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Translated Article†

SETTING THE STOCHASTIC MODEL FOR MID-TERM PREDICTION OF CRYPTOCURRENCY EXCHANGE RATE: THE BITCOIN CASE

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Abstract

Importance The article discusses the process of economic and mathematical modeling of time series describing the volatility of the bitcoin exchange rate through the Autoregressive Moving Average (ARMA) models.

Objectives We search for, and substantiate tools and mechanisms used to predict the cryptocurrency market developments.

Methods The research applies tools of stochastic analysis of stationary and non-stationary time series.

Results The ARIMA models provide for rather precise estimates of current and future changes in the digital money rates for a three to four month's time.

Conclusions and Relevance The bitcoin price will have approximated USD 11,000 by the end of Q3 2018. The methodological approaches to modeling help determine not only future trends, but also changes in exchange rates throughout the entire analyzable period. The findings provide empirical information for cryptocurrency market regulators and business community.

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Nowadays the habitual world of money and finance undergoes profound transformations. Innovation in finance, new technologies, tools and systems dramatically reshape conventional financial constructs. The origination of cryptocurrencies is one of the crucial milestones in such transformation. This process concurs with the energetic development of related technologies. However, the future landscape of the ecosystems is very foggy.

There are about 100 cryptocurrencies today. Some of them are of high capitalization, while the others resemble a *soap bubble*. For example, the bitcoin market capitalization has reached USD 322 billion. It approximated USD 27 billion in Q1 2017[1].

Notwithstanding rather a vivid dynamism of the digital money market in 2017, the legal nature of cryptocurrency is not equal in most countries. Some countries treat it as digital currency, while the others argue that cryptocurrencies could be regarded as money or currency, handling it like goods, intangible assets, medium of exchange [1].

Like money, cryptocurrencies serve as a medium of exchange in the market. They are currently used to pay for goods and services or transfer funds, i.e. as a medium of payment or exchange[2]. However, although many market actors do so to buy or sell goods and services, few of them recognize cryptocurrency as a unit of account.

In the mean time, some cryptocurrency market actors involve cryptocurrencies in their speculative schemes, making short- and long-term investments and profiteering from exchange transactions. As long as they exist, cryptocurrencies and bitcoin, in particular, generally proved to be profitable items to invest in, winning an increasing confidence of the public[3] [2–5]. Therefore, cryptocurrencies work for saving purposes of the above group of market actors, allowing them to have additional earnings in the future.

It is still worth mentioning that the cryptocurrency market is highly volatile, though the exchange rate is very expected to grow due to the limited issue of cryptocurrency. High volatility is registered not only in stock exchange, but also predicted by respectable experts. For instance, according to an interview with one of the bitcoin developers, this cryptocurrency has not yet ceased to be more than an experiment[4]. Jamie Dimon, top executive of J.P. Morgan Chase, expresses his skepticism about cryptocurrencies, calling bitcoin *a fraud*. Warren Buffett warned that bitcoin is a *mirage*[5].

Despite skeptical views on the cryptocurrency market, demand for financial instruments based on crypto-transactions remains stable and even gains momentum. The global community and national regulators demonstrate an increasing interest in the instrument, thus reinforcing the legitimacy of the cryptocurrency market worldwide.

To understand how countries treat cryptocurrency and scrutinize the legal status worldwide, we performed a respective analysis showing the position of cryptocurrencies per each quarter starting from 2013 through 2017 across 26 countries.

We referred to the following system of points to determine the position of cryptocurrencies:

–1 is assigned in the case of negative attitude to cryptocurrencies/total prohibition;

0 is assigned when the status of cryptocurrency is indefinite;

[†]For the source article, please refer to: Сафиуллин М.Р., Ельшин Л.А., Абдукаева А.А. Разработка стохастической модели среднесрочного прогнозирования курса криптовалют (на примере биткоина). *Финансы и кредит*. 2018. Т. 24. № 5. С. 1046–1060. URL: https://doi.org/10.24891/fc.24.5.1046

[1] According to Coin Market Cap.

[2] El'shin L.A., Abdukaeva A.A. [Financial instruments revitalizing business activities: Distinctions and prospects]. *Problema riska v sovremennykh krizisnykh usloviyakh mirovoi ekonomiki: materialy mezhdunarodnoi nauchnoi konferentsii* [Proc. Int. Sci. Conf. The Matter of Risk in the Current Crisis Situation in the Global Economy]. Ufa, Aeterna Publ., 2017, pp. 74–77.

[3] El'shin L.A., Abdukaeva A.A. [Opportunities for generating business activities through digital money]. *Metody, mekhanizmy i faktory mezhdunarodnoi konkurentosposobnosti natsional'nykh ekonomicheskikh sistem: materialy mezhdunarodnoi nauchnoi konferentsii* [Proc. Int. Sci. Conf. Methods, Mechanisms and Factors of International Competitiveness of National Economic Systems]. Ufa, Aeterna Publ., 2017, pp. 91–94.

[4] Vigna P., Casey M.J. *Epokha kriptovalyut. Kak bitkoin i blokchein menyayut mirovoi ekonomicheskii poryadok* [The Age of Cryptocurrency: How Bitcoin and the Blockchain Are Challenging the Global Economic Order]. Moscow, Mann, Ivanov i Ferber Publ., 2018, 432 p.

[5] Ibid.

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0.5 is assigned when countries are contemplating legalization issues;

1 is assigned when the cryptocurrency is recognized as private money, goods, asset;

2 is assigned when the cryptocurrency is duly accepted and subject to tax.

Please see the result in *Table 1* and *Fig. 1*.

As the analysis reveals, the legal status of cryptocurrencies is disputable and needs to be finally settled in most of the countries. In the mean time, although nations are not unanimous in their attitude to the cryptocurrency market, the latter is on the upswing as countries confer the legitimacy on it. The average points per quarter add to a time series with the apparently linear trend. *Fig. 1* showcases the situation. Consequently, the global community's confidence in cryptocurrencies grows stronger as we move from an analyzable period to another.

Notwithstanding the reassuring dynamism in legalizing and developing the cryptocurrency market, the digital money market is yet to reach its maturity. The Russian Federation crystallizes its approach to cryptocurrencies, urging various governmental agencies to consider the legalization of cryptocurrencies and formulate their legal identity. The saving function of cryptocurrencies may subsequently take a new turn in the nearest future. It is enough to say that the Ministry of Finance of the Russian Federation even suggested including cryptocurrencies into the 2017–2019 national financial literacy program[6]. Bearing in mind the opinion of A. Siluanov, Russia's Minister of Finance, the scientific community conducts multiple studies into investment in electronic currency, which may supposedly be a big risk. Investment in such an unregulated asset and possible consequences will be constantly on the agenda of the Russian authorities until 2023.

As the cryptocurrency market is insufficiently developed in Russia, if not being in its infancy, the business community is noticeably indifferent to the model that helps evaluate and forecast the future trends in the cryptocurrency market [6]. However, it is worth mentioning speculative schemes in the market and recent cryptocurrency legalization efforts of the Russian regulatory authorities, thus raising the need in this methodological tool. In 2017, there was a series of large-scale researches into this issue, which include, for instance, *Scenario-Based Modeling of the Cryptocurrency Market Development in the Russian Federation and Its Impact on Future Payments for Airflight Services in Aeroflot's Operations* (ordered by Aeroflot), *Legislative Regulation of Implementation and Practical Use of Modern Financial Technologies, Analysis of Global Expertise and Adaptation Mode for the Russian Federation* (ordered by the State Duma of the Federal Assembly of the Russian Federation). The State Duma of the Russian Federation announced a tender to examine ways to legislatively regulate the use of the blockchain technology in the financial market.

These efforts are taken as the Russian President instructed the Russian Government in 2017 to create the regulatory framework for cryptocurrency in the national economy[7]. In January 2018, the RF Ministry of Finance and the Central Bank of Russia elaborated and released the draft federal law *On Digital Financial Assets*[8].

Furthermore, although the global cryptocurrency market has been growing exponentially for the recent years and governmental regulators have been searching for mechanisms to control cryptocurrency circulation, many economists and governmental officials still believe it insignificantly impacts the macroeconomic and financial stability. These assumptions stem from an extremely low share of the cryptocurrency market in the total balance-of-payment system. For example, bitcoin accounts for 0.006 percent of total fiat money and 0.001 percent of money supply in the Russian Federation [7, 8].

[6] *Kriptovalyutu vstrechayut v Rossii s rasprostertymi ob"yatiyami* [Cryptocurrency is warmly welcome in Russia]. URL: https://mining-bitcoin.ru/news/kriptovalyuty-v-rossii?utm_referrer=https%3A%2F%2Fzen.yandex.com (In Russ.)

[7] *Perechen' poruchenii po itogam soveshchaniya po voprosu ispol'zovaniya tsifrovykh tekhnologii v finansovoi sfere* [The list of instructions following the meeting on the use of digital technologies in finance]. URL: http://kremlin.ru/acts/assignments/orders/55899 (In Russ.)

[8] *Proekt federal'nogo zakona O tsifrovykh finansovykh aktivakh* [Draft Federal Law On Digital Financial Assets]. URL: https://www.minfin.ru/ru/document/?id_4=121810 (In Russ.)

There is a strong likelihood that in the foreseeable future the cryptocurrency market will continue rising and penetrating national economic systems in different ways. Hence researchers and experts need to focus on the issue today as much as possible. The capitalization of the cryptocurrency market may be spurred if it is not only promoted as an advanced tool for transactions, but also driven by an increasing exchange rate (as a result of a limited issue of cryptocurrency like 21 million units of bitcoin, and speculative processes and deals in cryptocurrency exchanges) [9].

As aforementioned, it seems very important to find and devise a special toolkit to foresee and predict the way exchange rates of modern digital money will develop in the future.

It is fair to note that there are few scholarly publications on the subject. Studies mainly provide an expert assessment of the current and future developments in the cryptocurrency market or focus on the usage of special methods for technical analysis of stock exchanges so as to reveal the specifics and trends in the digital money exchange rates.

It is noteworthy that those scarce publications on the cryptocurrency market development seldom, if never, pursue creating models to predict a growth in the digital money market capitalization for the mid- and long-term horizon. It is quite understandable as the analyzable market is very difficult to interpret and model through traditional forecasting methods due to its infancy and its development paradigm, which implies decentralized regulation, unpegging from the so called underlying assets. It considerably complicates building multivariate economic-mathematical models allowing to make forecasts for a certain date in the future. However, as the cryptocurrency market rapidly intrudes into the global system of economic operations, such models would serve for the purpose.

If we conduct an in-depth analysis of the existing approaches to modelling and forecasting stock exchange rates of cryptocurrency, it would be fair to state the nontrivial nature of such exchange rate forecasts. Fundamental analysis proves to be ineffective for predicting the volatility of stock exchange quotations since the exchange rate is not pegged to any economy. Technical analysis falters too since it is impossible to determine the market situation because demand and supply depend on persons willing to buy or sell certain goods and services all over the world [10–13].

However, it is still necessary to address the issue by forging appropriate tools for predicting future development in the mid-term horizon. We believe it is possible to do so through the Autoregressive Integrated Moving Average (ARIMA) and Autoregressive Moving Average (ARMA) models. This approach proves useful when there are no proper tools to forecast changes in exchange rates of such financial assets. Their exchange rates unevenly fluctuate over time, being not pegged to underlying assets and depending on numerous speculative positions, etc.

ARMA, ARIMA models represent an important class of parametric models which help describe stationary and non-stationary series. As part of this research, we intend to find an autoregression model and integrated moving average with a minimum order of parameters, which allow to make plausible short-term forecasts of cryptocurrency volatility [14].

As the empirical and expert analysis shows, it is reasonable to refer to bitcoin for purposes of the research due to multiple reasons. For example:

- prevalence in global capitalization of cryptocurrencies (about 45 percent);
- the highest popularity among others cryptocurrencies, with its changes totally influencing the volatility of other types of cryptocurrencies in the market.

Dealing with methodological issues, we should note that the use of the above models requires five basic iterations:

1) constructing a time series;
2) testing the time series for stationarity, thus defining whether it relates to the ARMA or ARIMA model;
3) selecting properties of the model;
4) evaluating the reliability and adequacy of the model;

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5) setting predictive parameters of the analyzable time series.

We showcase the modeling process providing a detailed account of the sequence of iterations we perform.

Computations are based on data reflecting monthly fluctuations of bitcoin within the period from January 1, 2014 through March 18, 2018 (*Fig. 2*). The data proceed from Bitcoin.info virtual service of cryptocurrency wallets. The computations were processed via Eviews, IBM, SPSS software packages.

Stationary times series or series of probable stationarity can be modeled using the ARMA model combining two models, i.e. autoregression *p* and moving average *q*. In a generalized form, the ARMA model (*p, q*) is expressed as follows:

$$Y_t = a_0 + a_1 X_{t-1} + a_2 X_2 \ldots + a_n X_{t-n} + \varepsilon_t - \beta_1 \varepsilon_{e-1} - \\ - \beta_2 \varepsilon_{e-2} - \ldots - \beta_n \varepsilon_{t-n}.$$

G. Jenkins and G. Box offered the ARIMA (*p, d, q*) model for non-stationary data, which can be presented in a stationary form after successive differences *d* are subtracted [15], where *p*, *d*, *q* are structural parameters describing the order of corresponding parts of the model, whether it is autoregressive, integrated and moving average.

The model selection methodology comprises several steps.

First, the model is identified.

At the initial step of the research, it is necessary to determine whether the analyzable series is stationary.

A stationary series has such behavior and properties which remain the same in the future and in the past.

Various methods can be employed to evaluate the stationarity of the series. The augmented Dickey–Fuller test, autocorrelation function (*ACF*) and partial autocorrelation function (*PACF*) constitute the main approaches to checking the stationarity *BP*. *ACF* is computed as follows:

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

PACF is assessed as a partial correlation of values y_t and y_{t-k}, that is purified from an effect the evolving variable has on them[9].

We set the *ACF* and *PACF* for the input series (*Fig. 3*).

ACF coefficients demonstrate a slow decline in *ACF*, falling exponentially from the coefficient approximating 1. The autocorrelation coefficient is high in *PACF* within the first lag and approximates 0 within the following lags.

Thus, we infer that the input time series is non-stationary.

In addition to a visual analysis, we performed the augmented Dickey–Fuller test (*ADF* test) to check the stationarity of the time series. The test verifies the null hypothesis of a unit root in the equation:

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

The stationarity *BP* is proven if the test estimates exceed the statistic t_{observ} ($t_{crit} > t_{observ}$). *Fig. 4* displays the results of the test.

t_{observ} is set to equal –3.11 for the analyzable time series. Whereas the resultant values are lower than t_{observ} at different significance (1, 5 and 10 percent), we agree with the hypothesis of non-stationarity *BP.*

Therefore, we modeled the exchange rate of bitcoin using the ARIMA model.

1. Criteria for setting the model parameters.

After the model is chosen, its parameters should be configured. After the first difference is subtracted, the input time series is presented in a stationary form. Hence, *d* =1.

To model trends in exchange rates of cryptocurrencies, we tested models ARIMA (1,1,1), ARIMA (1,1,2), ARIMA (2,1,0), ARIMA (2,1,1), ARIMA (2,1,2).

To choose a model, we referred to the *ACF* and *PACF* and the Akaike information criterion – *AIC* (1) and Bayesian information criterion – *BIC* (2).

[9] Kantorovich G.G. [Time series analysis]. *Ekonomicheskii zhurnal VshE = HSE Economic Journal*, 2002, no. 1.
URL: https://ej.hse.ru/data/2010/12/31/1208182144/06_01_06.pdf (In Russ.)

The criteria help choose the most appropriate model out of possible models. The model with the lowest *AIC* and *BIC* wins. The assessment is based on the following formulas:

$$AIC = \ln \hat{\delta}^2 + \frac{2}{n} r; \quad (1)$$

$$BIC = \ln \hat{\delta}^2 + \frac{\ln n}{n} r, \quad (2)$$

where ($\hat{\delta}^2$) is the residual amount of squares divided by the number of observations;

r is the total number of summands of the ARIMA model.

The ARIMA model (2,1,1) has the lowest *AIC* and *BIC*.

Thus, the final model is expressed as follows:

$$\Delta X = 17{,}849 + 0{,}047 \Delta X_{t-1} - 0{,}296 \Delta X_{t-2} - $$
$$- 1{,}602 \varepsilon_{t-1} - 0{,}845 \varepsilon_{t-2} + \varepsilon_t.$$

2. Predictive Estimation.

Using the final model, we forecasted the bitcoin exchange rate for a four point distance. *Fig. 5* shows the results.

Table 2 characterizes the quality of the resultant model.

The reliability and adequacy of the results were verified by comparing factual and projected parameters of the bitcoin rate, and with the high value of *R*-square (Fig. 6).

As depicted in the graph, the projected values provide a very accurate view of the future fluctuations, being corroborated with the very precise forecast of daily changes in the trends.

We unavoidably observe an insignificant variance of absolute values of time series. This is quite acceptable, falling within standard error thresholds.

So, referring to the resultant estimates, we infer that the bitcoin exchange rate will have stable positive trends within the coming four months (*Fig. 7*).

The market value of bitcoin will have approximated USD 11,000 by the end of Q3 2018. It is noteworthy that the methodological approaches to modeling we use in this research enable us to foresee not only future trends shaping possible developments, but also changes in stock exchange rates throughout the analyzable period. The expected change in May 2018 will be insignificant, without seriously influencing the projected positive trend within the analyzable period.

The results provide much evidence confirming that the proposed forecast tools are promising, being based on autoregression mechanisms and integrated moving average. However, we ought to mention that the proposed model needs to be refined. For instance, due to frequent changes in the analyzable time series, it would be reasonable to apply stochastic volatility models.

The proposed toolkit may come in handy to model business processes involving crypto-transactions. First of all, it will help understand and predict stock exchange rates of cryptocurrencies since their use engenders high risks of financial loss in business operations due to considerable volatility [16].

Subsequently, the proposed methodological approaches open new opportunities for predicting and forecasting the digital market developments for a three/four month time, thus giving reasonable grounds to model the behavior of economic agents involved in crypto-transactions. Furthermore, considering active efforts worldwide and nationwide for legalizing the cryptocurrency market, it is necessary to forecast the analyzable market for more distant time horizons as compared with most models used as part of technical analysis, which is indispensable for generating analytical estimates in stock exchanges. The proposed methodological approach is capable of solving such vital and significant issues for today's economy, as the computations show.

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Table 1
Analysis of the legal status of cryptocurrencies

Country	2013				2014			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Russian Federation	0	0	0	0	−1	−1	−1	−1
Germany	1	1	2	2	2	2	2	2
Croatia	0	0.5	0.5	2	2	2	2	2
Denmark	0	0	0	0	0	0	0	0
Sweden	0	0.5	0.5	0.5	1	1	1	1
South Korea	0	0	0.5	0.5	0.5	0.5	0.5	0.5
Thailand	0	0	−1	−1	0	0	0	0
China	1	1	1	−1	−1	−1	−1	−1
USA	0.5	0.5	0.5	1	1	1	1	1
Singapore	0	0	0.5	0.5	1	1	1	1
Norway	0	0	0	1	1	1	1	1
Ukraine	0	0	0	0	0	0	−1	−1
France	0	0	0	−1	−1	−1	0.5	0.5
India	1	1	1	1	1	1	1	1
Australia	–	1	1	1	1	1	1	1
Belgium	0	0	0	0	−1	−1	−1	−1
Canada	0	−1	−1	−1	−1	1	1	1
Cyprus	1	1	1	1	1	1	1	1
Hong Kong	0	0	0	−1	−1	−1	−1	−1
Israel	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Japan	0	0	0	−1	−1	0.5	0.5	0.5
New Zealand	0	0	0	0	0	0	0	0
Slovenia	0	0	0	0.5	0.5	0.5	0.5	0.5
Spain	1	1	1	1	1	1	1	1
United Kingdom	0	0	0	0	0	1	1	1
Bulgaria	0	0	0	0.5	0.5	2	2	2

Continued from Table 1

Country	2015				2016				2017		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Russian Federation	–1	–1	–1	–1	–1	–1	0.5	0.5	0.5	0.5	0.5
Germany	2	2	2	2	2	2	2	2	2	2	2
Croatia	2	2	2	2	2	2	2	2	2	2	2
Denmark	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5
Sweden	1	1	1	1	1	1	1	1	1	1	1
South Korea	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2	2
Thailand	0	0	0	0	0	0	0	0	0	0	0
China	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1
USA	1	1	1	1	1	1	1	1	1	1	1
Singapore	1	1	1	1	1	1	1	1	1	1	1
Norway	1	1	1	1	1	1	1	1	1	1	1
Ukraine	–1	1	1	1	1	1	1	1	1	1	1
France	0.5	1	1	1	1	1	1	1	1	1	1
India	1	1	1	1	1	1	1	1	1	1	1
Australia	1	1	1	1	1	1	1	1	1	1	2
Belgium	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1
Canada	1	1	1	1	1	2	2	2	2	2	2
Cyprus	1	1	1	1	1	1	1	1	1	1	1
Hong Kong	–1	–1	0	0	0	0	0	0	0	0	0
Israel	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1
Japan	0.5	0.5	0.5	0.5	2	2	2	2	2	2	2
New Zealand	0	0	0	0	0	0	0	0	–1	–1	–1
Slovenia	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Spain	1	1	1	1	1	1	1	1	1	1	1
United Kingdom	1	1	1	1	1	1	1	1	1	1	1
Bulgaria	2	2	2	2	2	2	2	2	2	2	2

Source: Authoring

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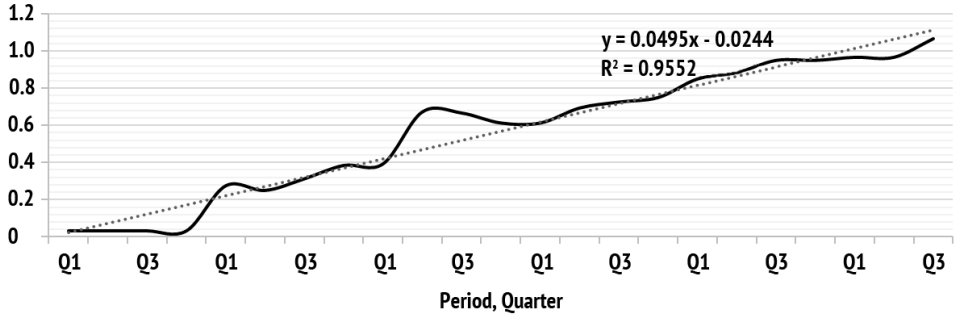
Table 2
Qualitative characteristics of the model

Fitting statistics	Mean
Stationary *R*-square	0.871
R-square	0.999
Root Mean Square Error (RMSE)	165.930
Mean Absolute Percentage Error (MAPE)	4.182
Maximum Absolute Percentage Error (MaxAPE)	39.607
Mean Absolute Error (MAE)	102.682
Maximum Absolute Error (MaxAE)	634.788

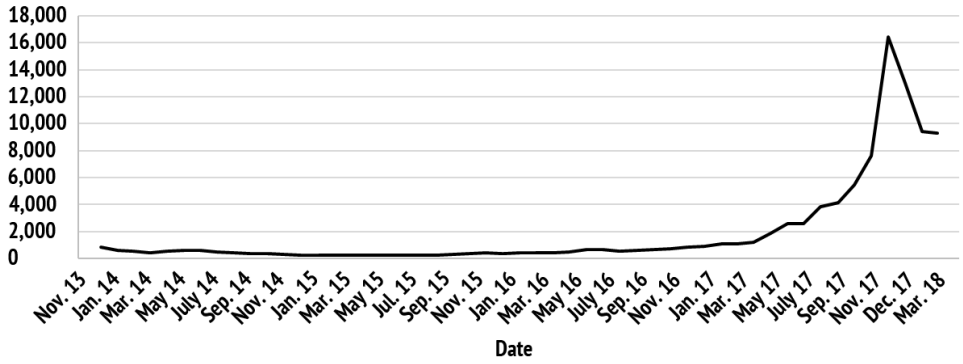
Source: Authoring

Figure 1
Average rating of the legal status of cryptocurrencies (the graph is generated on the basis of *Table 1* data)



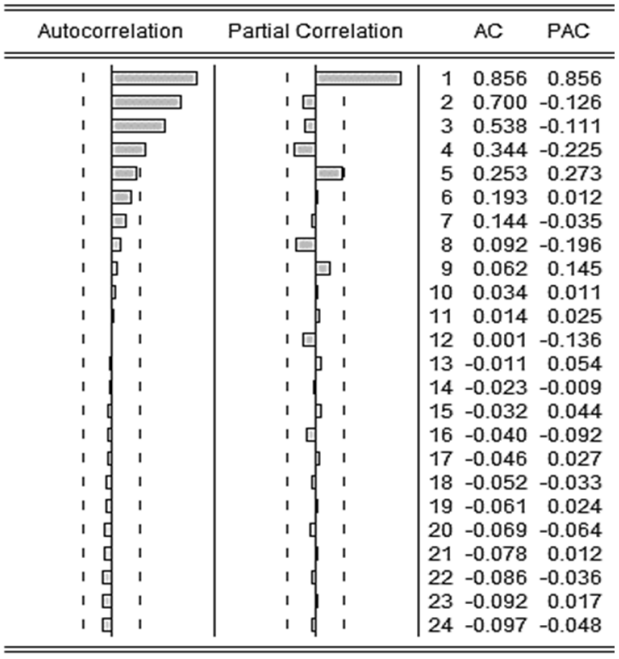
Source: Authoring

Figure 2
Trends in the bitcoin exchange rate, by month, USD



Source: Blockchain. URL: https://blockchain.info

Figure 3
Autocorrelation function (AC), Partial Autocorrelation Function (PAC)



	AC	PAC
1	0.856	0.856
2	0.700	-0.126
3	0.538	-0.111
4	0.344	-0.225
5	0.253	0.273
6	0.193	0.012
7	0.144	-0.035
8	0.092	-0.196
9	0.062	0.145
10	0.034	0.011
11	0.014	0.025
12	0.001	-0.136
13	-0.011	0.054
14	-0.023	-0.009
15	-0.032	0.044
16	-0.040	-0.092
17	-0.046	0.027
18	-0.052	-0.033
19	-0.061	0.024
20	-0.069	-0.064
21	-0.078	0.012
22	-0.086	-0.036
23	-0.092	0.017
24	-0.097	-0.048

Source: Authoring

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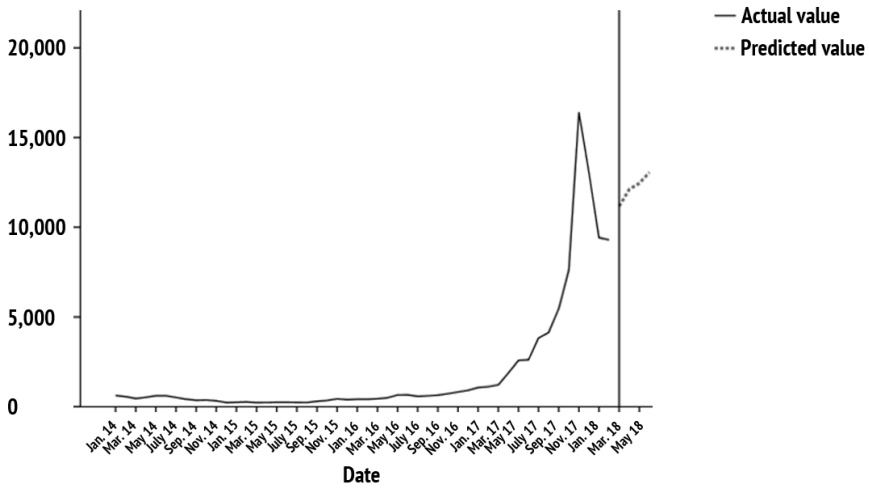
Figure 4
ADF test results

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		3.110313	1.0000
Test critical values:	1% level	-3.588509	
	5% level	-2.929734	
	10% level	-2.603064	

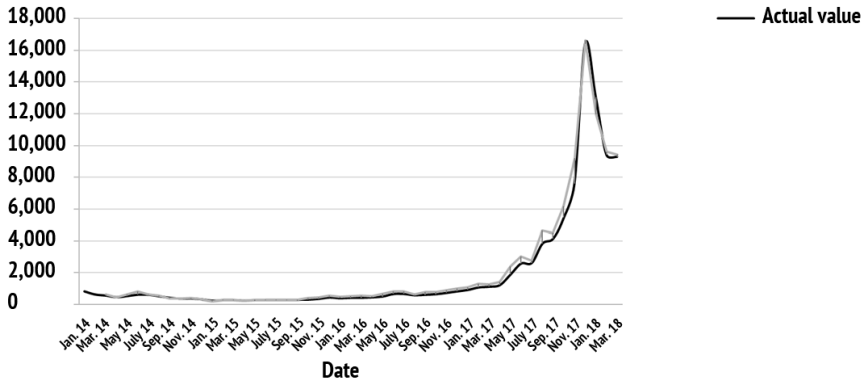
Source: Authoring

Figure 5
Predicted values of bitcoin exchange rate through the ARIMA model (2,1,1), BTC/USD



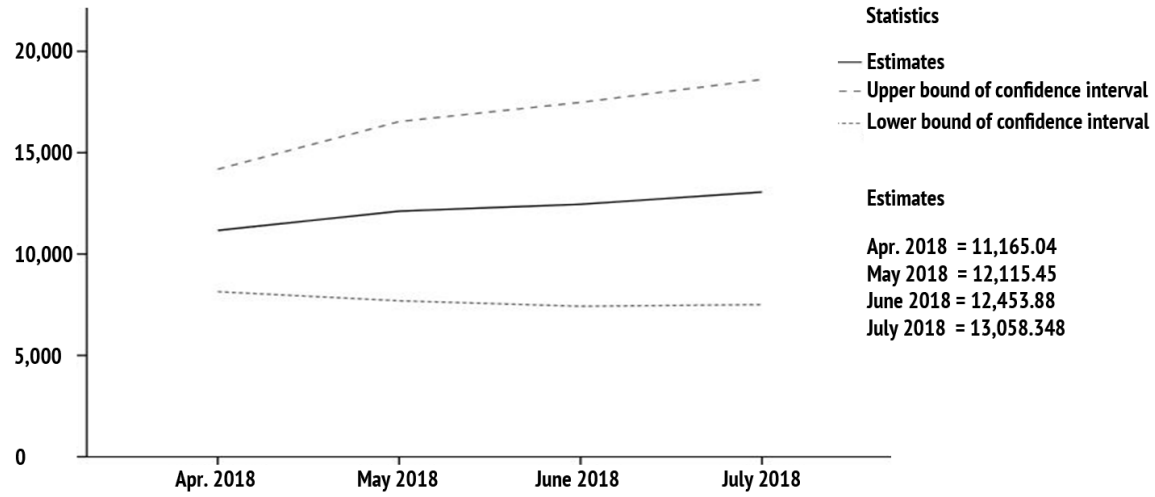
Source: Authoring

Figure 6
Convergence of predicted and factual values of the BTC/USD rate, BTC/USD



Source: Authoring

Figure 7
Predicted values



Source: Authoring

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Conflict-of-interest notification

We, the authors of this article, bindingly and explicitly declare of the partial and total lack of actual or potential conflict of interest with any other third party whatsoever, which may arise as a result of the publication of this article. This statement relates to the study, data collection and interpretation, writing and preparation of the article, and the decision to submit the manuscript for publication.