DEVELOPMENT OF FORECASTING MODEL FOR CRYPTOCURRENCY EXCHANGE RATE DYNAMICS USING STOCHASTIC ANALYSIS TOOLS

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Abstract: Accelerated rates of the crypto currency market development and its integration into the system of economic, operational, financial and other processes determine the need for a comprehensive study of this phenomenon. Particularly actual is the fact that discussions at the state level on the prospects of legalization of the crypto currency market and the possibilities of using its instruments in the economic activities of economic agents have intensified in recent months. Despite at times polar views and approaches that have been formed among Russian experts at the moment regarding the solution of this issue, the development of cryptology is extremely rapid regardless of its regulation. This causes and actualizes the conduct of scientific research in the field of assessing the prospects for the development of this market in order to predict possible effects and risks for the national economic system. Part of this paper is devoted to the solution of these questions aimed at finding methodical approaches to forecasting the dynamics of the crypto currency market development based on the "foresight" of future fluctuations in the value of "digital money" using special economic and mathematical tools.

Key words: crypto currency market, bitcoin, stochastic analysis, forecasting, autoregression models.

1 Introduction

Today there is a deep transformation of the traditional money and finance world. Innovations in the financial sector, new technologies, tools and systems entail serious and profound changes in habitual financial institutions. One of the most important stages of these transformation processes was the emergence of crypto-currencies accompanied by the rapid development of related technologies and the lack of a clear picture of the future landscape of ecosystems.

For today, various states demonstrate an ambiguous attitude to crypto-currencies. Some countries consider bitcoin as a commodity, the latter as a digital asset, others are recognized it as a currency. However, despite the uncertain legal status, most crypto-currencies are inherent in some functions performed by monetary units. For example, the most common crypto currency "bitcoin" to date can be used as a means of payment, as a measure of value, and also as a means of accumulation (Cheah & Fry, 2015; Sulkarnaeva et al, 2018).

Integration of the global crypto currency market into the economic turnover of national economies significantly transforms the usual regulatory mechanisms. The growth of the crypto currency market increases the pressure on monetary circulation, which accordingly affects the national economy as a whole. In this regard, it seems relevant to study the main directions that limit or, on the contrary, expand the range of regulation of financial markets and the development of the national payment system due to the integration of business processes into a "crypto space". The feasibility of this study is largely due to the fact that any violation of institutional reality based on traditional regulatory instruments may entail certain consequences, such as the violation of financial stability, which will undoubtedly affect the development of real sectors of economy (Elshin & Abdukaeva, 2017).

It should be noted that at the current time, even despite the exponential growth of the global crypto currency market in recent years, many economists and statesmen consider its influence on macroeconomic and financial stability as insignificant. The basis of this approach is the extremely low volume of the crypto currency market in the overall balance of the payment system. For example, in the Russian Federation, the weekly turnover of Bitcoin is only 0.006% of cash and 0.001% of the money supply (Elshin & Abdukaeva, 2017).

At the same time, in the foreseeable future, a scenario is likely to include a further activation of the market under investigation and its multi-structural integration into national economic systems, which makes it necessary to pay special attention to this issue today from the scientific and expert community. A significant contribution to the accelerated growth in the capitalization of the global crypto currency market can be made not only by its popularization as a progressive tool used in transactions, but also by the further growth of the exchange rate (as a result of the factor expressed in the limited emission of crypto currency (for example, Bitcoin emission is limited to 21 mln. units), and due to speculative processes as a result of speculative operations in crypto-exchanges (Nakamoto, 2008).

In connection with the foregoing, at the current time it is extremely urgent to search for and develop a special toolkit that allows us to anticipate and forecast adjustments to exchange rates of modern "digital money".

For the sake of justice, it should be noted that at the current moment in the scientific publishing space it is extremely rare to find works devoted to this topic. Mostly questions are of a research nature and aimed either at an expert assessment of current and forthcoming prospects for the development of the market under consideration, or on the use of special methods of exchange technical analysis that reveals the features and trends of exchange rate fluctuations of "digital money".

At the same time, it seems expedient within the framework of scientific research activities to use special methods of economic and mathematical modeling that involve the use of progressive tools and mechanisms.

The absence of a monetary body authorized to maintain the stability of the monetary system leads to a strong volatility in the crypto currency rate. The rate relative to fiat money is formed exclusively due to the demand and supply for the crypto currency; therefore, the daily fluctuations of the exchange rate can exceed 25% (Bouoiyour & Selmi, 2015; Villalobos Antúnez, 2016).

This adversely affects its use as a settlement currency in trading transactions and generates motivation for speculation. In addition, predicting a change in the exchange rate is a very nontrivial task: using a fundamental analysis for prediction of the volatility of exchange quotations is ineffective, since the rate does not depend on the economy of a particular country; the use of technical analysis is also ineffective, because it is impossible to determine the state of the market due to the formation of demand and supply caused by individuals' willing to buy or sell certain products or services around the world (Bariviera et al, 2017).

2 Methodology

In our opinion, one of the most effective mechanisms for predicting time series is the use of autoregressive moving average models (ARMA, ARIMA). This approach is particularly relevant in the absence of effective tools for forecasting exchange rate fluctuations of this kind for "financial assets" characterized by uneven fluctuations of rates over time, the absence of a "binding" to underlying assets, high level of speculative demand, and so on.

ARMA and ARIMA models are an important class of parametric models that allow describing both stationary and non-stationary series. The aim of this paper is to determine an autoregression model and the integrated moving average with the minimum number of parameters on the basis of which reliable short-term forecasts can be made.

The empirical and expert analysis has demonstrated the expediency of using bitcoin as the object of research. This is due to a number of reasons, the main ones of which are presented below:

- The dominant share in the total world capitalization of crypto-currencies (about 45%) [1]
- The most popular crypto currency, the fluctuations in the rate of which completely determine the volatility of the absolute majority of other types of crypto currencies in the market.

Returning to questions of methodological nature, it should be noted that the use of the models considered in the work involves the implementation of five major iterations:

1. Construction of time series
2. Checking the series for stationarity (as a result, the class of the model used is ARMA or ARIMA).
3. Selection of model parameters
4. Estimation of reliability and adequacy of the constructed model

Development of forecast parameters of the time series under study.

The modeling process applied to the object of research considered in this paper, is presented below with a detailed description of the sequence of solved iterations.

The calculations were carried out for data reflecting the dynamics of the "bitcoin" crypto currency exchange rate. The series describes the cost of bitcoin in the period from 01.10.2016 to 18.03.2018. (Fig 1) The source of the data was the virtual bitcoin wallet service "Blockchain.info" [2]. The calculations were carried out using the forecast analytical software Eviews and IBM SPSS.

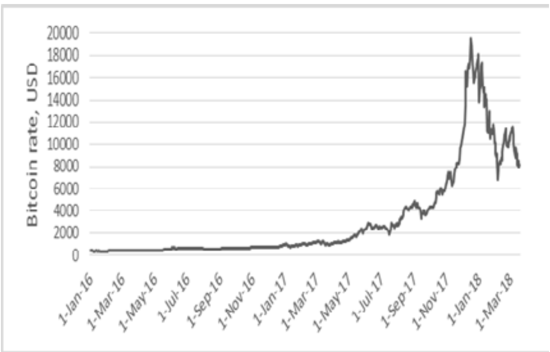

Fig 1. Dynamics of the change in the rate of crypto currency "Bitcoin" in the period from 01.10.2016 to 04.03.2018 in USD

Modeling of stationary time series, or series which can be reduced to stationary ones, can be performed using the autoregressive moving average class models (ARMA) which is a combination of two models: an autoregression of order p and a moving average of order q. In the generalized form. For non-stationary data, Box and Jenkins proposed the ARIMA model (p, d, q), which after taking d consecutive differences can be reduced to a stationary form (Box, & Jenkins, 1994), where , , q are the structural parameters characterizing the order for the corresponding parts of the models - autoregressive, integrated and moving average.

The model selection methodology consists of several stages.

[1] https://coinmarketcap.com/coins/
[2] Virtual bitcoin wallet service URL: https://blockchain.info/ru/

3 Model identification

At the initial stage of the study, it is necessary to find out whether the series under study has the property of stationarity.

The stationary series is a series which behavior and properties in the present and future coincide with the behavior in the past.

The stationarity of the series can be estimated using various methods. The basic methods for checking the stationarity of a time series are Dickey-Fuller extensions, and also the construction of an autocorrelation function (ACF) and a partial autocorrelation function (PACF). The calculation of the autocorrelation function is performed using the following formula:

$$\rho_k = \frac{\gamma_k}{\gamma_0} = \frac{cov(k)}{var} = \frac{cov(y_t; y_{t-k})}{var(y_t)};\ |\rho_k| \leq 1$$

A partial autocorrelation function (PACF) is defined as a particular correlation between the values y_t and y_{t-k} – "purified" from the influence of intermediate variables on them (Kantorovich, 2002). For the initial series, the autocorrelation function and the partial autocorrelation function were constructed (Fig 2).

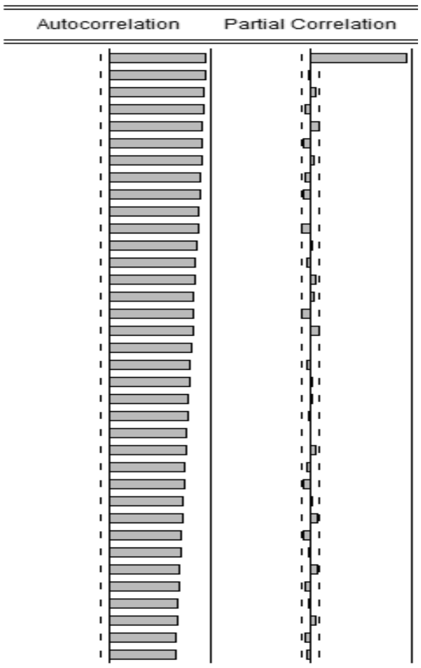

Fig 2. Autocorrelation function ((Autocorrelation) and partial autocorrelation function (Partial Correlation)

The autocorrelation function constructed is characterized by a slow decrease in the autocorrelation function coefficients over the decaying exponential from the value of the coefficient close to 1. The partial autocorrelation function has a high autocorrelation coefficient on the first lag, and values close to 0 on subsequent lags.

Thus, we can conclude that the initial time series is nonstationary.

In addition to visual analysis, an extended Dickey-Fuller test (ADF test) was carried out to verify the stationarity of the time series. The test consists in testing the null hypothesis about the presence of a unit root in the equation:

$$y_t = \alpha y_{t-1} + \varepsilon_t$$

The decision on the stationarity of the time series is adopted in the case when the calculated estimates of the test are greater than the observed statistics t_{obs} ($t_{crit} > t_{obs}$). The test results are shown in Table 1.

Table 1. Results of The Adf Test

		T-statistic	Prob.*
Augmented Dickey – Fuller Test Statistic		-0.742350	0.8334
Test Critical Values:	1 % level	-3.444158	
	5 % level	-2.861522	
	10 % level	-2.570019	

* Machinnon (1996) One – Sided P- Values

For the test series under study t_{obs} = -0.74. Since the values obtained with different importance levels (1, 5 and 10%) have values less than $t_{obs,}$ then the hypothesis of nonstationary time series is accepted.

Thus, the simulation of the bitcoin crypto currency rate was carried out based on the autoregressive integrated moving average (ARIMA) model.

4 Criteria for selecting model parameters

After selecting a model, you need to choose the corresponding parameters. After taking the first difference, the original series was reduced to a stationary form, so the parameter d = 1.

To simulate the dynamics of the change in the crypto currency rate, the following models were tested: ARIMA (1,1,1), ARIMA (1,1,2), ARIMA (2,1,0) ARIMA (2,1,1), ARIMA (2,1, 2).

The basis for choosing the model was the functions constructed by autocorrelation function and partial autocorrelation function, as well as the calculated Akaike criterion (3) and the Bayesian information criterion (4).

These criteria allow choosing the best model from the group of candidate models. The advantage is given to the model, the values of AIC and BIC of which are minimal. The calculation is made by the following formulas:

$$AIC = ln\hat{\delta}^2 + \frac{2}{n}r,$$

$$BIC = ln\hat{\delta}^2 + \frac{\ln n}{n}r$$

Where $\hat{\delta}^2$-a residual sum of squares divided by the number of observations,

r is the total number of terms in the ARIMA model.

The results of the calculation are shown in Table 2.

Table 2. Model selection based on AIC and BIC criteria

	AIC	**BIC**
ARIMA (2,1,1)	12,162,015	12,19668655
ARIMA (2,1,2)	12,086,669	12,13,000,837
ARIMA (1,1,2)	12.163773	12,19844515
ARIMA (1,1,1)	12,166,205	12,19220874
ARIMA (2,1,0)	12,181,602	12,20760531

The ARIMA model (2, 1, 2) has the minimum BIC and AIC criteria.

Thus, the final model took the following form:

$$\Delta X = 32{,}3 - 1{,}329\Delta X_{t-1} - 0{,}585\Delta X_{t-2} - 1{,}602\varepsilon_{t-1} - 0{,}845\varepsilon_{t-2} + \varepsilon_t$$

Qualitative estimates of the obtained model parameters are given in Table 3

Table 3. Model parameter estimates

	Coefficient	**Standard error**	**t-stat.**	**p-value**
C	32,328	8,913	3,627	0
AR	-1.329	0.01	-16.595	0
	-0.585	0.029	-7.4	0
d	1			
MA	-1.602	0.04	-29,523	0
	-0.845	0.04	-15,742	0

5 Getting forecast values

With the help of the received model, the bitcoin crypto currency rate was forecast for 10 points ahead. The prediction results are shown in Fig 3.

Fig 3. The forecast values of the bitcoin rate obtained with ARIMA (2, 1, 2)

Indicators which indicate the quality of the model obtained are given in Table 4.

Table 4. Qualitative characteristics of the model

Statistics	Average value
Stationary R-Squared	0.871
R-Squared	0.999
RMSE	165.93
MAPE	4,182
MaxAPE	39.607
MAE	102,682
MaxAE	634,788

6 Results and Discussion

The reliability and adequacy of the results obtained were confirmed by comparing the actual and forecast parameters of the bitcoin rate, and also proceeding from high R-squared value (Fig 4).

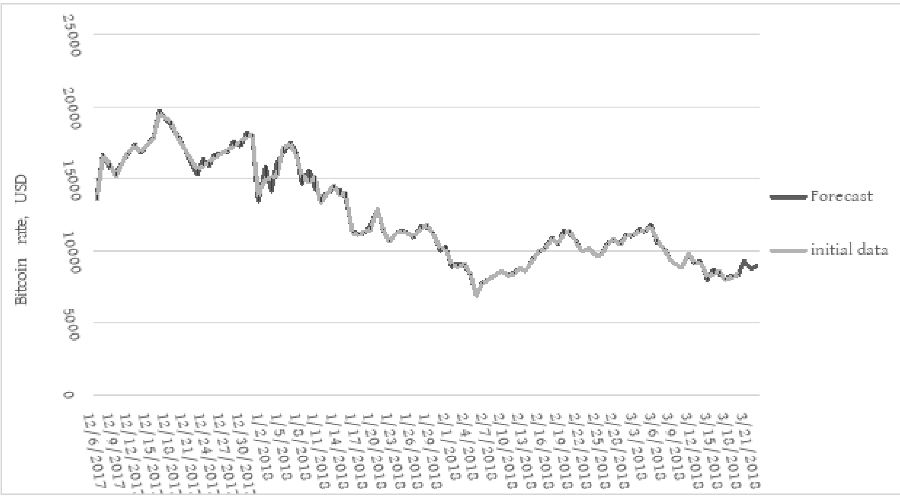

Fig 4. Convergence of forecast and actual data estimating bitcoin / USD exchange rate

As can be seen from the presented graph, the forecast values describe the forthcoming corrections with high accuracy, which is confirmed by the extremely high level of the forecast daily trend change. At the same time, undoubtedly, there are also minor discrepancies between the absolute values of the series, what is completely permissible and falls within the scope of the forecast error (Mustafina et al, 2017).

The obtained results in many respects testify to the prospects of the chosen forecasting tool based on the use of autoregressive algorithms and integrated moving average. However, it should be noted that the model constructed requires further improvement. So, for example, it seems appropriate to apply models of stochastic volatility in connection with the high variability of the study series (Vranken, 2017). Undoubtedly, given the extremely low (if not to say rudimentary) level of the crypto currency market development in the Russian Federation in terms of commodity turnover support it should be noted that at the current time there is a low level of demand on the part of the business community for this kind of model. However, taking into account the dynamically growing speculative demand in the crypto currency market, and also relying on the increased activity of state regulators in the sphere of legalization of the crypto currency market in the Russian Federation for some time past, the interest and importance to this kind of methodological tools is becoming increasingly important. It is enough to note that only in 2017 a whole series of large-scale research projects on this subject was implemented, for example, such studies as "Scenario modeling of the development of the Russian currency market in the Russian Federation and its impact on the development prospects of settlements for air transport services" in the activities of PJSC Aeroflot, and the "Legislative regulation of the introduction and practical application of modern financial technologies". Undoubtedly, such an intensification of activity on the problem posed is due in large part to the fact that at the end of 2017 the President of the Russian Federation approved the assignment to the Government of the Russian Federation in the field of regulation of the crypto currency market in the national economy. In January 2018, the Ministry of Finance jointly with the Central Bank developed and published a draft federal law "On Digital Financial Assets".

7 Conclusions

Taking into account the above-mentioned, as well as the methodological approaches proposed in the study, the possibilities of regulation of the crypto currency market by the state authorities are greatly expanded, and also they form stable bases for modeling and forecasting financial stability of the national economy due to its integration into the global system of "digital money".

8 Summary

Summing up the realized estimations and the developed methodical toolkit, it is necessary to note a very high level of its perspective within the framework of modeling of business processes based on the use of crypto transactions. This is due, first of all, to the urgent need to understand and predict exchange rates of the crypto currency, since its use in economic circulation forms very high risks of financial losses of economic entities caused by its significant volatility.

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Literature:

1. Cheah E.T., Fry J. (2015). Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin. Econom. Lett. 130, pp.32–36.
2. Elshin L.A., Abdukaeva A.A. (2017). Financial Instruments for Activization of Business Activity: Features and Prospects. Problem of Risk in the Current Crisis Conditions of the World Economy, pp.74-77.
3. Elshin L.A., Abdukaeva A.A. (2017). Possibilities of accelerating business activity of economic agents on the basis of crypto-transactions. Methods, mechanisms and factors of international competitiveness of national economic systems, pp. 88-91.
4. Nakamoto S. (2008). Bitcoin: A peer-to-peer electronic cash system. Bitcoin.org. URL: https://bitcoin.org/bitcoin.pdf
5. Bouoiyour J., Selmi, R. (2015). Bitcoin price: Is it really that new round of volatility can be on way? Munich Pers. RePEc Arch. 6558 (August). https://mpra.ub.uni-muenchen.de/id/eprint/65580.Bariviera A.F., Basgall M.J., Hasperué W., Naiouf M. (2017). Some stylized facts of the Bitcoin market. Physica A 484, pp.82–90.
6. Box J., Jenkins G. (1994). Time series analysis. Forecast and Management. Moscow: Mir.
7. Kantorovich G.G. (2002). Lectures: Analysis of time series. Economic Journal of the Higher School of Economics, pp.379-400.
8. Mustafina A.A., Kaigorodova G.N., Pyrkova G.K., Alyakina D.P. Syvorotkina K.A. (2017). Sanatorium and resort treatment as a factor of economic development in the Republic of Tatarstan. Astra Salvensis, 2(1), pp. 267–276.
9. Vranken H. (2017). Sustainability of bitcoin and blockchains. Current Opinion in Environmental Sustainability, 28, pp. 1-9.
11.Villalobos Antúnez J.V. (2016). Hipótesis para un derecho alternativo desde la perspectiva latinoamericana, Opción, 32(13), pp. 7-10.
12. Sulkarnaeva G.A., Khairullina L.B., Bulgakova E.V. (2018). Hygienic and ergonomic design aspects of production systems, Astra Salvensis, Supplement No. 1, pp. 609-616.