BROWNIAN MOVEMENT OF STOCK QUOTES OF THE COMPANIES LISTED ON THE BUCHAREST STOCK EXCHANGE AND PROBABILITY RANGES

BRĂTIAN Vasile[1]

"Lucian Blaga" University, Sibiu, Romania

Abstract
This paper aims to generate evolutions in continuous time of quotes for five companies listed on the Bucharest Stock Exchange, the first category, and determining ranges of probability where you can find these quotes in the future (one month, three months, six months). In this sense, the quotes of listed shares are considered random variables of continuous type and the model used to generate evolutions is the most accepted model for equities, currencies, indices.

Key words: *evolution of stock quotes in continuous time, brownian movement, probability ranges*

JEL classification: *C02, C13, G,17*

1. Introduction

The evolution of stock quotes is held by financial theory as a random evolution. In other words, the stock quote for a company is considered to be of the nature of a random variable. Random variables are those variables that can take different values after repeating the experience, being generated by accidental causes, even if conditions remain unchanged, and which are well

[1] *Associate professor / Ph.D. , Faculty of Economic Sciences / Department Finance and Accounting, bratianvasile@yahoo.com*

defined if there are known values that they can take and their afferent probability.

Random variables are of two categories:

- discrete random variables, for which they are known the different values they can take, and the probability of occurrence of them is one punctual, attached to each value;
- continuous random variables, for which they are not known the different values they can take, and the probability of occurrence of them can be established only on a certain range.

Between the two above categories, the most used category to characterize the stock quote is the second, respectively it is considered that the share price is a random variable of continuous type. In this sense, for modeling the evolution of stock quotes, it requests, for the most part, the stochastic equations of movement in continuous time.

That said, our approach aims to present the equation of movement of the stock quotes in continuous time, generate evolutions on this movement equation and establish probability ranges, at different intervals, for shares of five companies listed on the Bucharest Stock Exchange, the first category.

2. Methodology

The most used model for assessing financial assets that we find in financial practice is the evaluation model in continuous time, whose formal expression is (Wilmott, 2002, p. 75):

$$dC = \mu C dt + \sigma C dB \quad (1)$$

where:
C = quote of financial asset;
dC = differential of quote of financial asset;
dt = differential of time;
dB = brownian; variable extracted from the normal distribution of zero mean and variance dt;
μ = expected return of financial asset corresponding total time (drift);
σ = volatility of financial asset corresponding total time.

It is known that the movement of the stock quote follows an evolution that is subject of the log-normal rule and therefore, if we consider the function *F* with the following property $F = F(C) = lnC$ and develop in Taylor series, the differential of function F is given by the following expression:

$$dF = d(lnC) = \frac{dF}{dC}dC + \frac{1}{2}\frac{d^2F}{dC^2}dC^2 \qquad (2)$$

The above expression is similar to Ito lemma, but with the difference that instead of *dt* we have dC^2.

The use of heuristics $dC^2 = dt$ is proposed and discussed by Paul Wilmott (Wilmott, 2007, pp. 157 – 158). In this respect, it states that although the reasoning is lacking rigor, the result is correct.

Referring to this heuristic, John Weatherwax describes as (Weatherwax, MIT, 2008, p. 7):

$$\begin{aligned} dC^2 &= (a(C,t)dt + b(C,t)dB)^2 = \\ &= a(C,t)^2dt^2 + 2a(C,t)\,b(S,t)\,dtdB + b(C,t)^2dB^2 = \\ &= b(C,t)^2dt \end{aligned} \qquad (3)$$

Returning, if $dC = \mu Cdt + \sigma CdB$ is the equation that satisfies *C*, using heuristics $dC^2 = \sigma^2C^2dt$ and if the function *F* is defined with the property $F = lnC$, knowing that $\frac{dF}{dC} = \frac{1}{C}$ and $\frac{d^2F}{dC^2} = -\frac{1}{C^2}$, then:

$$\begin{aligned} dF &= d(lnC) = \frac{dF}{dC}dC + \frac{1}{2}\frac{d^2F}{dC^2}dC^2 = \\ &= \frac{1}{C^2}(\mu Cdt + \sigma CdB) + \frac{1}{2}\left(-\frac{1}{C^2}\right)\sigma^2C^2dt = \\ &= \frac{1}{C}\mu Cdt + \frac{1}{C}\sigma CdB - \frac{1}{2C^2}\sigma^2C^2dt = \\ &= \mu dt + \sigma dB - \frac{1}{2}\sigma^2dt = \\ &= \left(\mu - \frac{1}{2}\sigma^2\right)dt + \sigma dB = \\ &\left(\mu - \frac{1}{2}\sigma^2\right)dt + \sigma Z\sqrt{dt} \end{aligned} \qquad (4)$$

Expression (4) can be integrated and we obtain the following equation of movement (Weatherwax, MIT, 2008, p. 9):

$$\ln C(t) - \ln C(0) = \left(\mu - \frac{1}{2}\sigma^2\right)t + \sigma(B(t) - B(0)) \,, \qquad (5)$$

and the solution for *C(t)* is:

$$C(t) = C(0)\exp\left[\left(\mu - \frac{1}{2}\sigma^2\right)t + \sigma(B(t) - B(0))\right] \qquad (6)$$

where:
B(t) is a Gaussian process;
$B(t) - B(0) = Z\sqrt{t}$;
$Z \sim N[0,1]$.

Or for a time step *(Δt),* the movement equation for the quote of financial asset is:

$$C(t + \Delta t) = C(t) + \Delta t = C(t)\exp\left[\left(\mu - \frac{1}{2}\sigma^2\right)\Delta t + \sigma Z\sqrt{\Delta t}\right] \qquad (7)$$

Given the fact that at the initial moment the quote of financial asset is *C(0)*, then its return for a certain period until the moment *t*, in the future, is given by the following expression:

$$\ln\frac{C(t)}{C(0)} \qquad (8)$$

and will have the following normal distribution:

$$\ln\frac{C(t)}{C(0)} \sim N\left[\left(\mu - \frac{1}{2}\sigma^2\right)t, \sigma\sqrt{t}\right] \qquad (9)$$

That said, because the logarithm of the quote of financial asset is normally distributed, it can be determined a confidence interval for *C(t)*. Thus, with a probability of 99%, the future quote of financial asset, at the moment *t*, varies within the following limits:

$$C(0)exp\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right] \le C(t) \le C(0)exp\left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right] \quad (10)$$

3. Empirical results

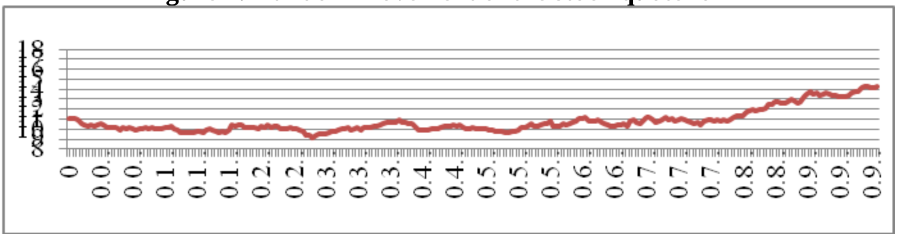
In the following, using our methodology described above, we generate evolutions in stock quotes of five companies listed on the first category of the Bucharest Stock Exchange and determine the ranges of probability where these quotes may be in the future (a month, three months, six months), after the period of analysis.

Companies selected by us, five in number, on the first category of the Bucharest Stock Exchange are: Groupe Societe Generale *(BRD);* S.N.G.N. Romgaz SA *(SNG);* OMV Petrom SA *(SNP);* S.N.T.G.N. Transgaz SA *(TGN);* Banca Transilvania SA *(TLV).*

For our analysis we considered the year of 252 trading days; period of analysis: 23. 10. 2014 – 23. 10. 2015.

a) Random movement of the stock quote for *BRD*, after the period of analysis, and ranges of probability (one month, three months, six months) are as follows:

Figure 1: Random movement of the stock quote for BRD



Source: own calculations

From the period of analysis, for *BRD*, we have:

- Stock quote on 23.10.2015: 11 lei
- $\mu = 0{,}3072504$
- $\sigma = 0{,}2310309$

Logarithm of the future stock quote for *BRD* is normally distributed as follows:

$$ln\frac{C(t)}{C(0)} \sim N\left(\left(\mu - \frac{1}{2}\sigma^2\right)t, \sigma\sqrt{t}\right)$$

Then:

$$P\left(\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right] \leq ln\frac{C(t)}{C(0)} \leq \left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right]\right) \rightarrow$$
$$\rightarrow P\left(C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]}\right) = 99\%.$$

As a result, the probability ranges where the stock quote of *BRD* may be after 1 month, 3 months and six months, after the period of analysis (*t = 0,0833, t = 0,25, t = 0,5)*, with a probability of 99%, replacing the data in the above equation, are:

a. *t = 0,0833*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 11e^{-0{,}1486623} \leq C(t) \leq 11e^{0{,}195404} \rightarrow 9{,}48 \leq C(t) \leq 13{,}37$$

b. *t = 0,25*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 11e^{-0{,}2278892} \leq C(t) \leq 11e^{0{,}3681704} \rightarrow 8{,}75 \leq C(t) \leq 15{,}89$$

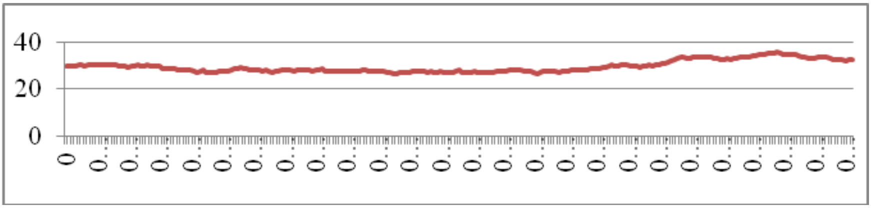
c. *t = 0,5*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 11e^{-0{,}2811965} \leq C(t) \leq 11e^{0{,}5617591} \rightarrow 8{,}30 \leq C(t) \leq 19{,}29$$

b) Random movement of the stock quote for *SNG*, after the period of analysis, and ranges of probability (one month, three months, six months) are as follows:

Figure 2: Random movement of the stock quote for SNG



Source: own calculations

From the period of analysis, for *SNG*, we have:

- Stock quote on 23.10.2015: 29,45 lei
- $\mu = -0{,}1701816$
- $\sigma = 0{,}1693282$

Logarithm of the future stock quote for *SNG* is normally distributed as follows:

$$ln\frac{C(t)}{C(0)} \sim N\left(\left(\mu - \frac{1}{2}\sigma^2\right)t, \sigma\sqrt{t}\right)$$

Then:

$$P\left(\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right] \le ln\frac{C(t)}{C(0)} \le \left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right]\right) \rightarrow$$
$$\rightarrow P\left(C(0)e^{\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right]}\right) = 99\%,$$

As a result, the probability ranges where the stock quote of *SNG* may be after 1 month, 3 months and six months, after the period of analysis (*t = 0,0833, t = 0,25, t = 0,5)*, with a probability of 99%, replacing the data in the above equation, are:

a. *t = 0,0833*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 29{,}45e^{-0{,}1414576} \le C(t) \le 29{,}45e^{0{,}110717} \rightarrow 25{,}56 \le C(t) \le 32{,}89$$

b. *t = 0,25*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 29{,}45e^{-0{,}2645627} \le C(t) \le 29{,}45e^{0{,}1723039} \rightarrow 22{,}60 \le C(t) \le 34{,}98$$

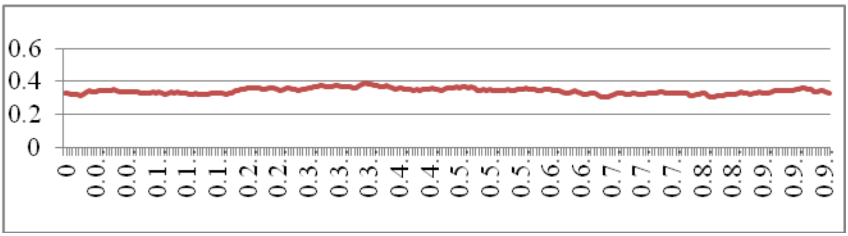
c. *t = 0,5*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 29{,}45e^{-0{,}4011702} \le C(t) \le 29{,}45e^{0{,}2166526} \rightarrow 19{,}71 \le C(t) \le 36{,}57$$

c) Random movement of the stock quote for *SNP*, after the period of analysis, and ranges of probability (one month, three months, six months) are as follows:

Figure 3: Random movement of the stock quote for SNP



Source: own calculations

From the period of analysis, for *SNP*, we have:

- Stock quote on 23.10.2015: 0,3295 lei
- $\mu = -0{,}2860057$
- $\sigma = 0{,}2243552$

Logarithm of the future stock quote for *SNP* is normally distributed as follows:

$$ln\frac{C(t)}{C(0)} \sim N\left(\left(\mu - \frac{1}{2}\sigma^2\right)t, \sigma\sqrt{t}\right)$$

Then:

$$P\left(\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right] \leq ln\frac{C(t)}{C(0)} \leq \left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right]\right) \rightarrow$$
$$\rightarrow P\left(C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]}\right) = 99\%.$$

As a result, the probability ranges where the stock quote of *SNP* may be after 1 month, 3 months and six months, after the period of analysis (*t = 0,0833, t = 0,25, t = 0,5)*, with a probability of 99%, replacing the data in the above equation, are:

a. t = 0,0833

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 0{,}3295e^{-0{,}1929829} \leq C(t) \leq 0{,}3295e^{0{,}1411415} \rightarrow 0{,}2716 \leq C(t) \leq 0{,}3794$$

b. t = 0,25

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 0{,}3295e^{-0{,}3672115} \leq C(t) \leq 0{,}3295\,e^{0{,}2116249} \rightarrow 0{,}2282 \leq C(t) \leq 0{,}4071$$

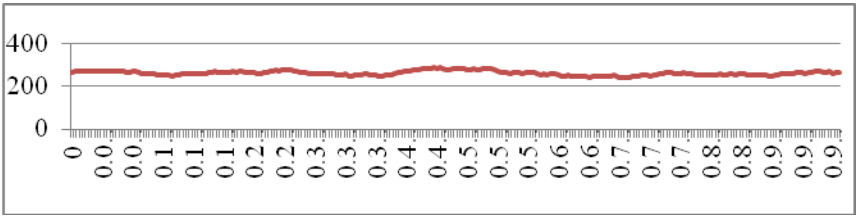
c. t = 0,5

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 0{,}3295e^{-0{,}5648857} \leq C(t) \leq 0{,}3295\,e^{0{,}2537125} \rightarrow 0{,}1872 \leq C(t) \leq 0{,}4246$$

d) Random movement of the stock quote for *TGN*, after the period of analysis, and ranges of probability (one month, three months, six months) are as follows:

Figure 4: Random movement of the stock quote for TGN



Source: own calculations

From the period of analysis, for *TGN*, we have:

– Stock quote on 23.10.2015: 265 lei
– $\mu = 0{,}1253335$
– $\sigma = 0{,}1810374$

Logarithm of the future stock quote for *TGN* is normally distributed as follows:

$$ln\frac{C(t)}{C(0)} \sim N\left(\left(\mu - \frac{1}{2}\sigma^2\right)t, \sigma\sqrt{t}\right)$$

Then:

$$P\left(\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right] \leq ln\frac{C(t)}{C(0)} \leq \left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right]\right) \rightarrow$$
$$\rightarrow P\left(C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \leq C(t) \leq C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]}\right) = 99\%,$$

As a result, the probability ranges where the stock quote of *TGN* may be after 1 month, 3 months and six months, after the period of analysis (*t = 0,0833, t =*

0,25, t = 0,5), with a probability of 99%, replacing the data in the above equation, are:

a. *t = 0,0833*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 265e^{-0{,}1257312} \le C(t) \le 265e^{0{,}1438816} \rightarrow 233{,}69 \le C(t) \le 306$$

b. *t = 0,25*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 265e^{-0{,}2607747} \le C(t) \le 265e^{0{,}2607747} \rightarrow 204{,}17 \le C(t) \le 343{,}95$$

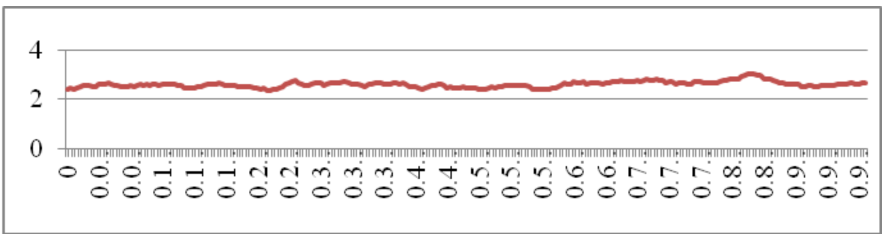
c. *t = 0,5*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 265e^{-0{,}2757997} \le C(t) \le 265e^{0{,}3847459} \rightarrow 201{,}12 \le C(t) \le 389{,}34$$

e) Random movement of the stock quote for *TLV*, after the period of analysis, and ranges of probability (one month, three months, six months) are as follows:

Figure 5: Random movement of the stock quote for TLV



Source: own calculations

From the period of analysis, for *TLV*, we have:

- Stock quote on 23.10.2015: 2,42 lei
- $\mu = 0,4642714$
- $\sigma = 0,2518782$

Logarithm of the future stock quote for *TLV* is normally distributed as follows:

$$\ln\frac{C(t)}{C(0)} \sim N\left(\left(\mu - \frac{1}{2}\sigma^2\right)t, \sigma\sqrt{t}\right)$$

Then:

$$P\left(\left[\left(\mu - \frac{1}{2}\sigma^2\right)t - 2{,}58\sigma\sqrt{t}\right] \le \ln\frac{C(t)}{C(0)} \le \left[\left(\mu - \frac{1}{2}\sigma^2\right)t + 2{,}58\sigma\sqrt{t}\right]\right) \rightarrow$$
$$\rightarrow P\left(C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]}\right) = 99\%,$$

As a result, the probability ranges where the stock quote of *TLV* may be after 1 month, 3 months and six months, after the period of analysis (*t = 0,0833*, *t = 0,25*, *t = 0,5)*, with a probability of 99%, replacing the data in the above equation, are:

a. *t = 0,0833*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 2{,}42e^{-0{,}1515253} \le C(t) \le 2{,}42e^{0{,}2235881} \rightarrow 2{,}07 \le C(t) \le 3{,}02$$

b. *t = 0,25*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 2{,}42e^{-0{,}2167853} \le C(t) \le 2{,}42e^{0{,}4330603} \rightarrow 1{,}94 \le C(t) \le 3{,}73$$

c. *t = 0,5*

$$C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t-2{,}58\sigma\sqrt{t}\right]} \le C(t) \le C(0)e^{\left[\left(\mu-\frac{1}{2}\sigma^2\right)t+2{,}58\sigma\sqrt{t}\right]} =$$

$$= 2{,}42e^{-0{,}2432353} \le C(t) \le 2{,}42e^{0{,}6757853} \rightarrow 1{,}89 \le C(t) \le 4{,}75$$

4. Conclusions

The table below summarizes the probability ranges of the stock quotes for the analyzed companies and the real quote (observed) on the Bucharest Stock Exchange for dates 22.11.2015 (one month), 22.01.2016 (three months) and 22.04.2016 (six months). As you can see, all quotes are within the ranges of probability calculated.

Table 1: The probability ranges of the stock quotes and the real quotes (observed)

No. crt.	Companies	The probability ranges of the stock quotes	Real stock quote (observed) on BSE
1	BRD	1 month: $9{,}48 \le C(t) \le 13{,}37$	12,62 lei
		3 months: $8{,}75 \le C(t) \le 15{,}89$	10,4 lei
		6 months: $8{,}30 \le C(t) \le 19{,}29$	10 lei
2	SNG	1 month: $25{,}56 \le C(t) \le 32{,}89$	29,10 lei
		3 months: $22{,}60 \le C(t) \le 34{,}98$	24,2 lei
		6 months: $19{,}71 \le C(t) \le 36{,}57$	24,6 lei
3	SNP	1 month: $0{,}2716 \le C(t) \le 0{,}3794$	0,31 lei
		3 months: $0{,}2282 \le C(t) \le 0{,}4071$	0,2505 lei
		6 months: $0{,}1872 \le C(t) \le 0{,}4246$	0,2330
4	TGN	1 month: $233{,}69 \le C(t) \le 306$	267 lei
		3 months: $204{,}17 \le C(t) \le 343{,}95$	260 lei
		6 months: $201{,}12 \le C(t) \le 389{,}34$	270 lei
5	TLV	1 month: $2{,}07 \le C(t) \le 3{,}02$	2,6050 lei
		3 months: $1{,}94 \le C(t) \le 3{,}73$	2,32 lei
		6 months: $1{,}89 \le C(t) \le 4{,}75$	2,65 lei

Source: own calculations

5. References

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