delta RES0^t \end{pmatrix}^T. \quad (5)$$

Then the model of the system in the state space, in accordance with (1) -(4) has a form

$$x^{t+1} = F^t x^t + G^t u^t + w^t, \quad (6)$$

$$y^t = H^t x^t + v^t, \quad (7)$$

where the operator of evolution $F^t = \begin{pmatrix} \frac{S^t}{S^{t+1}} & 0 & 1 & 0 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$, control $G^t = \begin{pmatrix} 0.144 & -0.31 & -\beta_1 & 0 \\ 0.856 & -0.69 & 0 & \beta_0 - \beta_2 \\ 0 & 0 & -\beta_1 & 0 \\ 0 & 0 & 0 & \beta_2 \end{pmatrix}$, and observation $H^t = S^t \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$.

Monthly data from 01.01.2015 to 01.12.2019 (*t* = 0, ..., 59 = *T*) were taken from the website of the Central Bank of Russia [8]. See table 1.

Table 1. Data for calculations

t	0	1	2	3	…	58	59
$M2^t$	31616	31034	31225	31029	…	48083	
$M4^t$	42910	45155	43881	43204	…	61680	
ex^t	27.9	29.4	32.9	30.7	…	35.4	
im^t	12.2	15.4	17.1	16.2	…	23.2	
RES^t	385.5	376.2	360.2	356.4	…	540.9	542
S^t	59.233	69.939	61.781	58.062	…	63.873	64.082

KALMAN FILTER AND INTERPRETATION OF CALCULATION RESULTS

Kalman filter is widely used in economic studies (see, for example, [3, 9, 10]). It makes it possible to evaluate the parameters of the system, evaluate and predict the unobservable characteristics of the state of the system and its output.

Model parameters

$$\theta = (\sigma v_0 \, \sigma\delta \, \sigma_P \, \beta)^T , \tag{8}$$

where $\sigma\delta$ - is the vector of standard deviations of errors in (1) - (4). We choose the initial state estimate $\hat{x}^{0|0}$ (a rough assessment) $(500 \quad 200 \quad 7 \quad 11)^T$, and the covariance matrix of this estimate $\sigma_P^2 I$, I is the identity matrix. We take the covariance matrix of the observation error vector v^t equal $R = \sigma {v_0}^2 \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix}$.

The estimation of the vector of model parameters was carried out by minimizing the mean square sum of errors in predicting money supplies $M2^t$ и $M4^t$ in the fit window (*Tl* is the initial moment, *Tu* is the final moment of the window).

$$RMSE(\theta) = \sqrt{\frac{1}{Tu-(Tl-1)} \sum_{t=Tl}^{Tu} \{[(y^t)_0 - (\hat{y}^{t|t-1})_0]^2 + [(y^t)_1 - (\hat{y}^{t|t-1})_1]^2\}} ,$$

$$\hat{\theta}_{RMSE} = \arg\min_{\hat{\theta}} RMSE(\hat{\theta}) .$$

Here $\hat{y}^{t|t-1}$ is the forecast for information at time *t* - 1 (i.e., up to the value y^{t-1} and u^{t-1}) of the output vector at the next moment. Calculations done at *PTC® Mathcad Prime® 4.0*.

We select the fitting window in the middle of the data time series, leaving the beginning and the end to check the adequacy of the model. *Tl* = 13 (01.02.2016), *Tu* = 51 (01.03.2019) (see Fig. 2).

The minimum *RMSE* turned out to be equal to 732.01 billion RUB (for the random walk model (when the forecast is the previous value) *RMSERW* = 1150 billion RUB) in the same window. The behavior of the training curve shows that not all mechanisms for money supply changing are taken into account by the model. For example, the peaks of *M*2 on January 1 of each year from the cash injected by the Central Bank loans issued by commercial banks in December and are not explained. But their repayments in January are counterweighted in accordance with (1) by import for rubles decreases (see Fig. 4).

The layout of the dashed curve characterizes the adequacy of forecasting (when a pre-trained KF using the observed output and control at the moment *t*-1 makes a forecast of the state and the output at the moment *t*). The average accuracy of such forecasts of the masses *M*2 and *M*4, calculated for the right dashed curves in Fig. 2, turned out to be 0.6 and 0.4%, respectively.

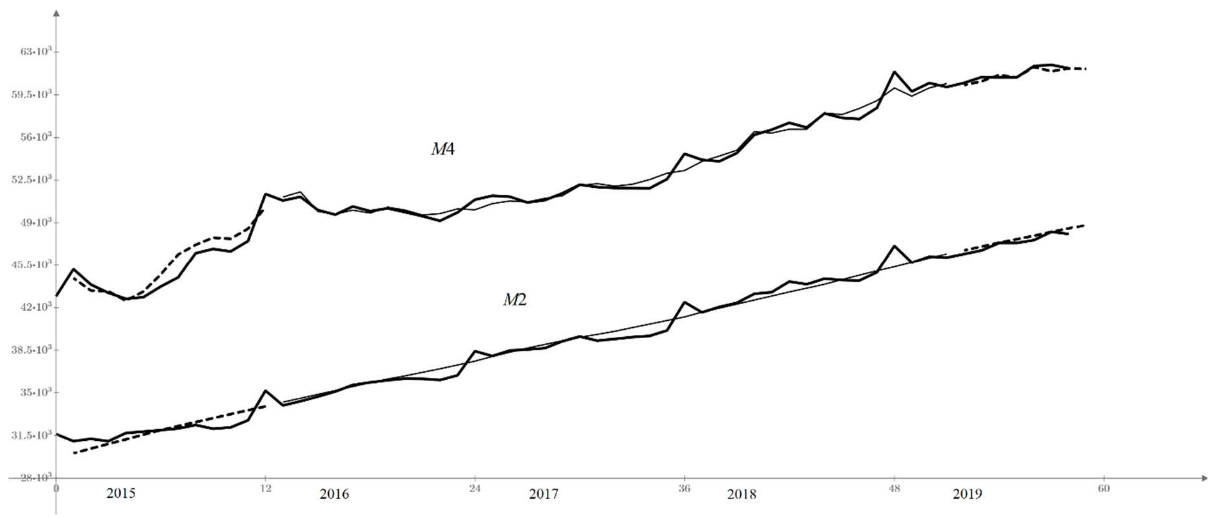

Figure 2. Monthly data from 01.2015 to 12.2019 Observed money supply (solid curve), adjusted forecast according to information a month ago (thin solid curve - training), forecast according to the estimated model (dashed curve), billion RUB.

Having an estimate of the forecast accuracy for the KF, in practical forecasting, it is natural to train the model using the latest available data. Suppose we want to give a forecast of the money supply at the time of 12.01.2019 ($T = 59$), then Tu = 58. All further results relate to this learning window. The forecasts of the masses of $M2$ and $M4$ turned out to be 48727 and 61.781 billion RUB. In fact, the money supply turned out to be 49195 and 62.733 billion RUB, i.e., forecast errors amounted to 0.95 and 1.5%.

Estimated parameters (8):

$\beta_1 = 0.114$ shows that with an increase / decrease in the dollar exchange rate by 1 RUB per month, during the same month it decreases / increases by \$ 0.114 billion the creation of additional ruble deposits and the arrival of rubles from outside. The paper [2] also found a decrease in the money supply $M1$ in Russia in 1996–2004 with an increase in the dollar exchange rate (albeit without discussing possible mechanisms).

$\beta_2 = 0.048$, that is, the increase in Currency Reserve Assets of Russia is accompanied by leaking 5% of increase abroad.

$\beta_0 = 0.666$, т. о. $1/(1+\beta_0) = 0.6$ – the portion of income from sales abroad (not taken into account in foreign trade in goods) going to Currency Reserve Assets of Russia (an example is the "budget rule").

$\sigma v_0 = 25.0$ billion RUB (≈ 0.05 %) – an estimate of the error in observing money supply, other errors estimates are small.

For an estimate of the departure of currency abroad, see Fig. 3. There, for comparison, the balance of currency flows during trading $0.856ex^t - 0.69im^t$ is given (actually inflow).

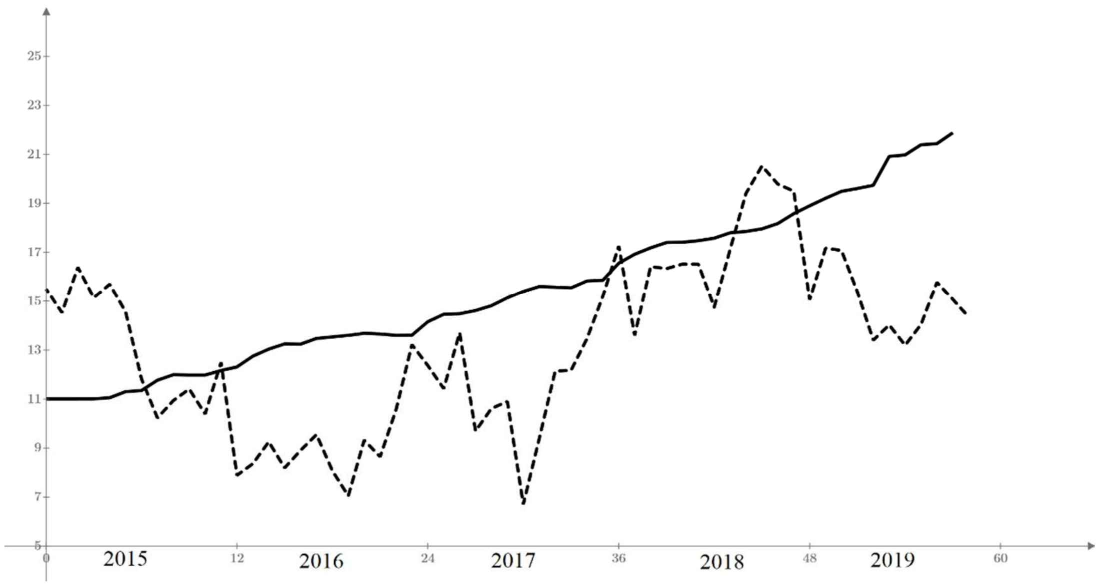

Figure 3. Indicators for the months from 01.2015 to 11.2019, \$ billion. Estimation of the departure of currency abroad DA^t (solid curve), the arrival of currency during trading (dashed curve).

The departure of currency abroad includes, in particular, voyages and trade in services (for example, according to the Central Bank of Russia in 2017 ≈ \$ 5 billion per month), tourism, acquisition of assets abroad, etc. One can notice a large outflow of foreign currency, not backed by trade in 2016 and 2019.

Ruble flows see in Fig. 4. There is also a negative balance of ruble flows in trade $(0.31im^t - 0.144ex^t)\frac{S^t + S^{t+1}}{2}$ (actually outflow).

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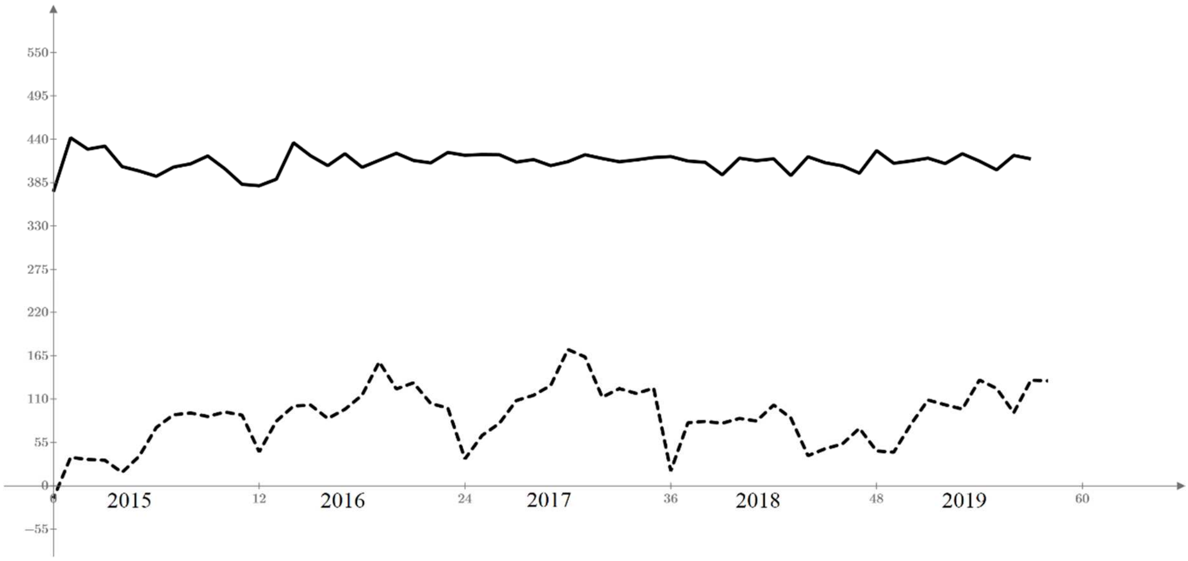

Figure 4. Indicators for the months from 01.2015 to 11.2019, billion RUB. Estimation of the creation of deposits and the arrival of rubles from outside (RA' - the solid curve), the departure of rubles during trading (the dashed curve).

The rubles leaving during trading are likely to return quickly, therefore, subtracting them from RA' (solid curve), we obtain an estimate of the creation of additional ruble deposits by banks (~ 300 billion RUB per month). See Fig. 5. For comparison, there are also shown (smoothed by a moving average with a window of 6 months) monthly changes in ruble deposits according to the data of the Central Bank of Russia [7].

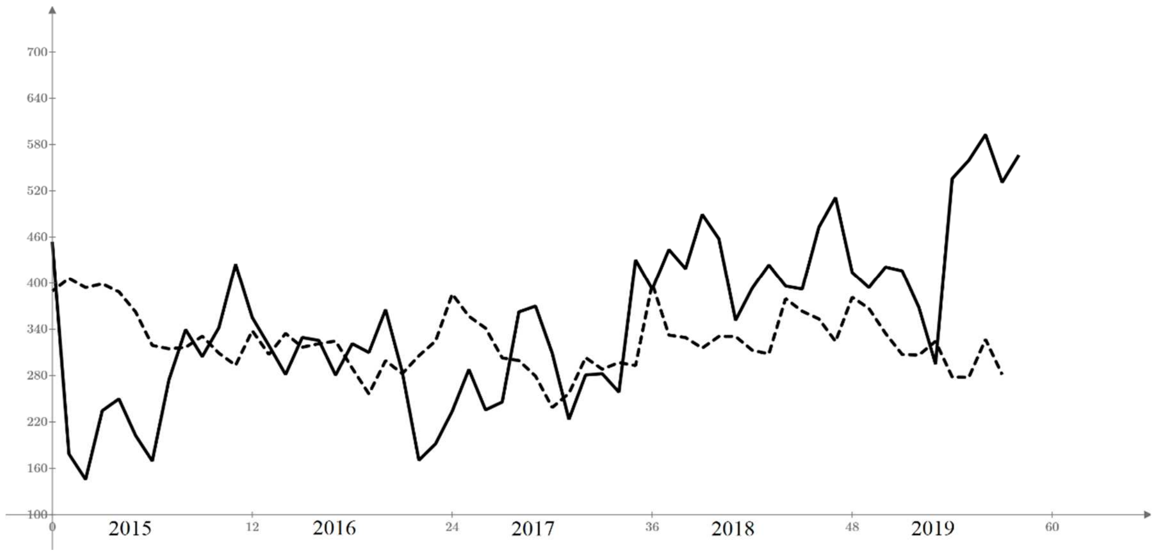

Figure 5. Estimation of monthly creation of additional deposits in rubles (dashed curve) and actual changes for the month of ruble deposits according to the Central Bank of Russia (continuous curve). Billion RUB.

In the crisis beginning of 2015, the failure of actual deposits is associated with an abnormal purchase of currency from abroad (as evidenced by the peak of the balance of the financial account of the Russia), at the end of 2019 the situation is the opposite.

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SIMULATION

The questions of the significance of estimates and the adequacy of the model when using the Kalman filter are not as simple as, for example, in regression analysis. In particular, since the filter forecast is heavily based on the known previous output, it will always be good, even with an unsuccessful model. This also applies to the dotted curves on Fig. 2. To check the adequacy of the model of the system, it is necessary to compare its functioning with the estimated parameters (simulation) with the behavior of the real system. To do this, we use the equations of dynamics (6) and (7) without noise elements, where the above estimated parameters β are substituted in the evolution and control operators. Start with the same initial state vector, controls – real ones (5).

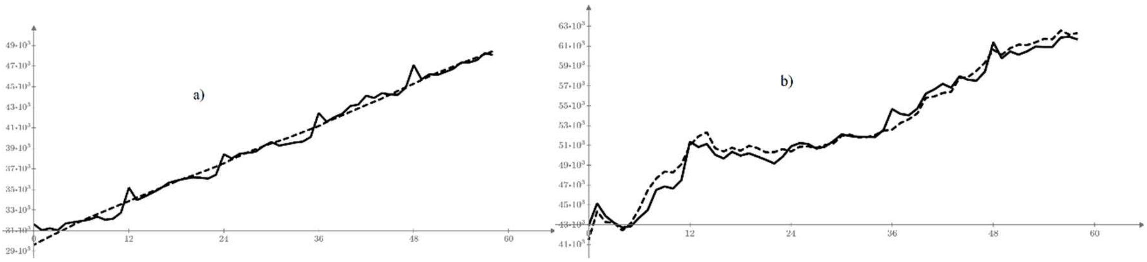

Figure 6. Comparison of real (solid curves) and simulated (dashed curves) financial indicators from 01.2015 to 12. 2019. a) $M2$, b) $M4$ (billion RUB).

A good (in general) coincidence of the curves in Fig. 6 allows us to make a conclusion about the adequacy of the proposed model to the real system. Differences (especially in currency deposits) require further clarification of the model.

CONCLUSION

The paper obtains evidence that the main drivers of cross-border flows of rubles and currency, in addition to trade, are the exchange rate of the ruble and the country's excess profits not taken into account in trade. Measures of their influence on the money supply in Russia have been found. In general, the picture looks like this. Trade (imports) carries away from the country about 100 billion RUB per month, which, apparently, are returned in the form of acquisition of Russian assets. Additional ruble deposits are created by banks for another 300 billion RUB a month. With the five-year average of $M2$ money supply in 38 trillion RUB, this leads to real inflation of 9.5% per annum. Trade (export) brings to the country about $ 15 billion a month, which go abroad for voyages and the purchase of services, tourism, the acquisition of assets abroad, etc. In fact, ruble and foreign currency deposits turned out to be economically unconnected, this explains some arbitrariness of the ruble exchange rate (surges in accordance with the level of psychological distrust of the ruble).

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