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Bitcoin financial bubbles: digitalization and modeling

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***Abstract* — The subject of scientific research is economic relations arising in the process of establishing the value of Bitcoin in the financial market. The hypothesis that the Bitcoin market is really subject to the formation of financial bubbles, and that the most significant of them was observed in 2017. The phenomenon of cryptocurrency has arisen quite recently and, therefore, at present there are very few empirical and theoretical studies related to this problem. It should be noted that the interest of the scientific community in digital money is growing every year. The digitization of the financial segment is a priority in the framework of Russia's economic growth. As part of the research, the Bitcoin market was analyzed. Several financial bubbles have been identified, and an econometric model of the behavior of the Bitcoin value in the digital virtual instruments market has also been compiled. The relevance and debatable nature of the theoretical and methodological foundations of cryptocurrency in different markets, the high practical significance of digital money in the modern economic system predetermined the goal and objectives, determined the choice of the object of study. Purpose of the study: bitcoin cost behavior modeling in the digital finance market based on time series. The methodological basis of the present study includes the methods of system-structural, functional, factor and comparative analysis with the construction of analytical models based on the synthesis of modern scientific methods of knowledge of economic and social phenomena. The methodological tools of scientific research are graphic, analytical, statistical and economic-mathematical methods of information processing.**

Keywords* — bitcoin, cryptocurrency, financial bubble, virtual currency.

I. INTRODUCTION

The processes of world globalization make universal money in demand, allowing to conduct instant transactions on the Internet. Thus, the emergence of cryptocurrency is a kind of indicator of transformations occurring in the whole society. Discussion of the Bitcoin market issues from the standpoint of financial bubbles [1] in the context of the economic growth of cryptocurrency should be adequately reflected in scientific and applied research revealing the theoretical and methodological aspects of the digitalization of cash flows [2,3]. For the first time, the concept of digital currency was put forward by the Dutch mathematician David Chaum in Blind Signature for Untracked Payments. The scientist invented a technology that combines the characteristics of cash (anonymity) with the features of electronic payments (security). Then, in 1990 Wei Dai, an expert in the field of cryptography, proposed the B-money technology, it was this technology that inspired one of the "fathers" of the new philosophy of crypto-anarchism, a leading Intel Corp. employee Timothy May, to become ardent supporters of crypto-anarchy. The term "cryptoanarchism" first appeared in 1994 on the pages of Time magazine. Cryptanarchists put the privacy of personal information and the inviolability of personal freedom at the forefront. Currently, many of those who use bitcoin are committed to this ideology.

Cryptocurrencies change the common idea of people about what money can be like. In the traditional view, a currency is always emitted by a specific state represented by a national or state bank, but the cryptocurrency is decentralized, it is a non-state, more precisely, supranational structure. We can say that cryptocurrency is the digital currency of the new industrialization on the cryptocurrency market. In developed countries, state borders are becoming increasingly transparent, and the population is becoming more mobile, the processes of globalization of digital finance make universal money in demand, allowing instant transactions on the Internet. Thus, the emergence of cryptocurrency is a kind of indicator of digital transformations occurring throughout society.

Bitcoin as a digital currency, thanks to which the cryptocurrency market appeared, developed and gained popularity. It was due to Bitcoin that the technology of the distributed registry or blockchain became known to the public, the appearance of which is put by scientists on a par with the invention of the Internet.

Cryptocurrencies are designed to be difficult to extract and deflate by nature. But, as you know, they are unstable, since the size of their market is still relatively small. As the market capitalization of cryptocurrencies grows, so their stability will grow either. At the present moment, there are about 1,500 cryptocurrencies (cryptocoins) in free circulation. Cryptocurrencies other than bitcoin are often called “altcoins”. Although there are many altcoins that are simple clones based on the bitcoin system, the most successful of them have a unique advantage that Bitcoin either cannot or does not want to provide. Altcoins appear through so called "hard forks", also called forks.

II. Research Methodology

The originality of the author's approach is characterized by a creative way of discussion analysing, conducting econometric analysis using various modeling methods, taking into account the volatility, fluctuations and the existence of multiple financial bubbles.

Special attention to cryptocurrency, in particular to Bitcoin, is explained by the fact that Bitcoin can be used as an alternative currency to the national one [6]. Bitcoin volatility is very high and exceeds the volatility of gold and dollar [5]. Hence, there is a particular interest in studying the Bitcoin market, its behavior patterns, and also in developing models for predicting the change in the Bitcoin rate. In Figure 1 it can be seen that in 2017, the cost of Bitcoin increased sharply. Obviously, the value of Bitcoin was overestimated, since such a sharp change in the fundamental value is impossible, given that the fundamental value of Bitcoin is considered to be 0 [8].

In 2012, the European Central Bank published the study "Virtual currency schemes", which sets out the logic of the official financial authorities approach to the problems associated with virtual currency. Famous American anthropologist and sociologist Bill Maurer published a number of scientific articles in which he examines the social characteristics of digital money, and Nigel Dodd, a professor of sociology at the London School of Economics, published a new book in 2014, The Social Life of Money, in which one of the chapters is devoted to studying alternative monetary concepts, including the cryptocurrency Bitcoin.

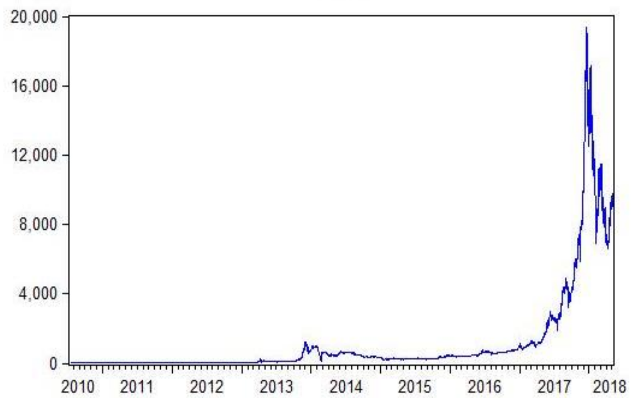


Fig. 1 Bitcoin spot rate fluctuations

In Russia, everything related to cryptocurrency is a completely unexplored area, partly due to the fact that we use very little virtual money and, accordingly, have little empirical data for analysis [4].

For testing multiple financial bubbles statistics GSADF (Generalized Supremum Augmented Dickey-Fuller Statistics) proposed by Phillips in 2015 [9] is often used.

According to the researchers who developed this statistics, one is based on the following equation for the time series:

$$y_t = \mu + \delta y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta y_{t-1} + \varepsilon_t \qquad (1)$$

Where y_t is the variable under investigation (Bitcoin value),

μ - constant,

p - maximum number of lags,

φ_i - coefficient for lag differences

ε_t - mistake.

Since the fluctuations of Bitcoin, judging by Figure 1, are a process of random walk, that is, a non-stationary series, you will most likely have to work with a number of first differences (if these differences represent a stationary series). The need to apply a number of first differences for analysis explains the use of the ARIMA model (p, d, q) in this study.

The formulas for the ARIMA process (p, d, q) are presented below [4].

$$y'_t = \propto + \varphi_1 y'_{t-1} + \cdots + \varphi'_p y'_{t-p} + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} + \varepsilon_t \qquad (2)$$

$y'_t -$ разность первого порядкаfirst order difference

$\varepsilon'_t -$ ошибка для периода t .

Also, due to the instability of the Bitcoin value formation processes, in particular, due to the assumption that there are multiple financial bubbles on the Bitcoin market, it is assumed that conditional heteroscedasticity may occur in the model. Conditional heteroscedasticity implies a change in the variance of observations at time t, depending on previous observations.

Most often, in such cases, the GARCH (p, q) model is applied, which, like any model whose goal is to eliminate heteroscedasticity, includes not only regression for the variable of interest to the researcher, but also separately for error variance, which depends both on previous observations and errors for previous observations, that is, errors are subject to a process of type ARMA (p, q) [6].

$$\sigma_t^2 = \propto_0 + \propto_1 y_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \text{first order difference} \qquad (3)$$

Where σ_t^2 - the variance of the error in the period t,

y_{t-1}^2 - the value of the square of the dependent variable of the previous period.

Capitalization of the first and most popular cryptocurrency - Bitcoin, has the greatest impact on the total capitalization of the cryptocurrency market, as Figure 2 clearly demonstrates.

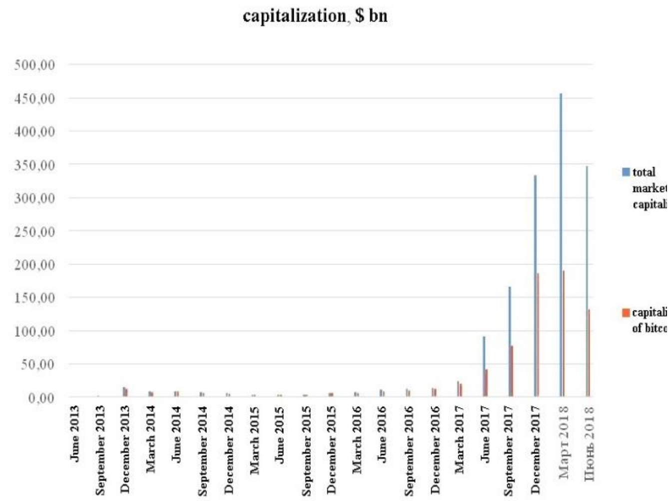


Fig. 2. Total capitalization of the cryptocurrency market as a whole and Bitcoin in particular for 2013-2018, $ billion [11]

The leader in both the value of one unit and the total value, of course, is Bitcoin, which is the pioneer and founder of the entire market. Obviously, it is precisely Bitcoin, despite the differences of the miners' community, that has the greatest trust both from individuals who use it as a medium of circulation and from those who invest in Bitcoins as a virtual asset.

III. RESULTS OF THE RESEARCH

For analysis, the daily data of the Bitcoin rate from July 17, 2010 to May 6, 2018 was taken from the Finance Yahoo website [10], so the total number of observations was 2851. It is worth noting that for the construction of GSADF statistics described in the previous chapter, all the data were used, but for the further construction of a model that could at least roughly describe the process of changing the rate (since the exact rate forecasting model in the presence of multiple price bubbles is rather difficult to compile), a subsample was completed, ending on April 6, 2018. The data from April 7 to May 6 were not used in the subsample in order to be able to predict the Bitcoin rate for this period of time using the constructed model and compare it with the actual rate observed in reality.

In order to exclude the effect of inflation on the formation of the Bitcoin value, all data were adjusted for the level of inflation so that the daily spot rate of Bitcoin was divided by the average daily level of inflation. Of course, a change in the value of the Bitcoin spot rate was insignificant, but for the purity of the experiment, this procedure was necessary.

Recall that the null hypothesis for the GSADF test indicates that the process under study is stationary. Accepting an alternative hypothesis means that the process has an explosive character. Thus, when the estimated GSADF statistic exceeds the critical level, it is concluded that there is a financial bubble in the market.

We present a graphical result of calculating the GSADF statistics and its critical value.

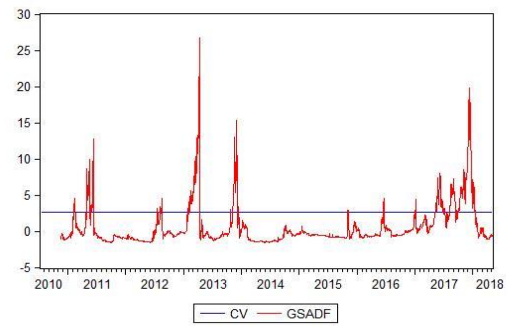


Fig. 3. The results of the calculation of the GSADF statistics and its critical value

As can be seen from Figure 3, there are about eight "suspicious" zones on the graph, where the calculated value of the statistics exceeds its critical value: at the end of 2010, at the beginning of 2011, in the middle of 2012, at the beginning and at the end of 2013, as well as in the middle and at the end of 2016 and at the beginning of 2017. However, after a closer look, it turns out that the jumps in the cost of Bitcoin at the end of 2010, as well as in the middle and end of 2016, consist of only a few observations, so that these deviations cannot be characterized as a financial bubble. These were only random fluctuations in value, which did not lead to a further increase in the value of Bitcoin, but, on the contrary, were characterized by a rapid decline.

In 2017, the most significant financial bubble was observed (at the peak of December 18, Bitcoin's cost exceeded the value by April 18 almost 15 times), which, according to the schedule, already burst in early 2018, and now the bitcoin market is no longer characterized by the presence of a financial bubble. The spread and popularization of the blockchain system, which underlies all cryptocurrencies, also contributed to the rise in the value of Bitcoin. It was seen as the future technology for the financial market, so many investors enthusiastically began to buy Bitcoins.

However, one of the objectives of this work is an attempt to compile a corresponding model of time series, with which it would be possible to determine at least the general direction of change in the exchange rate of Bitcoin.

First you need to check the series for stationarity, because non-stationary time series is much more difficult to predict. In general, the course fluctuation graph (Figure 1) shows that the series is non-stationary, however, in order to confirm this hypothesis, a Dickie-Fuller test was conducted on unit roots. The null hypothesis of this test implies the presence of unit roots in the characteristic polynomial of the time series. In other words, when the null hypothesis is fulfilled, the series is considered to be non-stationary, and if the alternative is performed, it is considered stationary. The test results are shown in Table 1.

TABLE I. I. DICKIE-FULLER TEST RESULTS FOR THE TIME SERIES BITCOIN SPOT RATE

			t-Statistic	Prob.
Dickie-Fuller statistics			-1.015006	0.7500
Critical values:	1% level		-3.432475	
	5% level		-2.862365	
	10% level		-2.567254	

As can be seen from Table 1, prob statistics is greater than 0.05, which means that there is no reason to reject the null hypothesis of the series non-stationarity. Thus, we can say that the fluctuations of the Bitcoin rate are the process of Random walk, which can be represented as:

$$y_t = \theta y_{t-1} + \varepsilon_t, \tag{4}$$

In order to get rid of nonstationarity, we make a series of first-order differences, $y_t'$where

$$y_t' = y_t - y_{t-1} \tag{5}$$

A series of first order differences was also tested for stationarity, the results can be seen in Table 2.

TABLE II. II. DICKIE-FULLER TEST RESULTS FOR THE FIRST DIFFERENCIES TIME SERIES BITCOIN SPOT RATE

			t-Statistic	Prob.
Dickie-Fuller statistics			-9.294598	0.0000
Critical values:	1% level		-3.432475	
	5% level		-2.862365	
	10% level		-2.567254	

As can be seen from table 2, prob statistics are less than 0.05, which allows us at the 5% significance level to reject the null hypothesis of the series non-stationarity (the prob value is less than 0.001, which, generally speaking, allows us to reject the null hypothesis and on 1% level). So, since the series of the first differences is stationary, we will work with the series of the first differences of the spot rate, and not with the spot rate itself. In view of this, the forecast will use the ARIMA (p, d, q) - AutoRegressive Integrated Moving Average model,

where p is the level of the autoregressive part,

d is the number of times of the first-order differences application,

q is the level of the moving average.

IV. Discussion of Results

Fig. 4. THE CORRELOGRAM FOR DIFFERENCES OF THE FIRST ORDER OF THE SPOT RATE

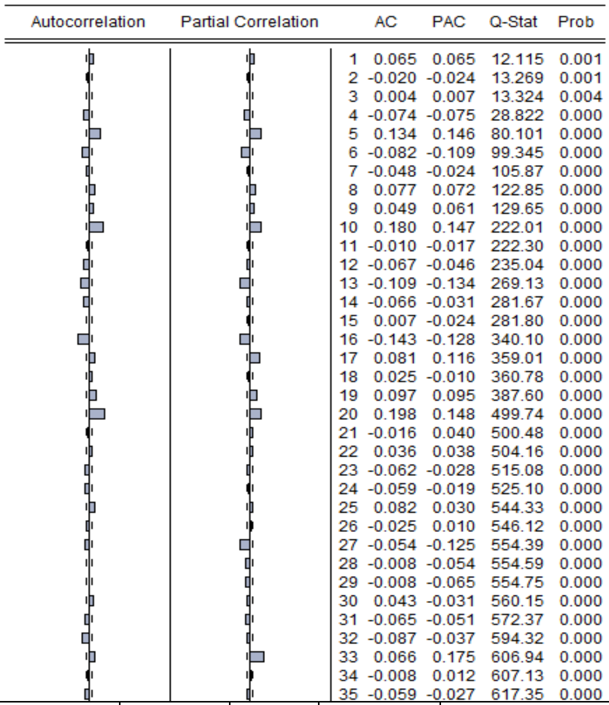
Let us analyze the correlogram of the difference of the first order, which can be seen in Figure 4.

As can be seen from Figure 4, there are no strong peaks in either the private correlation function or the autocorrelation function. Both of them, up to about 20 lags, resemble a sinusoidal distribution. After 20 lags, the functions are distributed more or less evenly within the limits of acceptable values, with the exception of some emissions that are present in the private correlation function at 27 and 33 lags. It can be assumed that in this case both the autoregression process and the moving average process take place. From the correlogram it can be seen that the first distinguished values of functions from the overall picture appear on the 5th lag, then on 10, 16 and 20 lags. Therefore, we assume that the processes AR and MA are of the fifth order. Thus, we construct the ARIMA function (5,1,5), which will look like this:

$$y_t' = \theta_1 y_{t-5}' + \gamma_1 \varepsilon_{t-5} + \varepsilon_t \tag{6}$$

Where y_t' – разность первого порядка

TABLE III. III. THE RESULTS OF COMPILING THE ARIMA MODEL (5,1,5)



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.065	0.065	12.115	0.001
		2	-0.020	-0.024	13.269	0.001
		3	0.004	0.007	13.324	0.004
		4	-0.074	-0.075	28.822	0.000
		5	0.134	0.146	80.101	0.000
		6	-0.082	-0.109	99.345	0.000
		7	-0.048	-0.024	105.87	0.000
		8	0.077	0.072	122.85	0.000
		9	0.049	0.061	129.65	0.000
		10	0.180	0.147	222.01	0.000
		11	-0.010	-0.017	222.30	0.000
		12	-0.067	-0.046	235.04	0.000
		13	-0.109	-0.134	269.13	0.000
		14	-0.066	-0.031	281.67	0.000
		15	0.007	-0.024	281.80	0.000
		16	-0.143	-0.128	340.10	0.000
		17	0.081	0.116	359.01	0.000
		18	0.025	-0.010	360.78	0.000
		19	0.097	0.095	387.60	0.000
		20	0.198	0.148	499.74	0.000
		21	-0.016	0.040	500.48	0.000
		22	0.036	0.038	504.16	0.000
		23	-0.062	-0.028	515.08	0.000
		24	-0.059	-0.019	525.10	0.000
		25	0.082	0.030	544.33	0.000
		26	-0.025	0.010	546.12	0.000
		27	-0.054	-0.125	554.39	0.000
		28	-0.008	-0.054	554.59	0.000
		29	-0.008	-0.065	554.75	0.000
		30	0.043	-0.031	560.15	0.000
		31	-0.065	-0.051	572.37	0.000
		32	-0.087	-0.037	594.32	0.000
		33	0.066	0.175	606.94	0.000
		34	-0.008	0.012	607.13	0.000
		35	-0.059	-0.027	617.35	0.000

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.738869	5.534540	0.675552	0.4994
AR(5)	0.787540	0.043080	18.28071	0.0000
MA(5)	-0.657192	0.052648	-12.48283	0.0000
R-squared	0.042450	Mean dependent var		3.460935
Adjusted R-squared	0.041776	S.D. dependent var		186.1943
S.E. of regression	182.2636	Akaike info criterion		13.24984
Sum squared resid	94411301	Schwarz criterion		13.25612
Log likelihood	-18844.90	Hannan-Quinn criter.		13.25210
F-statistic	62.99542	Durbin-Watson stat		1.805494
Prob (F-statistic)	0.000000			

From table 3 it can be seen that all coefficients are significant at a significance level of 1%, since all prob is less than 0.01, which gives grounds to reject the hypothesis that coefficients are insignificant. In general, the model is also significant at the 1% level, since prob F-statistics is less than 0.01.

The value of R^2 is rather small, but it is logical to assume that for a time series model, even with significant coefficients for variables, the level of explained variation of the dependent variable will not be as high as for models with spatial data. In this case, the first-order difference is quite strongly influenced by random factors, which does not allow the variables included in the model to predict the dependent variable with high accuracy.

Since price fluctuations were quite strong during the last price bubble, it is possible that the error variance increases with time (the presence of heteroscedasticity), so you need to look at the error graph (Fig. 5).

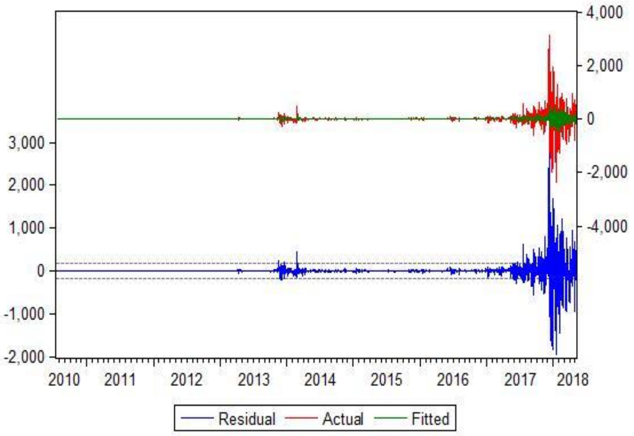


Fig. 5. Graph of oscillations of errors in the ARIMA model (5,1,5)

From Figure 5 it can be seen that during financial bubbles, the error dispersion increases, which in principle is quite logical. In order to verify the presence of heteroscedasticity, we will test the conditional heteroscedasticity of the ARCH Test, which takes the square of the error as the dependent variable and the square of the error of the previous period as the regressor.

TABLE IV. THE RESULTS OF THE TEST FOR HETEROSCEDASTICITY

Heteroscedasticity Test: ARCH			Prob
F-statistic	418.1070	Prob. F(1,2842)	0.0000
Obs*R-squared	365.3757	Prob. Chi-Square(1)	0.0000

Since prob F-statistics is less than 0.01, an alternative hypothesis about the presence of heteroscedasticity is accepted. Of course, heteroscedasticity needs to be somehow taken into account in the model, since without this the estimates will prove ineffective, and the evaluation of the covariance matrix is biased and untenable.

For this purpose, we use the GARCH model, which is very common precisely for predicting the volatility of currencies and the value of assets in the stock market [12]. Within this model, a separate regression is estimated for the error variance, which helps to predict the error to some extent.

After analyzing the correlogram, as well as for reasons of maximal simplifying the forecasting process, it was decided to use the GARCH (1,1) model.

The GARCH (1,1) model for error variance is as follows[16]:

$$\sigma_t^2 = \alpha_0 + \alpha_1 y_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \text{ first order difference} \quad (7)$$

Where σ_t^2 - the variance of the error in the period t,

y_{t-1}^2 - the value of the square of the dependent variable of the previous period.

TABLE V. THE RESULTS OF THE TEST FOR HETEROSCEDASTICITY

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	-0.000316	0.000627	-0.503148	0.6149
AR(5)	0.505662	0.301843	1.675247	0.0939
MA(5)	-0.481034	0.305974	-1.572141	0.1159
Variance Equation				
C	6.88E-07	2.39E-07	2.876962	0.0040
RESID(-1)^2	0.253684	0.008225	30.84260	0.0000
GARCH(-1)	0.842360	0.003410	247.0450	0.0000
R-squared	0.011407	Mean dependent var		2.412210
Adjusted R-squared	0.010704	S.D. dependent var		183.6136
S.E. of regression	182.6283	Akaike info criterion		5.853355
Sum squared resid	93788908	Schwarz criterion		5.866022
Log likelihood	-8232.597	Hannan-Quinn criter.		5.857926
Durbin-Watson stat	1.832804			

If we compare the results from Table 5 with the results from Table 4, we see that the estimates of the coefficients in the initial ARIMA regression (5,1,5) decreased, and the coefficient for the variable MA (5), that is, ε_{t-5}, became insignificant, and with AR (1) or y_{t-5}' remained significant, but only at the 10% significance level. At the same time, in the regression equation for dispersion, all coefficients are significant at the 1% significance level.

Thus, the model, of course, requires refinement for more accurate forecasting, but it can be used to study the general direction of change in the value of Bitcoin.

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