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APPROACHES TO MODELING CAPITAL OF COMMERCIAL BANKS IN THE DYNAMICS

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A mixed boundary value problem for partial differential equations of parabolic type was posed. It is based on the stochastic model accounts for the distribution of density in the accumulation of money and material space, which allows evaluating the bank's capital in the dynamics. A simulation model of the dynamics of the bank's capital was formulated in view of investing in risk-free assets in an inflationary environment. Approbation of the models was held on the base of the data of JSC "Bank Orenburg". The estimation of the financial risks of the bank was held.

Introduction

Commercial Bank is an active element of the market economy, the main purpose of which is the accumulation of funds and the provision of credits. The current financial and banking crisis clearly showed that even the largest banks in Russia which have a sufficiently large capital and fulfill all the requirements of Central Bank of Russia can fall into crisis situations and suffer losses, testing often insurmountable difficulties in settling accounts with debt and creditors. Most often, the failure to fulfill the obligations is connected with the lack of funds, so it is important to monitor the dynamics of the capital of commercial banks to know the moment of entry into the risk zone and prematurely proactively take steps to avoid this situation.

The study of financial management in the credit sector, certain issues about essence of cash flows and management has been the aim of the research of many foreign and domestic authors. As a rule, scientific papers on the topic include cash management issues in corporate structures more often than any other issues. In the works, which were written by Renner A.G., Lenert A.G. [1], was conducted a study evaluating the probability of reducing the volume of deposits of individuals, but wasn't study the dynamics of bank capital. In the works by Sitnikova A.Y. [2] Prokaza T.V. [3], Luchenko K. L. [4], Sorokina M. G. [5] were studied the bank's cash flows, but were not take into account the stochastic nature of inflows and outflows of cash, bank capital forming. In the paper by Turenova E. L. [6] was proposed a model of the dynamics of the company's capital at the Poisson flow receipt of funds, but was not take into account the specificity of capital formation in relation to banking. Based on all the above, the task of modeling the dynamics of the capital of a commercial bank is an actual and insufficiently elaborated.

1. A stochastic model of the dynamics of bank capital

Money and material accumulation on bank accounts are described as a system of stochastic differential equations (1) (similar to the description of the dynamics of family monetary and material accumulations [7]):

$$\begin{cases} dx = V_1 dt + dW; \\ dy = V_2 dt + dW_1, \end{cases} \tag{1}$$

where x – accumulations of money on bank account at moment of time *t*, rub.; *y* – material accumulations on bank account at moment of time *t*, rub.; *t* – time, month.; V_1 – the rate of change in the monetary accumulations on bank account, rub./ month.; V_2 –the rate of change in the material accumulations on bank account, rub./ month.; $\vec{W} = (W, W_1)$ – two-dimensional stochastic Wienerprocess.

To determine the V_1, V_2 consider the function $F(x,t)$ of the form:

$$F(x,t) = D(x,t) - R(x,t),\ \ D(x,t) \geq 0,\ \ R(x,t) \geq 0\,, \tag{2}$$

where $D(x,t)$, $R(x,t)$ – functions, which are describing the possible deterministic income and expense accounts, respectively.

Let the customer of the bank at time *t*puts into the account with the monthly rate α_i (in shares), monetary mass with the size of $x(t)$. Then the proceeds of the contribution is given by the expression

$$D_i(x,t) = \alpha_i\, x(t)\, \theta(x, x_0{}^i)\,, \tag{3}$$

where $\theta(x, x_0{}^i) = \begin{Bmatrix} 0, & npu\ x < x_0{}^i \\ 1, & npu\ x > x_0{}^i \end{Bmatrix}$, $x_0{}^i$ – the minimum amount of savings, which allows to make an investment in the bank, rub.

Customers make a choice between holdings based on the available funds in his account, and the account attractiveness, guided by the highest possible profit in the future. Characteristics of the deposits included in the model (JSC "Bank Orenburg"):

1. Deposit «Posterestante» (D_1): $\alpha_1 = 8{,}33*10^{-6}$; $x_0{}^1 = 5$.
2. Deposit «Savings» (D_2): $\alpha_2 = 6.25*10^{-3}$; $x_0{}^2 = 300$.
3. Deposit «Anniversary» (D_3): $\alpha_3 = 9.17*10^{-3}$; $x_0{}^3 = 1000$.
4. Deposit «Comfort» (D_4): $\alpha_4 = 9.58*10^{-3}$, $x_0{}^4 = 500000$
5. Deposit «Leader» (D_5): $\alpha_5 = 1*10^{-2}$; $x_0{}^5 = 3000000$.

Thus, the function $D(x,t)$ is:

$$D(x,t) = \begin{cases} 0, \ if \ \ x(t) < x_0^1 \\ D_i(x,t), \ \ x_0^i \le x(t) < x_0^{i+1}, \ i = 1,2..5, \ x_0^6 = \infty \end{cases}. \tag{4}$$

The next step is to consider the loans provided by the bank. Let γ_i is a monthly lending rate (in shares), n_i - lending period, month, $P^i_{\min}$ – the minimum amount of credit, rub., $P^i_{\max}$ – the maximum amount of credit, rub., $x(t)$ – the amount of the granted loan, $R_i(x,t)$ – accumulated at time *t* amount, including accrued interest:

$$R_i(x,t) = x(t) \cdot (1+\gamma_i)^{n_i}. \tag{5}$$

Characteristics of loan agreements included in the model are:

1. Credit "State" (R_0): $12 \le n_0 \le 120$, $0.0105 \le \gamma_0 \le 0.0181$, $P^0_{\min} = 10000$, $P^0_{\max} = 500000$.

2. Credit «Consumer» (R_1): $12 \le n_1 \le 60$, $0.0154 \le \gamma_1 \le 0.0229$, $P^1_{\min} = 10000$, $P^1_{\max} = 300000$.

3. Credit «Pension» (R_2): $12 \le n_2 \le 60$, $0.0105 \le \gamma_2 \le 0.0212$, $P^2_{\min} = 10000$, $P^2_{\max} = 500000$.

One client takes only one loan at the one period of time in the bank. Clients make their choice based on the minimum amount, which they will have to pay. Thus, the function R takes the form:

$$R(x,t) = \min R_i(x,t), \ P^i_{\min} < x(t) < P^i_{\max}. \tag{6}$$

As part of the material accumulations can eventually be converted in to cash savings (lease), then

$$V_1(x,y,t) = F(x,t) + D_d(y,t), \tag{7}$$

where $D_d(y,t) = q_1 \beta_1 y(t) \tilde{\theta}(y(t), y_2)$, if $y(t) > y_2$, then share β_1 from $y(t)$ converted at the rate of q_1 (in shares).

Since the material accumulation depreciated with time, then

$$U(y,t) = q_2 \ y(t) \tilde{\theta}(y(t),0), \tag{8}$$

where q_2 - the share of depreciation in a month.

Given the fact that a certain amount (β)of cash savings translates into the material accumulations:

$$V_2(x,y,t)dt = \beta F(x,t) - U(y,t). \tag{9}$$

We introduce the function density distribution of accounts in the space of monetary and material savings. Let ΔS - elementary area around the point (*x,y*), and value $\Delta Q(x,y,t)$ - the number of accounts on the area ΔS, then

$$u(x,y,t)=\lim_{\Delta S\to 0}\frac{\Delta Q(x,y,t)}{|\Delta S|} \quad (10)$$

From the stochastic system of differential equations (1) was the transition to the differential equation in partial derivatives (11):

$$\begin{aligned}\frac{\partial u}{\partial t} &= -\frac{\partial}{\partial x}\left(\left(c_1(x,y,t)+V_1(x,y,t)\right)u(x,y,t)\right)-\frac{\partial}{\partial y}\left(\left(c_2(x,y,t)+V_2(x,y,t)\right)u(x,y,t)\right)+\\ &+\frac{1}{2}\frac{\partial^2}{\partial x^2}\left(b_1(x,y,t)u(x,y,t)\right)+\frac{\partial^2}{\partial x\partial y}\left(b_{12}(x,y,t)u(x,y,t)\right)+\frac{1}{2}\frac{\partial^2}{\partial y^2}\left(b_2(x,y,t)u(x,y,t)\right)\end{aligned} \quad (11)$$

where vector c and matrix b are infinitesimal characteristics of the Wiener random process defined by [8] on the model: $\mathrm{d}\xi(\mathrm{t},\omega)=\Psi(\xi(\mathrm{t},\omega),\mathrm{t})\mathrm{dt}+\mathrm{G}(\xi(\mathrm{t},\omega),\mathrm{t})\mathrm{dW}(\mathrm{t},\omega)$, $\xi(0,\omega)=\xi_0(\omega)$ in accordance with the following relationships $\mathrm{c}(\mathrm{t},\omega)=\Psi(\xi(\mathrm{t},\omega))$, $\mathrm{b}(\mathrm{t},\omega)=\mathrm{G}(\mathrm{t},\omega)\cdot\mathrm{G}^{\mathrm{T}}(\mathrm{t},\omega)$.

Equation (11) is considered in $D=(0<t<T)\times(X\min<x<X\max)\times(Y\min<y<Y\max)$,

where *X*min, *X*max – left and right borders of monetary accumulations bank accounts, ruble.; *Y*min, *Y*max – left and right borders of material accumulations bank accounts, ruble., *T*– simulation horizon, month.

Initial conditions for modeling the dynamics of the bank's capital will be approximated roughly based on statistical data about the number of accounts with the given values of money and material accumulations in the initial time period of the research, in those areas, which will break the area D for the numerical solution:

$$u\big|_{t=0}=\varphi(x,y),\ x\in[X\min,X\max],\ y\in[Y\min,Y\max]. \quad (12)$$

We will accept boundary conditions equal zero because the number of accounts with the minimum and maximum possible monetary and material accumulation aspires to zero:

$$u\big|_{x=X\min}=0,\ u\big|_{x=X\max}=0,\ y\in[Y\min,Y\max]\ ,\ t\in[0,T] \quad (13)$$

$$u\big|_{y=Y\min}=0, u\big|_{y=Y\max}=0,\ x\in[X\min,X\max], t\in[0,T] \quad (14)$$

We will accept a function $u(x,y,t)$ satisfying to the equation (11), initial (12) and to boundary conditions (13)-(14) as the solution of a task (11-14).

The next step is passing to dimensionless variables:

$$\xi=\frac{x-X\min}{X\max-X\min},\ 0\le\xi\le 1;\ \eta=\frac{y-Y\min}{Y\max-Y\min},\ 0\le\eta\le 1;\ \tau=\frac{t}{T}, 0\le\tau\le 1 \quad (15)$$

we will pass from a task (11-14) to a task:

$$\frac{\partial\,\psi}{\partial\,\tau}=\frac{1}{T(X\,\text{min- Xmax})}\frac{\partial}{\partial\,\xi}((c_1(\xi,\eta,\tau)+V_1(\xi,\eta,\tau))\psi(\xi,\eta,\tau))+$$
$$+\frac{1}{T(\text{Y min- Ymax})}\frac{\partial}{\partial\,\eta}((c_2(\xi,\eta,\tau)+V_2(\xi,\eta,\tau))\psi(\xi,\eta,\tau))+$$
$$+\frac{1}{T(X\,\text{max- Xmix})^2}\frac{\partial^{\;2}}{\partial\,\xi^2}(b_1(\xi,\eta,\tau)\psi(\xi,\eta,\tau))+ \tag{16}$$
$$+\frac{1}{T(X\,\text{max- Xmin})(Y\,\text{max- Ymin})}\frac{\partial^{\;2}}{\partial\,\xi\,\partial\,\eta}(b_{12}(\xi,\eta,\tau)\psi(\xi,\eta,\tau))+$$
$$+\frac{1}{T(Y\,\text{max- Ymin})^2}\frac{\partial^{\;2}}{\partial\,\eta^2}(b_2(\xi,\eta,\tau)\psi(\xi,\eta,\tau))$$

$\psi\big|_{\tau=0}=\phi(\xi,\eta)=\varphi(\xi(X\max-X\min)+X\min,\eta(Y\max-Y\min)+Y\min)$, $\xi\in[0,1],\eta\in[0,1]$,

$\psi\big|_{\xi=0}=0$, $\psi\big|_{\xi=1}=0$, $0\le\eta\le1, 0\le\tau\le1$,

$\psi\big|_{\eta=0}=0, \psi\big|_{\eta=1}=0$, $0\le\xi\le1$, $0\le\tau\le1$,

where $\psi(\xi,\eta,\tau)=u(\xi(X\max-X\min)+X\min,\eta(Y\max-Y\min)+Y\min,\tau T)$,
$\psi(\xi,\eta,\tau)\in C^2(G)\cap C(\overline{G}), G=(0<\tau<1)\times(0<\xi<1)\times(0<\eta<1)$.

The problem was solved numerically by means of the Implicit-explicit finite difference method by the Crank-Nicolson method. As a result, we have the scheme which is always numerically stable and convergent, providing that $\Theta=0,5$. Parameter is characterizing the weight of implicit part of the final finite differences scheme.

If we know distribution density of accounts in space of money and material accumulations, it is possible to estimate the capital of the bank at every moment of the researched time period.

Approbation of the model was held on the base of the data of JSC "Bank Orenburg". Results of calculation of money supply of bank for the end of the third month are provided in figure 1.

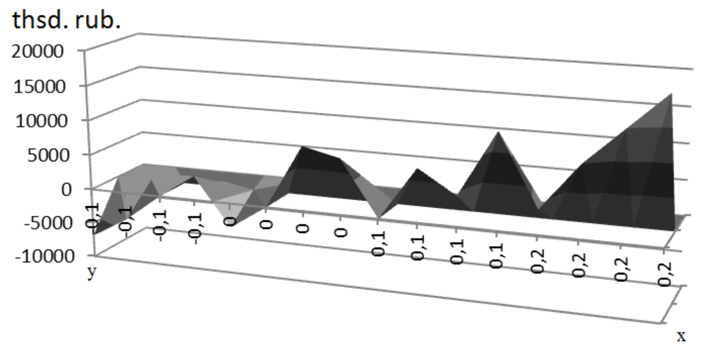

Fig. 1. Distribution of money supply of commercial bank (t=3 month)

Results of calculation of the capital of bank (total money supply) are provided in table 1.

Table 1

The size of the bank's capital at different times, rub.

Point of time, month	t=1	t=2	t=3	t=4	t=5
Bank’s capital, rub.	12197352	12518892	12652142	12974292	13227542

We can see that results of modeling have shown financial stability, i.e. the bank is far from the introduction in a risk zone which is understood as area in which the bank's capital is less than some critical value. If capital is less than critical value, then bank stops issuance of credits, but at the same time, is obliged to perform payments for deposits

2. Simulation modelling of dynamics of the bank's capital

The model offered in section 1 has a number of short comings: restrictions for the amount of monetary and material accumulations; it is supposed that the random factor is described by Wienerprocess. For elimination of these short comings, we will construct a simulation model of dynamics of the bank's capital.

Let bank's capital at the moment t (t=0,1…T), where T – the modeling period, depends on the capital in a preceding period, rates of inflation and rates of investment in risk-free assets. Capital outflow occurs at the expense of issuance of credits and payments for deposits. The capital inflow is created due to receipt of deposit deposits of physical persons and legal entities, settlement of the credits and percent on the credits by clients of bank. There is some critical value of the capital in case of which the bank ceases to issue the credits, but continues to work with the purpose of accumulation of the money. However at the same time, the bank is obliged to perform payments for deposits of clients. Thus, there are two cases in the model. First of them is when value of the capital in the previous time point is more critical and the second one is when value of the equity in the previous time point is less critical are provided in model. The bank's capital at the moment t will be created as the algebraic amount of the previous capital brought to current value of time and the current cash transactions performed in bank, taking into account the intensity of these operations.

There is information on intensity of banking operations, on the sizes of the issued credits, the amount of payments for deposits, the amounts which arrive in bank on account of clearing of accounts payable, and also about the sizes of deposit deposits. For creation of simulation model it is required that the parameters entering the model possessed property of stationarity. The analysis of initial information has shown that time series "The average amount of receipts according to the credit agreement" does not contain a trend and it is a stationary time series

For time series "The average amount of receipts on a deposit contribution", "The average amount of payments under the deposit contract", "The average size of the issued credit" was allocated a trend by methods of the regression analysis so that the remains after allocation of a trend were stationary. The trends of time series are:

$$f_D^{dep}(t) = 472432 - 74774{,}2 \cdot \ln(t),$$

$$f_R^{dep}(t) = 331641 - 50339 \cdot \ln(t), \quad f_R^{kr}(t) = 466000 - 3362{,}27 \cdot t,$$

where $f_D^{dep}(t)$ – trend of time series "The average amount of receipts on a deposit contribution" at the moment of time t; $f_R^{dep}(t)$ – trend of time series "The average amount of payments under the deposit contract "at the moment of time t; $f_R^{kr}(t)$ – trend of time series "The average size of the issued credit" at the moment of time t.

Then in the assumption of stationarity of remains after allocation of trends the simulation model of dynamics of the commercial bank's capital will take a form:

$$Y_t = \begin{cases} \frac{Y_{t-1}(1+r)}{(1+d)} + \sum_{i=1}^{\lambda_t^1}(f_D^{dep}(t) + D_{t,i}^{dep}) + \sum_{i=1}^{\lambda_t^2}(f_D^{kr}(t) + D_{t,i}^{kr}) - \\ \qquad - \sum_{i=1}^{\lambda_t^3}(f_R^{dep}(t) + R_{t,i}^{dep}) - \sum_{i=1}^{\lambda_t^4}(f_R^{kr}(t) + R_{t,i}^{kr}), \quad Y_{t-1} > Y^{kr} \\ \frac{Y_{t-1}(1+r)}{(1+d)} + \sum_{i=1}^{\lambda_t^1}(f_D^{dep}(t) + D_{t,i}^{dep}) + \sum_{i=1}^{\lambda_t^2}(f_D^{kr}(t) + D_{t,i}^{kr}) - \sum_{i=1}^{\lambda_t^3}(f_R^{dep}(t) + R_{t,i}^{dep}), \quad Y_{t-1} \le Y^{kr} \end{cases} \tag{17}$$

$$Y_0 = u, \quad t = 1,2..T,$$

where Y_t – the amount of capital the bank at the moment of time t; u – the size of the bank's capital at the initial time period of the study; r – compounding rate of capital; d – discount rate; $D_{t,i}^{dep}$ – the remains after the allocation of the trend for the i-th depositary deposit ($i = 0,1..\lambda_t^1$), entered in the t-th time point after the allocation of the trend time series "The average amount of receipts on a deposit contribution" ; λ_t^1 – random variable corresponding to the amount of deposits received in the t-th time point; $f_D^{kr}(t)$ – trend of time series "The average amount of receipts on a deposit contribution" at the moment of time t; $D_{t,i}^{kr}$ – the remains after the allocation of the trend for the i-th depositary deposit ($i = 0,1..\lambda_t^1$), entered in the t-th time point after the allocation of the trend time series "The average amount of receipts according to the credit agreement"; λ_t^2 – random variable corresponding to the amount of income on credit contracts in the t-th time point; $R_{t,i}^{dep}$ – remains after the allocation of the trend for the i-th deposit agreement ($i = 0,1..\lambda_t^3$),entered in the t-th time point after the allocation of the trend time series "The average amount of payments under the deposit contract"; λ_t^3 – random variable corresponding to the amount of income on credit contracts in the t-th time point; $R_{t,i}^{kr}$– remains after the allocation of the trend of time series "The average size of the issued credit" for the i-th loan agreement ($i = 0,1..\lambda_t^4$)in the t-th time point; λ_t^4 – random variable corresponding to the amount of loans issued in the t-th time point; Y^{kr} – the critical value of the bank's capital when the bank stops issuance of credits, but at the same time, the bank is obliged to perform payments for deposits of clients.

Computational experiment was held on the base of the data of JSC "Bank Orenburg". The analysis has shown that random variables λ_t^1, λ_t^2, λ_t^3, λ_t^4 are distributed under Poisson's.

The algorithm is developed for modeling of the equity of bank according to model (17). Similar algorithm is provided in work [8]. Also was developed the software which is allow to calculate bank's capital in dynamics on the basis of statistical data on the amount of receipts on the credits and deposits, the amount of payments for credit and deposit agreements.

The analysis of estimates of laws of the distributions of the equity of bank calculated for various number of imitations has shown that 50000 imitations are enough for achievement of the set degree of accuracy 0.01. Conducting of the retrospective prediction has showed that the model adequately describes the dynamics of the bank's capital. The relative deviation of the bank's capital from the expectation values of the modeled process is not more than 0.01.

By results of computing experiment the analysis of random variables "The size of the bank's capital in the time point *t*" was carried out. Histograms of empirical distribution densities of the bank's capital, for example, for *t=4* (1st month) and *t=8* (2nd month) are provided in the figure 2, the specified random variables are distributed normally.

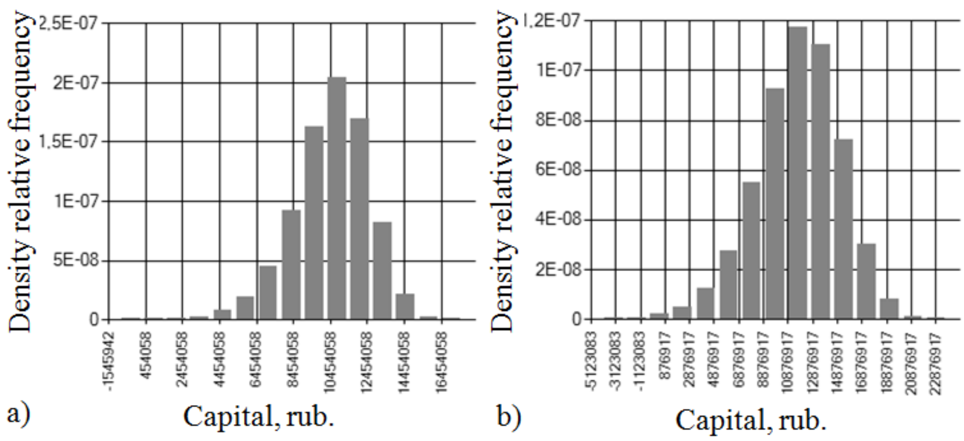

Fig. 2.The schedule of empirical distribution density of a random variable
a) "The size of the bank's capital for the end 4 weeks"
b) "The size of the bank's capital for the end of the 8 week"

Estimates of parameters of distribution of the size of the bank's capital is provided to various time points received as a result of modeling are shown in table 2.

We can notice that average size of the bank's capital is growing. The analysis of point estimates, for example, for the end of the first and second month, has shown that the average size of the capital in a month has increased practically by 1,5 million rubles. However, along with increase in an average also the mean-square deviation is growing, therefore by the end of the 12th week the risk of achievement of values of the capital below critical level increases grows: ($\rho(Y_4 < Y^{kr}) = 0{,}00006$; $\rho(Y_8 < Y^{kr}) = 0{,}00106$; $\rho(Y_{12} < Y^{kr}) = 0{,}0046$). The risk was estimated as the number of the imitations which have specified to values of the capital below of the critical level to total quantity of imitations.

The analysis has shown that the risk of an exit of values of the capital below critical level increases eventually, however on the researched interval he remains within 0,5% therefore, in general, the bank is far from the introduction into a risk zone and bank is capable to bear responsibility according to credit and deposit agreements. The specified coefficient can be used by bank as an introduction risk assessment in an unreliability zone where the zone of unreliability is understood as the size of the bank's capital of less then Y^{kr}. If the risk of the introduction in a zone of unreliability exceeds values, acceptable for the bank, the managing link needs to review financial policy of bank.

Table 2

Estimates of parameters of distribution of the size of the bank's capital in various time points, when *d*=0.0022, *r*=0.08, *u*=10 million rubles, Y^{kr}=0.5million rub.

Time point, *t*, week	Estimates of parameters of distribution of the size of the capital				
	Estimates of mathematical expectation of the bank's capital, rub.	Estimates of coefficient of variation	Estimates of mean-square deviation, rub.	Estimates of skewness	Estimates of kurtosis
1	10247582,99	2,988	68667,7	-0,150	2,138
2	10519708,94	3,944	104148,9	-0,059	1,230
3	10808323,97	4,448	134984,9	-0,010	0,727
4	11124362,38	4,738	165255,0	-0,026	0,512
5	11470094,20	5,101	204513,0	0,014	0,524
6	11833355,05	5,370	247470,2	0,048	0,512
7	12234330,47	5,516	292179,8	0,059	0,442
8	12658312,03	5,570	339188,5	0,064	0,396
9	13117357,03	5,668	396889,9	0,068	0,391
10	13612429,63	5,738	461892,6	0,056	0,372
11	14144130,32	5,772	534265,1	0,050	0,342
12	14728618,85	5,779	614963,0	0,045	0,333

Some distinctions in the results received in case of approbation of models (table 1, 2) are caused by the following reasons: in model (16) borders of range of definition of density of money and material savings are established, inflation and a possibility of investment of the equity are not considered; in model (17) material accumulations are not considered.

Conclusion

In work the dynamic model for distribution density of accounts in the space of monetary and material accumulations is offered in the form a mixed boundary value problem for partial differential equations of parabolic type. The numerical solution of the mixed regional task has allowed to receive distribution density of accounts in space of monetary and material accumulations and to find the bank's capital in every time point from the researched period. The given model requires a certain nature of capital allocation, besides in model there are restrictions for minimum and the maximum money savings on bank accounts.

The simulation model of dynamics of the commercial bank's capital offered in work is partly free from the specified shortcomings. It is considering four main cash flows: the income arriving under deposit agreements; the income arriving according to credit agreements; expenses under deposit agreements; the expenses connected with issuance of credits. Computational experiments were held. The offered model allows not only to estimate the bank's capital at a certain period of time but also and to collect descriptive statistics of values of the capital: estimates mathematical expectation of the bank's capital, mean-square deviation, coefficient of variation, skewness, kurtosis and others. On the base of the characteristics received as a result of modeling it is possible to draw a conclusion about financial stability of the bank, to estimate risk of the introduction at a zone of financial unreliability (a risk zone). For an introduction risk assessment in a zone of unreliability it is offered to use coefficient of risk of an exit of values of the capital below critical level.

The stochastic model of dynamics of the bank's capital should be used if there is information on nature of capital allocation of bank and its increments.

Otherwise, if it is possible to transform temporary ranks to a stationary type – it is recommended to use a simulation model of dynamics of the commercial bank's capital.

The offered models allow to solve actual problems of an assessment, the analysis and capital management of commercial bank, in particular, to research the size of the bank's capital in dynamics, to estimate risk of bankruptcy of bank, to develop the strategy of investment of means of bank to satisfy the level of acceptable risk.

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DEVELOPMENT OF TOOLS FOR PROCESSING BIG DATA

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