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Methods of simulation mathematical modeling of the Russian derivatives market in modern times*

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Методы имитационного математического моделирования российского срочного рынка на современном этапе***

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Introduction. The paper is devoted to simulation modeling. Basic methods of the simulation mathematical modeling in the derivatives market are described. A group of realistic non-Gaussian Levy processes that generalize the classical Black-Scholes model is considered. The work objective is to study the most efficient methods of market forecasting, as well as the software implementation of the simulation mathematical modeling technique of the Russian derivatives market based on the Levy model. This research is relevant due to the demand for applications that simulate the dynamics of financial assets and evaluate options in realistic models of the derivatives market, allowing for jumps.
Materials and Methods. Basic methods for forecasting the derivatives market, methods for determining the volatility rate at a known option price, are considered. The most effective types of Levy processes for the simulation mathematical modeling of the Russian derivatives market at the present stage are highlighted. The possibilities of the Java language for the implementation of mathematical methods are considered.
Research Results. A program is developed in the Java programming language that implements the Levy mathematical model, which includes Gaussian and generalized Poisson processes. The program for calculating the mathematical method is created in the free integrated application development environment NetBeans IDE to work with any operating system.
Discussion and Conclusions. The result of the simulation mathematical modeling analysis has shown that the most efficient methods in the derivatives market are those based on realistic non-Gaussian Levy processes. The software implementation of such mathematical methods can be used for educational purposes. The developed application has demonstrat-

Введение. Работа посвящена имитационному моделированию. Описаны основные методы имитационного математического моделирования на срочном рынке. Рассмотрена группа реалистичных негауссовских процессов Леви, которые обобщают классическую модель Блэка-Шоулса. Целью работы явилось исследование наиболее эффективных методов прогнозирования рынка, а также программная реализация метода имитационного математического моделирования российского срочного рынка, основанного на модели Леви. Данное исследование актуально в связи со спросом на приложения, позволяющие симулировать динамику финансовых активов и оценивать опционы в реалистичных моделях срочного рынка, допускающих скачки.
Материалы и методы. Рассмотрены основные методы прогнозирования срочного рынка, способы определения уровня волатильности при известной цене опциона. Выделены наиболее эффективные виды процессов Леви для имитационного математического моделирования российского срочного рынка на современном этапе. Рассмотрены возможности языка *Java* для реализации математических методов.
Результаты исследования. Разработана программа на языке *Java*, реализующая математическую модель Леви, включающую в себя гауссовский и обобщённый пуассоновский процессы. Программа для реализации математического метода создана в свободной интегрированной среде разработки приложений *NetBeans IDE* для работы с любой операционной системой.
Обсуждение и заключения. В результате анализа имитационного математического моделирования на срочном рынке наиболее эффективными являются методы, основанные на реалистичных негауссовских процессах Леви. Программная реализация таких математических методов может использоваться в учебных целях. Разработанное при-

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ed high quality and speed of calculations using software resources.

ложение показало высокое качество и скорость расчётов с помощью программных ресурсов.

Keywords: mathematical modeling, numerical method, volatility index, option, Levy process, classical Black-Scholes model, derivatives market, Gaussian process, generalized Poisson process.

Ключевые слова: математическое моделирование, численный метод, индекс волатильности, опцион, процесс Леви, классическая модель Блэка-Шоулса, срочный рынок, гауссовский процесс, обобщённый пуассоновский процесс.

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Introduction. A modern market economy cannot exist without an efficient operation of the financial market. Here, a special place is occupied by the primary market, which provides hedging the risks of an undesirable abrupt change in prices in the stock or currency markets. The Russian derivatives market is rapidly growing, attracting more and more investors. In this regard, there is a growing demand for software tools to simulate the dynamics of financial assets and evaluate options in realistic models that allow leap in prices.

In an explicit or implicit way, through processing the incoming information, each of the market participants can predict future price movements. That is, a trading system is an algorithm for converting various information into a forecast with certain levels of confidence. The system trader instructs the forecasting algorithm, discretionary/intuitive trader uses his experience/intuition. Due to the fact that any forecast has a probabilistic nature, some of the forecasts do not come true. A good forecast should be justified from the point of view of statistics, be representative and should use certain probabilities, patterns, cause-effect relations. The idea underlying the forecast should be rational and explainable.

Adequate modeling of the derivatives market allows participants to profit. Thus, the study of methods of simulation of mathematical modeling of the Russian derivatives market is of current interest, since it provides solving the problem of determining an adequate cost of the derivatives contract. The novelty of the study lies in the software implementation of simulation modeling of option pricing in the Merton model in *Java*. *Web*-based applications are of particular interest. *Java* is a natural language for solving this problem.

Materials and Methods. First of all, it is necessary to consider the most common methods for predicting the derivatives market behaviour. The research methodology is based on the study of various modeling methods of the Russian derivatives market and the selection of the most effective of them. The basic methods of market forecasting include:

- statistical;
- intuitive;
- modeling-based;
- Delphi method.

Technical analysis is a method for predicting a likely price change based on patterns presented in the form of similar price variation in the past under similar circumstances. That is, it can be argued that technical analysis uses statistical methods and certain models. The objects of forecasting can be various market characteristics: the direction of increments, increments, volatility, trending, etc. The object of forecasting depends on the idea with which the trader intends to profit from the market. Most processes on the derivatives market are stochastic, that is, their behaviour is not deterministic. The subsequent state of the market can be described by both quantities that can be predicted and random variables [1]. For example, the use of sentiment or patterns involves predicting direction and volatility, and the use of marketmaking involves predicting volatility and timing.

In the derivatives market, in addition to currency, there is a possibility of trading in securities and metals. When conducting operations with Russian securities, you should remember that their prices are constantly changing, and it is important to guess the right moment for their purchase and sale. This is a peculiarity of the operation with Russian securities.

Due to the instability of the economies of many countries, including Russia, there is a great opportunity to conclude a bad deal. In the derivatives market there is a concept of a relative strength index (RSI) with which you can determine the income from the transaction [2]. To calculate the growth rate of enterprise income, you can use DeMark's method, which is quite efficient for a technical analysis of the situation on the derivatives market. Under market fluctuations, the fundamental properties of deformed martingales will be important for calculating the spread in case of stock buybacks, since the best forecast for market behaviour in such cases is to study its current state [3]. The securities market of Russia and the United States is not the same, and when analysing income on the Russian market, a zero result can be obtained with respect to the American model. This is due to the fact that the sold securities on the Russian market may lose their value in a few minutes, in contrast to the American market, where the established rate for securities is kept for a long time. This trend indicates the stability of the company and the desire to stay as long as possible in the global currency market. But here it is necessary to consider the weight of the Russian currency market in world currency relations [4].

One of the main directions of generating income on the stock exchange is determining the exchange rate development. Each stockbroker seeks to develop his own forecasting method and put it into practice. There are many indicators suitable for calculation on the exchange, but one of the most common is the calculation of the moving average. According to this technique, the calculation is carried out for a certain period, while the simplest completed transactions are calculated, then at the intersection of the indicator with the current rate, the transaction is concluded. The method is quite reliable, but requires continuous monitoring. To make it easier to trace the change in the exchange rate, this method should be used for short periods of time [5].

There is a concept of a weighted moving average estimate, with the help of which the data are tracked recently, while the indicator smooths the fluctuation of the course. This strategy is similar to the previous one, and the data obtained using it are close to the data obtained using the calculation of the moving average. The advantage of this method is that you need to track trends only at latest.

The next method is an exponential moving average method. When using it, data from recent times and data from an earlier period are compared. This method calculates fewer profitable trades, but at the same time all trades are completed without risk of loss.

Price forecasting is possible, but only if there is a connection between their past values and future ones. This connection can indeed be observed during trends. Traders, observing the unidirectional change in prices, react accordingly and enter transactions in the direction of the trend, creating a positive relationship between changes in the past and in the future. When the market grows without corrections or grows in the channel, the bulk of speculators consciously buys, counting on a continuation, and by the very fact of purchases, the market provides further growth. A trend exists until the bulk of the trend-creating traders starts to make profits. An essential point for the continuation of the trend is the lack of counter-trend trading, that is, there should not be too massive pressure from market orders in the opposite direction. If the visible structure of the trend is violated, this can affect speculators who created this trend with their deals, which will lead to profit taking and stopping the trend.

Research Results. Among the existing methods of mathematical simulation and analysis of financial markets in the context of the Russian derivatives market, first of all, it is necessary to note a group of realistic non-Gaussian Levy processes that generalize the classical Black-Scholes model. The advantage of this group of processes is the ability to model leaps in the price of the underlying asset and a more realistic risk assessment. Thus, the methods of mathematical simulation and analysis of financial markets are based on Levy processes with a constant, local, and random diffusion component. There are also models that have stochastic volatility. Such are the models of Heston, Bates and Blasher [6].

Black-Scholes pricing model determines the theoretical price of European options. It implies that if the underlying asset is traded on the market, then the option price on it is implicitly set by the market itself [7]. The model is widespread and can be used in practice to analyse financial markets including urgent ones. According to this model, the main element in determining the value of an option is the expected volatility of the underlying asset. Thus, with the known value of the option, you can determine the level of volatility expected by the market [8].

The current value of the European *call C(S,t)* option at time *t* before its expiration corresponds to the following expressions:

$$C(S,t) = SN(d1) - Ke^{-r(T-t)}\,N(d2),$$

$$d1 = \frac{ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}};$$

$$d2 = d1 - \sigma\sqrt{(T-t)},$$

where S is the current price of the underlying share; $N(x)$ is the standard normal distribution function; K is the exercise price of the option; r is the risk-free interest rate; $(T - t)$ is the time until the expiration of the option term (option period); σ is the yield volatility (the square root of the variance) of the underlying stock.

The price of the European *put* option matches the expression:

$$P(S,t) = Ke^{-r(T-t)}N(-d2) - SN(-d1).$$

The random process $X = (Xt)$ $t \geq 0$, specified on the probability space (Ω, F, P) and taking values in the d-dimensional Euclidean space R^d1, s called the d-dimensional Levy process under the following conditions:

1. The process consists of trajectories that belong to a certain space D^d, consisting of vector functions, it is continuous on the right and has left limits.

2. For any $n \geq 1$ and the set $0 \leq t0 < t1 < \ldots < tn$, values $Xt0$, $Xt1–Xt0$, … , $Xtn–Xtn–1$ are independent.

3. The process is uniform in time. For any $s \geq 0$ and $t \geq 0$:

$$Xt + s - Xs = Xt - X0.$$

4. The process is stochastically continuous. For any $t \geq 0$ and $\varepsilon > 0$:

$$lim\, P(|Xs - Xt| > \varepsilon) = 0,$$
$$s - t.$$

5. $X0 = 0$.

In case of a finite Levy measure, the processes are:

• Gaussian;

• generalized Poisson;

• Merton model;

• Coe model.

Levy processes with an infinite number of jumps at any time interval have a Levy measure Π with the property $\Pi(R) = \infty$. Such processes are actively used in modeling financial markets. Here we can highlight:

- variance gamma (VGP);
- hyperbolic (HP);
- generalized hyperbolic (GHP);
- normal inverse Gaussian (NIG);
- normal moderately stable (NTS);
- KoBoL or CGMY processes.

Levy processes provide modeling asset price dynamics as flexibly as possible because they contain two components: Brownian motion (process diffusion) and spasmodic component [9]. Currently, there are many models based on Levy processes that successfully operate on the price dynamics of various assets and are used in the pricing of options, as they are martingales. Levi-Ito decomposition breaks Levy processes into simple components and helps to understand their nature. Such decomposition is the basis for modeling Levy processes using the sum of two components: the Brownian motion and the composite Poisson process. Such a structure of the stochastic process is called jump-like diffusion and has the following form [10]:

$$Xt = yt + \sigma Bt + \sum_{i=1}^{Nt} Yi,$$

where Bt is Brownian motion; Nt is the Poisson process, which counts the number of jumps of the process X by the time t; Yi are independent identically distributed random values of jumps.

Two extreme examples of the case of a finite Levy measure are the Gaussian and generalized Poisson processes. If Levy processes combine both of the above processes, then they are called jump diffusion. The most interesting models of this kind are the Merton model and the Coe model [10]. To speed up the calculations and maintain visualization, the authors have developed an application in the *Java* programming language that provides the implementation of these models.

In *Java*, the whole code is stored as classes. Thus, typing a source file with the *java* extension, it is compiled into a new bytecode file. Due to the fact that *Java* is designed to execute bytecode, the programs written in this language work at a rather high speed [11].

The whole calculation under the compilation will consist of several *java* files. In one of them, we carry out calculations of the Levy process with jumps. This file will perform the final calculation from all other files. In one of the *java* files, we will implement the Black-Scholes formula (Listing 1), which will be required in the future.

Listing 1: Black-Scholes formula implementation

```
public static double normcdf(double z) {
      if (z <= -7.0)
            return 0.0;
      else if (z >= 7.0)
            return 1.0;
      else {
            double pi = 3.141592653589793;
            double b1 = -0.0004406;
```

```
            double b2 =  0.0418198;
            double b3 =  0.9;
      return 1.0 / (1.0 + exp(-sqrt(pi)*(b1*pow(z,5.0) + b2*pow(z,3.0) +
b3*z)));
      }
}
// Black Scholes call or put price
public static double BSPrice(double S,double K,double r,double q,double v,double
T,char PutCall) {
      double d1 = (log(S/K) + (r-q+v*v/2.0)*T)/v/sqrt(T);
      double d2 = d1 - v*sqrt(T);
      double BSCall = S*exp(-q*T)*normcdf(d1) - K*exp(-r*T)*normcdf(d2);
      if (PutCall=='C')
            return BSCall;
      else
            return BSCall - S*exp(-q*T) + K*exp(-r*T);
}
}
```

In two other *java* files, we calculate an abstract process that describes the generation of a sequence of prices over time. That is, in one *java* file, the explicit option price formula is calculated, which considers the initial price, trend and volatility (the formulas for calculating the prices of options $C(S,t)$ and $P(S,t)$ are given above), in another *java* file, Merton simulation of hopping diffusion occurs. The hopping diffusion formula takes into account that the jumps will be normally distributed.

Having developed the program interface, after compilation, we obtain an application for quick and convenient calculation based on random number generation. Similarly, a data set is generated at each start (Fig. 1, 2).

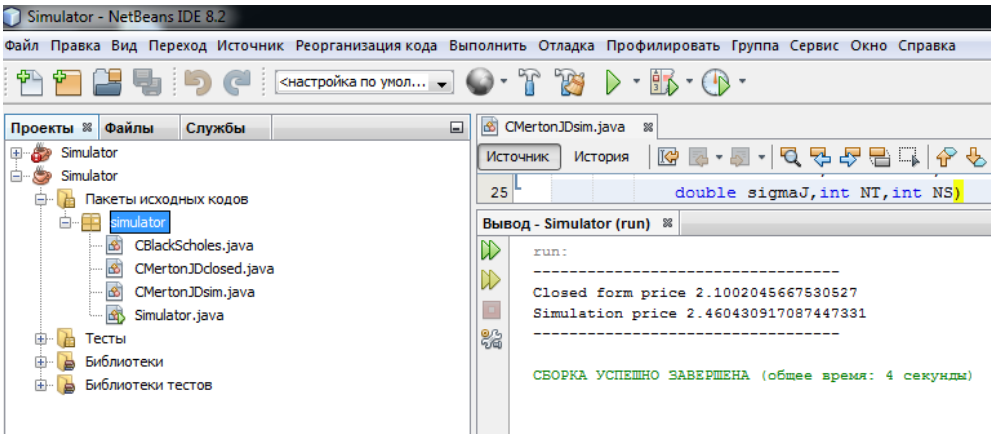

Fig. 1. The first program start

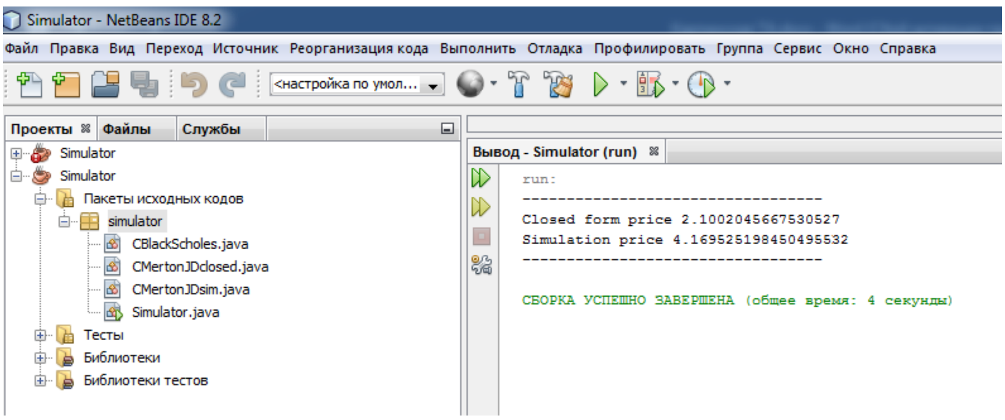

Fig. 2. The second program start

When the program was first launched, the simulation price was much closer to the explicit option price formula. Thus, in the second case, it was possible to sell the option more profitably than in the first case. After numerous calculating the program, you can predict other options for buying or selling an option. Here, it is necessary to consider all possible factors that can affect the market. Let us run the program ten times, the calculation results of which are presented in Table 1.

Table 1

Results of tenfold start of the program

No.	*Closed form price*	*Simulation price*
1	2.1002045667530527	2.460430917087447331
2	2.1002045667530527	4.169525198450495532
3	2.1002045667530527	2.472669282703422532
4	2.1002045667530527	1.065976524175292432
5	2.1002045667530527	1.119330912080574833
6	2.1002045667530527	2.687540413685037333
7	2.1002045667530527	1.184835796571303834
8	2.1002045667530527	4.53211404384426131
9	2.1002045667530527	8.00388383946741132
10	2.1002045667530527	1.685687889204974432

The simulation shows possible scenarios in the derivatives market and allows you to evaluate losses. Accordingly, selling an option is most profitable in the ninth case with *Simulation price* equal to 8.00388383946741132. Based on this forecast, the option holder can get the most profit from the transaction. To buy an option, the best forecast occurs in the fourth case with *Simulation price* equal to 1.065976524175292432.

Thus, *Closed form price* is the ideal price, and *Simulation price* is the price set by the market, which considers its volatility and leaps. Thus, you can distribute your limits on the market, predicting the size of losses and incomes.

First, the explicit option price formula (real price) *Closed form price* is calculated (Listing 2). It gives the mathematical expectation of the payment of an option, that is, it takes into account all possible options for the development of events. Next, we write the cells we need to implement the formula.

Listing 2: explicit option price formula

```
{     // Expected jump value
      double kappa = exp(muJ + 0.5*sigmaJ*sigmaJ) - 1.0;
      // Initialize the price
      double Price = 0.0;
      double sigman,rn,BSPrice,lambda,Probability;
      for (int n=0; n<N; n++) {
            sigman = sqrt(sigma*sigma + n*sigmaJ*sigmaJ/T);
            rn = r - lambdaJ*kappa + n*log(1.0+kappa)/T;
            BSPrice = CBlackScholes.BSPrice(S0,K,rn,q,sigman,T,PutCall);
            lambda = lambdaJ*(1.0+kappa);
            Probability = exp(-lambda*T) * pow(lambda*T,(double)n)/factorial(n);
            Price = Price +  Probability*BSPrice;
      }
      return Price;
}
```

After that, the program implements a simulation of Merton jump-diffusion (Listing 3). *Simulation price* characterizes the option price depending on some simulation trajectory. Methods for generating numbers for an abstract process are contained directly in files with implementable processes, as, for example, when calculating an explicit option price formula. To implement market leaps, we use a random number generator.

Listing 3: Merton jump-diffusion simulation

```
public class CMertonJDsim {
    public static  double JDsim(char PutCall,double S0,double K,double rf,
            double q,double sigma,double T,
```

```
            double lambdaJ,double muJ,
            double sigmaJ,int NT,int NS)
{     // Time increment
      double dt = T/NT;
      // Random number generator and set the seed
      Random rng = new Random();
      // Define the distributions
      double poissrnd = poissonRandomNumber(lambdaJ*dt);
      double N01 = normalDestribution(0.0,1.0);
      double Nus = normalDestribution(muJ - 0.5*sigmaJ*sigmaJ,sigmaJ);
      // Expected value of k, and drift term
      double kappa = exp(muJ) - 1.0;
      double drift = rf - q - lambdaJ*kappa - 0.5*sigma*sigma;
      // Initialize the stock price paths and the payoff
      double Payoff = 0;
      //vector<vector<double> > S (NT,vector<double> (NS));
        double[][] S = new double[NT][NS];
      // Perform the simulation
for (int s=0; s<NS; s++) {
      S[0][s] = S0;
      for (int t=1; t<NT; t++) {
            double J = 0.0;
            if (lambdaJ != 0.0) {
                  int Nt = (int) poissonRandomNumber(rng.nextGaussian());
                  if (Nt > 0)
                        for (int i=0; i<Nt; i++)
                              J += (int) normalDestribution(0,1);
                  }
                  double Z = normalDestribution(0,1);
                  S[t][s] = S[t-1][s]*exp(drift*dt + sigma*sqrt(dt)*Z + J);
            }
            // Calculate the payoffs
            if (PutCall == 'C')
                  Payoff = Payoff + max(S[NT-1][s] - K, 0.0);
            else if (PutCall =='P')
                  Payoff = Payoff + max(K - S[NT-1][s], 0.0);
      }
      return exp(-rf*T)*(Payoff/NS);
    }
    static double poissonRandomNumber(double lambda) {
        double L = Math.exp(-lambda);
        int k = 0;
        double p = 1;
        do {
            k = k + 1;
            double u = Math.random();
            p = p * u;
        } while (p > L);
        return k - 1;
    }
    static double normalDestribution(double s, double m) {
            // create random object
            Random rand = new Random();
            // generating integer
            double nxt = rand.nextGaussian();
```

```
            return nxt * s + m;
      }
}
```

Having performed the simulation several times, from the received *Simulation price*, you can choose the average value that will illustrate the jumps in the price of options. As a result, the closer *Closed form price* value is to one of the *Simulation price* values, the more favourable the price for buying options.

Discussion and Conclusions. The practical result of the study is a developed application that simulates market jumps and implements a complex mathematical formula. The considered model of Levy processes, including the Gaussian and generalized Poisson processes, is an effective method for calculating the most important characteristics of financial risk. It provides decision-making on the implementation of a particular trading strategy using contracts on the Moscow Exchange. The study results indicate that the Merton model of jump diffusion chosen for the application development is an effective method of mathematical simulation. This application can be used to train personnel in markets with exchange risks. The calculations show the price that the market sets. It considers all possible scenarios, as well as possible option price variation, according to which it is possible to determine profit or loss. Using such calculation, a derivatives market participant can make the most profitable decision to buy an option if the simulation shows a price lower than the market price or for sale when the simulation price is the highest.

It is established that the *Java* programming language can be leveraged when creating high-quality applications for calculating on exchanges; it reduces the time on mathematical calculations and simplifies the operation with exchange calculations. At the same time, *Java Virtual Machine* is an analogue of a virtual computer located in RAM and interpreting byte code. All actions of the *Java* program are closed inside this virtual computer in such a way that there is a possibility to prevent their destructive actions.

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