Research article

Different GARCH models analysis of returns and volatility in Bitcoin

Changlin Wang*

Management School, Liverpool University, London City, United Kingdom

* Correspondence: Email: c.wang83@liverpool.ac.uk.

Abstract: To research returns and volatility of Bitcoin (BTC), this paper uses daily closing price of Bitcoin from October 1st, 2013 to July 31th, 2020 to be sample data, and there are 2496 observations in the data. In methodology, the paper utilizes GARCH models to analyze Bitcoin's returns and volatility. Firstly, the data is tested by ADF test to verify stability and diagram tests sequence. After that, lag order and determination of mean value equation shows lag 4 period is the best. Besides, the paper does autocorrelation test of residual series and find that there is no significant autocorrelation in the residual term of the Bitcoin returns, but the residual squared has significant autocorrelation. In addition, the paper makes a linear graph of squared residuals and use ARCH-LM test to find the data is suitable to modeling by GARCH models, because the data has strong ARCH effect. In results, this paper use GARCH (1,1) model to find that returns and volatility of Bitcoin have clustering characteristics and returns and volatility of Bitcoin is a persistent process, but its effect gradually reduces by the time. Because of limitation of GARCH (1,1) model and researching asymmetry of returns and volatility of Bitcoin, this paper uses TARCH and EGARCH models to find that returns and volatility of Bitcoin is without "Leverage Effect". In order to further explaining this special phenomenon, safe-property is quoted in this research. In the end, this paper finds that Bitcoin as a safe-haven property can hedge financial risks in economic depression time, and it has a revised asymmetric effect between positive and negative shocks, so it is a conducive asset to add into portfolios of investors.

Keywords: Bitcoin; returns; volatility; GARCH models; asymmetry

JEL Codes: C22, G11, G15

1. Introduction

Since publication of Bitcoin (BTC) in October, 2008, there are a great number of researchers who pay attention on it. Bitcoin, the most famous and important one of cryptocurrencies, based on blockchain technology with cryptology and its transaction is by P2P method. Producing bitcoins is by its special algorithm with a lot of calculations, and it does not depend on any currency institutions to issue. It uses distributed ledger which combines with many nodes in Bitcoin internet to record trade information. Besides, it uses cryptology to protect safety of system in processes of Bitcoin transactions. In addition, there are only about 21 million bitcoins which can be mined in Bitcoin internet. Bitcoin system releases some bitcoins to miners every 10 mins once. Apart from this, quantity of mining bitcoins will be maximum in 2140.

And, researching Bitcoin, this paper has to refer to blockchain. Blockchain is a series of trade information records which are also called blocks. Besides, the blocks connected in series by cryptography and protected the content. It is a new method of application of computer technology, such as storage of distributed data, P2P transmission, encryption algorithm and consensus mechanism. In addition, Blockchain, an essential technology of Bitcoin, has a lot of new advantages in different sides. For examples, firstly, it is a decentralized system, which is a big different point than other currencies' system. In normal system, there is a center to control and collect all information and data from a lot of transactions. However, this characteristic of blockchain can effectively improve safety of system, because there is no center in this system or all nodes are centers to be a whole system. Therefore, committing crime in this system is too difficult with high risk for those hackers. Secondly, theoretically, information transferring in blockchain is irreversible. In this system, when people trade with others with blockchain, process of the information transferring to next point cannot be changed again. Information will be stored forever, when the information is recorded and verified to the blockchain once. Modification of database is invalid on a single node, unless more than 51% nodes can be controlled at the same time in the system. Thus, the stability and reliability of data with the blockchain are extremely high. Thirdly, the system is opened. The data of the blockchain is open to everyone, but private information of all parties and every transaction information are encrypted with secret keys. In addition, anyone can check and query the data and develop related applications in blockchain, through the opened interface, so the information of the whole system is highly transparent. Fourthly, consensus-based specifications and protocols is adopted by blockchain, such as a set of open and transparent algorithms. Therefore, data can be freely and safely exchanged between all nodes in the whole system in a distrustful environment, which makes trust of people change to the trust of machines, and any artificial intervention does not work. Fifthly, one of features of blockchain is anonymity. the transactions between all nodes follow a fixed algorithm, and interaction of its data does not need to be trusted, because the program rules in the blockchain will judge whether the activity is effective or not by themselves so the counterparty does not need to let the other party generate trust by revealing its identity, which is very helpful to the accumulation of credit. The reasons why a lot of people focusing on Bitcoin is due to the advantages of it.

Normally, there are no virtual currencies outside of online gaming communities. However, because Bitcoin's functions and characteristics, it can be seen as a new and creative digital currency outside of communities of games, which is remarkable in this development of currency. Due to its specifics of Bitcoin, many people highly evaluating in Bitcoin, virtual currency market has seen huge growth in a great number of new currencies, and people invest more and more money in

cryptocurrencies with and frequency of transactions. When more and more people start to focus on cryptocurrencies, its price rapidly increased over past several years. In this period, it price always up and down, which means it has high volatility. Obviously, there were a great number of people whose emotion follows its price. Gradually, Bitcoin are more likely to be an asset due to this trend, which is unlike a traditional currency, because its volatility is frequency than traditional currencies.

Although financial creativities are conducive to developments of finance industry, these bring some new problems. New turmoil in the financial markets shows enormous opportunities and challenges for governments, economists, financial institutions and entrepreneurs. For example, Bitcoin improves financial development, but there are a great number of criminals who want to commit crimes by Bitcoin, such as money laundry and swindle. Therefore, governments of various countries should impose laws and policies with actions to protect investors' properties. Generally, Bitcoin not only bring new creativities, but also brings new turmoil. In order to avoiding risks, governments should strength supervision and institutions of ICO and cryptocurrencies should be more transparency.

Although there are a great number of literatures to research returns and volatility of Bitcoin, but asymmetric researches are not enough. More importantly, using different GARCH models to further analyzing Bitcoin's returns and volatility is less. And this paper uses different GARCH models to analyze more longer sample time than other researches and finds characteristics in Bitcoin and quotes safe-haven property and revised asymmetry to explain why returns and volatility of Bitcoin do not have "Leverage effect", which is rare in the area study. The last but not least, conclusion of this paper can help investors to make a strategy in order to hedging financial risks, because this paper finds that Bitcoin is a safe-haven property with revised asymmetric effect between positive and negative shocks and its returns and volatility have clustering characteristics.

2. Literature review

2.1. Bitcoin with blockchain

Originally, Bitcoin and blockchain were firstly published by Satoshi Nakamoto from Bitcoin White Book in October, 2008. Generally, decentralized control system and cryptography are essential technologies of cryptocurrencies that is digital assets to facilitate secure, verify transactions and create additional assets (Narayanan et al., 2016; Hua et al., 2019). In addition, macroscopically, the blockchain is a cutting-edge technology that combines cryptology and computer technology through distributed computing and P2P transferring to constitute distributed system. In Bitcoin system, every block is a storage space that stores trade information and data between every node. The blockchain use chains to connect with every block in order to achieving point-to-point communication and sharing information and data (Satoshi, 2008). Frame of Bitcoin was largely designed by locking its protocol. For instance, blockchain is essential technology of Bitcoin. There is no clear alternative to keeping installed Bitcoin software, maintaining compatibility with intermediary systems. Instant transaction validation seems to require an equally fundamental change. In these and other sides, it will be hard for Bitcoin to adjust (Rainer et al., 2015). After that, cryptocurrency was famous day by day, so that there a great number of cryptocurrencies came up with new conceptions and technologies, such as Ethereum and Litecoin, Tron. Nowadays, a number of digital currencies with computing power are waiting in the wings. For example, Litecoin can confirm reade information four times, which is faster than Bitcoin. This improving function potentially facilitate retail using and other time-sensitive transactions. The

electronic and computational burden of mining of Bitcoin are reduced in NXT by replacing work-proof mining with equity proof, and allocating responsibilities of blockchain according to the proportion of bitcoins held. Besides, Zerocash can improve protection of privacy by hiding identifiers in the public transaction history and Peercoin allows supply of money to slightly grow by 1% a year (Ben-Sasson et al., 2014). Although there are a lot of different cryptocurrencies, their core is decentralization and distributed ledger. Blockchain and distributed ledger improve safety of system, because every block connects with each other, which means all points are center. If hackers want to change any data, they must change over 50% points in this large system. This means that cost of tamper data is very high than before. Apart from this, Satoshi Nakamoto found that his team sets up an electronic trading system that does not rely on trust. The system relies on digital signatures and cryptology, which provide strong supervision over ownership, but this is not a way to prevent repeat consumption. They proposed a point-to-point (P2P) network that is using working proof to record the history of common trade information in order to solving this problem. If honest nodes control most of the CPU power, an attacker can quickly change the unrealistic history of computing for these transactions. The unstructured simplicity of network is robust, because nodes in this system simultaneously work with little coordination. They do not need to be verified and identified because the message is not routed to any particular location, just delivered as best as possible. Nodes can leave and rejoin the network, accepting the working proof chain as proof of what happened when they left. They vote with their CPU power, extend valid blocks to indicate that they accept valid blocks, and reject invalid blocks by refusing to process invalid blocks. Through this consensus mechanism, any necessary rules and incentives can be implemented (Satoshi, 2008).

2.2. Valuation of Bitcoin

Due to only 21 million bitcoins and premium of blockchain technology, Bitcoin price has increased more than 700 times over least five years, and now there are at least 35 Bitcoin exchange markets where Bitcoin prices are quoted in standard currencies. These exchange markets trade with the daily transaction volume over 1 million dollars. With more and more people focusing on cryptocurrencies, some cryptocurrencies have grown faster recently, with other currencies such as Bitcoin, Ethereum, Litecoin and Ripple becoming more popular. However, there is still a lot of discussion about whether cryptocurrencies, and bitcoin in particular, should be classified as currencies, assets or investment vehicles, which is itself a key topic. Our analysis assumes that we are looking at cryptocurrency transactions in the form of financial assets that most users use for investment purposes, either as long-term investments in new technologies or as short-term profits. Studying the fluctuations of cryptocurrencies is an important hedging or pricing tool in financial investment. As such, these results will be particularly useful in terms of portfolio and risk management, and can help others make better informed decisions about financial investments and the potential benefits and pitfalls of using cryptocurrencies (Chu et al., 2017). In addition, in order to providing their design decisions with competitivity, alternative digital currencies need to firstly gain confidence in their adoption and valuation. Services of Bitcoin are benefits for Bitcoin to receive early enthusiasm of positive media coverage and buyers and sellers on the Silk Road. This combination of advantages will be hard to achieve with alternatives to virtual currencies, but few of that are willing to convert traditional currencies into a competitive one without good expectations of growth. Whether or not Bitcoin evolves as its supporters imagine, it provides researchers with an excellent experiment, a laboratory and an attractive means of

trading for some traders and consumers (Rainer et al., 2015). Bitcoin is intended as a currency to exchange, but it can also be used as an asset to invest. Dirk et al. (2015) found that returns attributes of Bitcoin are unlike those of traditional assets, providing significant diversification of investments. Through an analysis of the bitcoin public ledger, they found that there are a third of all bitcoins which are held by investors. Especially, some investors receive bitcoins and they never send them to others. A small number of users, both numerically and in bitcoin balances, seem to be using bitcoin as a medium of exchange. This phenomenon shows that Bitcoin mainly is being held as an asset for investments' purposes, but not be a currency for trading. Whether bitcoin's volatility leads to investment rather than currency, and thus to a medium of exchange, is a question for future research. Because the scale of bitcoin investments and transactions is relatively small comparing with other assets, there is not direct risks or even threats to stability of finance and currency. However, it is important to stress that this conclusion is based on its size. A significant increasing in global is acceptance of using Bitcoin or similar virtual currencies to trade, which could influence the behaviors of consumers and producers, changing relative monetary policies. Because global dispersion of Bitcoin and its independence from any central bank or supranational institution, regulation will be difficult and challengeable (Dirk et al., 2015). Article of Koutmos (2018) examines link between returns and transactions activities of bitcoin. The literature of so far has concluded that the price of Bitcoin is unexplainable based on economic factors. The article highlights how important to use microstructural variables that can explain returns of bitcoin. Binary value-at-risk model used here to show a high correlation between returns of bitcoin and its activities of trading, although returns can relatively explain changes in trading activities, rather than the other ways around. In order to understanding bitcoin, more empirical work is needed. As people can see here, this sort of work might pay more attention to the microstructure and new variables of Bitcoin than the usual economic variables that explain the returns on traditional assets (Dimitrios, 2018). From a market linkages perspective, Klein et al. (2018) used different models to provide that Bitcoin is different from gold, especially in downturns time. When financial markets fall under similar shocks, Bitcoin shows dropping and a positive coupling effect, comparing with gold. In a portfolio application, this point suggests that Bitcoin is not a hedged equity investment. However, scale of their sample is limited and they are looking at only a small fraction of these recessions. Given the relative youth of the market, this result should be tested again, when the cryptocurrency markets are mature. Now, Bitcoin as an asset is unlike any traditional assets from an econometric point of views.

To the early, there were most literatures about Bitcoin technologies and development, but recently people do more and more researches on finance. On one hand, Popper (2015) considered that Bitcoin is digital gold in cryptocurrencies. And Bouri et al. (2017) emphasized that Bitcoin is valuable investment in financial crisis, and it can be a necessary asset in portfolio investment. On the other hand, Yermack (2013) argued that Bitcoin facilitates economic transactions to finish in capitalization of market, so it is more like a speculative investment than currencies. The author concluded that volatility of Bitcoin has adverse influences in stability of Bitcoin as a currency. After these researches, there were some comprehensive literatures as follow. Kristoufek (2014) argued that Bitcoin, a special and new asset, shows two characteristics that are asset and currency. Besides, research of Dyhrberg (2016) showed that Bitcoin combines some advantages of traditional currencies, such as, gold, RMB and dollar, in financial markets. Therefore, it can be a useful tool for market sentiment analysis, risk analysis and portfolio management. Both of them thought that Bitcoin not only has features of currency, but also has features of asset. Furthermore, some researchers started to study returns and volatility of Bitcoin with bitcoin price fluctuation. Over past five years, price of Bitcoin changed rapidly. The

highest price was $19783 in Nov. 2017, but the lowest price was $3122 after crazy increasing in Dec. 2018. (https://www.coindesk.com/price/bitcoin) Obviously, volatility and returns of Bitcoin had a huge change between a period of short time, which means that returns-volatility of Bitcoin which was fluctuated in the time.

Figure 1. Daily price of Bitcoin (USD).

2.3. Returns and volatility of Bitcoin

About returns and volatility of Bitcoin, Balcilar et al. (2017) concluded that Bitcoin's volume can be used to predict returns, but it is too hard to be used to forecast its volatility. In addition, a special research by Ciaian et al. (2016) pays attention to the determinants of volatility of Bitcoin price. The paper shows that number of bitcoins as supply-side variable has a smaller impact on the price of Bitcoin than unique number of Bitcoin daily transactions as demand-side variable. However, cryptocurrencies still a relatively unexplored area of research, and there are little researches to know about volatility of Bitcoin price. As cryptocurrencies seem to gain legitimacy and profits, it is important to understand driving forces behind market movements, especially with creation of derivatives markets. Christian et al. (2018) tried to tease out drivers of long-term volatility of Bitcoin. They find that realized volatility of S&P 500 has a very significant negative impact on the long-term volatility of Bitcoin, and the volatility risk premium of S&P 500 has a significant positive impact on the long-term volatility of Bitcoin. In addition, they found a strong positive correlation between the Baltic Dry Freight index and the long-term volatility of Bitcoin, and reported a significant negative correlation between bitcoin trading volumes. It's worth noting that the set of data we considered—such as those related to crime—doesn't seem to really explain bitcoin's volatility, despite extensive media coverage of the topic. They also tested the escape security index proposed by Engle et al. (2012), and found that the long-term fluctuation of Bitcoin tended to decrease during the escape security period. This result is consistent with our finding of a negative correlation between bitcoin volatility and U.S. stock market risk. (Christian et al., 2018). Besides, Aalborg et al. (2019) found that quantity of Bitcoin that uses unique address in Bitcoin network is a positive relationship with daily returns of Bitcoin. The author demonstrated that forecasting Bitcoin's returns and volatility can use volume of Bitcoin, however,

sometime there are some returns cannot be explained. Bitcoin's price, likes other price of assets, cannot be predicted. More importantly, trading volume of Bitcoin improving is positive to forecasting its volatility. Excepting in finance, Bitcoin are used to trade energy. The paper of Efthymia and Konstantinos (2018) indicated that there are significant return spillovers from energy and technology stocks to Bitcoin. Short-term volatility spillover from technology companies to Bitcoin, and volatility of Bitcoin impacts on energy companies for a long time. Both ways Asymmetric impact spillovers between Bitcoin and stock. Finally, they demonstrate the implications and benefits of portfolio management from the low dependence of bitcoin on the stock index. From geopolitical view, Ahemet et al. (2019) indicated that Bitcoin is a conducive tool to hedge geopolitical risks, for example, confliction of different countries. They found that if they implement a BGSVAR estimation procedure, there is a predictive power on the price volatility and the returns of Bitcoin, which changes in the global GPR index. Klein et al. (2018) illustrated that cryptocurrencies will remain highly volatile with the coming recession, and it is still very unclear that they will continue to exhibit huge developments in both directions. Important price changes in passwords depend on several factors. Firstly, investors will continue to make profits at peak of Bitcoin price movements, but cryptocurrencies continued to sharply drop. Secondly, investor behaviors will be strongly impacted by regulatory decisions. Regulators still put pressure on the legal framework for cryptocurrencies. Thirdly, cryptocurrency ecosystem has to hence its own standards of propriety to be accepted by traditional investors, because repeated network attacks, such as MtGox, Instawallet, etc.

2.4. Different GARCH models on returns and volatility of Bitcoin

After predicting returns and volatility of Bitcoin, researchers started to use different models to find returns and volatility of Bitcoin. Volatility of price is early investigated on financial markets, but volatility of price of Bitcoin is not sufficient to find. Because Bitcoin price rapidly change, now more and more researchers gradually focused on this area. Therefore, the excessive volatility of Bitcoin and how to correctly judge it has not been studied enough to provide a wide research gap. The purpose of article of Jamal and Refk (2015) is to provide a discussion of bitcoin's price fluctuations using several extensions selected in the optimal GARCH model. In this case, results of their paper suggest extreme volatility in the price of Bitcoin. Conditional variances tend to follow a long memory process between December 2010 and 2010 June 2015.We noted that there was a less volatile period between persistence and clustering in January and June 2015, but this appears to be temporary. It is worth noting that from the two substages under consideration, the bitcoin volatility process seems to be significantly more affected by negative news than by positive shocks. Not surprisingly, the bitcoin market is highly motivated by self-fulfilling expectations. It is caused by the behavior of non-professional noise traders that may lead to the serious bubble behavior of Bitcoin and increase the volatility of the price (Bouoiyour et al., 2015). While bitcoin users were known primarily as technocrats, liberals, and criminals (Yermack, 2014), today it is dominated by individual noise traders and speculators. This has always highlighted how far the bitcoin market is from mature. The lack of regulation and transparency adds to the uncertainty surrounding the cryptography market. Therefore, if it is hard to predict the future of the currency. We know we are at a point of no technical return behind this digital currency. Its philosophy is also not to be outdone by seeing cryptocurrencies in general and related electronic technology transactions. As technology becomes more and more integrated into our daily lives, it is clear that the cryptocurrency Bitcoin will continue to grow, and bitcoin may be replaced by better

currencies (Jamal and Refk, 2015). Methodologically, "The time series of Bitcoin price are substantially more volatile than those of EURUSD exchange rates, for the sake of comparison, with market bubbles and crashes relatively abundant. Substantial arbitrage opportunities are available for currency USD or EUR currency pairs involving CNY. The HARRVJ model captures well the dynamics of daily Realized Volatility as aggregated on the 5-minute grid". (Lukáš and Taisei, 2017). The time series model is an essential model of volatility research, but there are less variables in this model, so that more and more researchers used GARCH models to improve integrality of test. Ardia et al. (2019) found that Bitcoin daily log-returns have regime changes in their volatility dynamics by Markov-switch GARCH model. And Markov-switch GARCH model shows better in-sample performance than standard single-regime GARCH models. Comparing with different GARCH models, Paraskevi (2018) found that AR-CGARCH is the optimal model with the best goodness-of-fit to data, which means that AR-CGARCH model is the best model to research volatility and returns of Bitcoin. Furthermore, Christina et al. (2019) used bivariate diagonal BEKK-GARCH (1,1) model that allows the modelling of the variance with the covariance and applying the impulse response analysis in a VAR framework to research volatility of Bitcoin and Ethereum. The delayed response of bitcoin volatility to shocks in Ethereum's returns demonstrates the inefficiencies of the bitcoin market, as shocks take time to fully price. Notably, this provides room for a lot of profit and speculation in the most frequently traded cryptocurrency. This can help traders build profit strategies in the derivatives market. This is crucial for traders who are reluctant to include weak cryptocurrencies in their portfolios. As a result, holding bitcoin at a time of weak demand in the bitcoin and Ethereum markets may yield exceptional returns for investors, but it does not prove beneficial as a haven (Christina et al., 2019). Since results of Christian et al. (2018) show that the prediction of bitcoin volatility using the GARCH-MidAS model is superior to the prediction based on the simple GARCH model. For example, when constructing portfolios of Bitcoin and other assets, such as stocks and bonds, their results can be used for improved time-varying portfolio weights. Their results may also be useful for the pricing of bitcoin futures, as they predicted changes in bitcoin volatility over a longer period of time. Finally, simulating bitcoin fluctuations can use the GARCH-MIDAS model in global economic activity or alternative scenarios based on U.S. stock market developments. They predicted to identify these possibilities in future research. However, all of their results are based on a relatively short sample period is that they would like to emphasize. It will be interesting to see if their results hold true in longer samples, and when Bitcoin becomes more mature. Chu et al. (2017) found that, about modeling, IGARCH and GJRGARCH models show the best fit for the volatility of the most popular and largest cryptocurrencies. The IGARCH model belongs to the standard GARCH framework and contains a conditional wave process, which is highly persistent (with unlimited memory), as shown in the literature (Caporale et al., 2003). However, while the conventionally innovative IGARCH (1,1) seems well suited to many users of cryptocurrency, it has shown that this may be due to structural changes in data, which may not be explained, For example, policy changes (Caporale et al., 2003). Therefore, further analysis of the data set may require confirmation or rejection of possible structural changes. The future work is to fit the multivariable GARCH model to describe the combined behavior of the model of bitcoin, Dash, Dogecoin, Litecoin, Maidsafecoin, Monero and Ripple exchange rates. This will require methodological and empirical development. In addition, we have used value at risk because it is the most popular measure of risk in finance. However, the transfer of value in risk highlights the inadequacy of Basel III expectations (for example, see Kinateder and Wagner (2014)). Therefore, another future effort is to use expected shortages rather than VAR model (Chu et al., 2017).

3. Data

3.1. Data selection

This paper selected closing price of Bitcoin (BTC) from Coindesk that is a famous Bitcoin exchange in all over the world to be research data in period of October 1st, 2013–July 31th, 2020, and there are 2496 observations in the data. By using Eviews 6.0, the data can be showed as a graph that is Figure 2. It illustrates daily closing price of BTC climbed to the top at \$1139.331 on December 5th, 2013, because European sovereign debt crisis (ESDC) happened between 2010 and 2013. In this period, financial crisis made investors to be scared to invest financial products, such as stocks, bonds and futures. However, research found that they are willing to put their money in traditional currencies, such as, gold, and silver and cryptocurrencies, such as, Bitcoin, Ethereum and Litecoin in down-trend economic tendency (Bouri et al., 2017). After that, daily closing prices of BTC slightly change from the beginning of 2014 to the end of 2015. In addition, BTC closing price rapidly increased during 2016–2017. Its closing price suddenly reached to historical peak at \$20000 that is 23 times more than one year ago in that time, although there were several fluctuations in the period of 2017. There are some reasons about why daily closing price of BTC rising up as follow. Firstly, due to global financial markets crashing in September, 2016, investors went to hedge negative shocks of financial crisis, leading to investing currencies which conclude traditional currencies and digital currencies. That is because traditional and digital currencies still at low price and their premiums were normal even undervalued, resulting in those currencies as safe-haven property in that time. Secondly, some countries, such as Australia, India, Pakistan and Venezuela, open their markets to reform their currency system and relevant laws in order to avoiding risks and hedging, so more and more investors and medias started to pay attention on BTC. Thirdly, quantity of BTC reduced in 2016–2017, which means BTC will be less than before and harsh calculation will be hard than before, so every reducing of BTC makes its mining to be hard than before. However, when its closing price rase up so high with more and more terrified emotion of investors, the price suddenly had a vertiginous drop from \$20000 to \$13000. There were a great number of investors to sell their BTC, but BTC price return to \$17000, which only used 2 months. During September, 2017–December, 2017, most people guessed BTC will overtake historical peak again, but, unfortunately, BTC closing price fell off a chiff from \$17000 to \$6000 in Dec. 2017–Feb. 2018. After that, investors gradually started to sell a great number of BTCs and change their investment ways. On one hand, BTC price was overvalued and overheat in that time, so it lost real valuation and more investors were not to invest but to speculate it in its price increasing time. On the other hand, global financial trend slowly recovered, so that more investors were willing to put their money into undervalued assets, because they can earn more money from undervalued assets than overvalued assets. After crazy time, BTC closing price continued to dramatically decrease at \$6000 with some fluctuations. Until Oct. 2018, BTC closing price had a big crash to \$3800 in Jan. 2019. There are some reasons as follow. The first, cryptocurrencies bubbles were broken by survival of the fittest. There were a lot of bad cryptocurrencies to be weeded out by market. The second, Coindesk, the biggest cryptocurrencies exchange platform in Japan, attacked by hackers, which leads investors to lose a lot of money, so they lose their heart in cryptocurrencies markets. More importantly, some counties started to reinforce limitation and supervision in trade of cryptocurrencies in order to avoiding money laundering and other financial crimes. Besides, some countries banned trade of cryptocurrencies, such as China and Korea. After four months, closing price of BTC rapidly grew up

at \$11000 again. The main reason is BTC halve again, which means it will be hard to mining than before, so investors focus on it again and think it will be more valuable. After crazy time again, closing price of BTC gradually trended to down-trend. Until July, 2020, BTC's daily price kept to fluctuate with mean at \$8000.
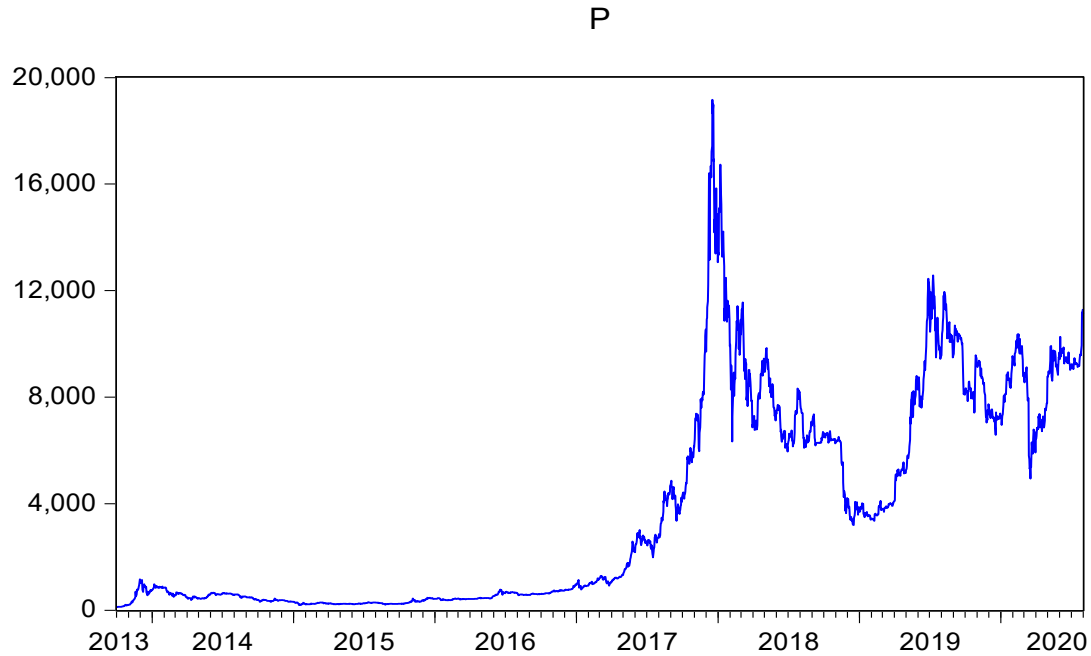
P

Figure 2. Daily closing price of Bitcoin (USD).

P_t is used to be closing price of Bitcoin on day t. In estimation process, daily rate of return is considered to be a variable which can be easily observed. In order to reducing the errors in this process, natural logarithm treats the daily rate of return, which means that the daily return of Bitcoin is expressed as a logarithmic first-order difference of the closing prices of the next two days. Formula of Bitcoin returns is that:

$$r = \log\left(\frac{P_t}{P_{t-1}}\right) \tag{1}$$

All analysis of data of the research is based on Eviews 6.0 and Excel to finish.

3.2. Statistics analysis

Figures 2 and 3 show the descriptive statistics of Bitcoin's daily return rate.
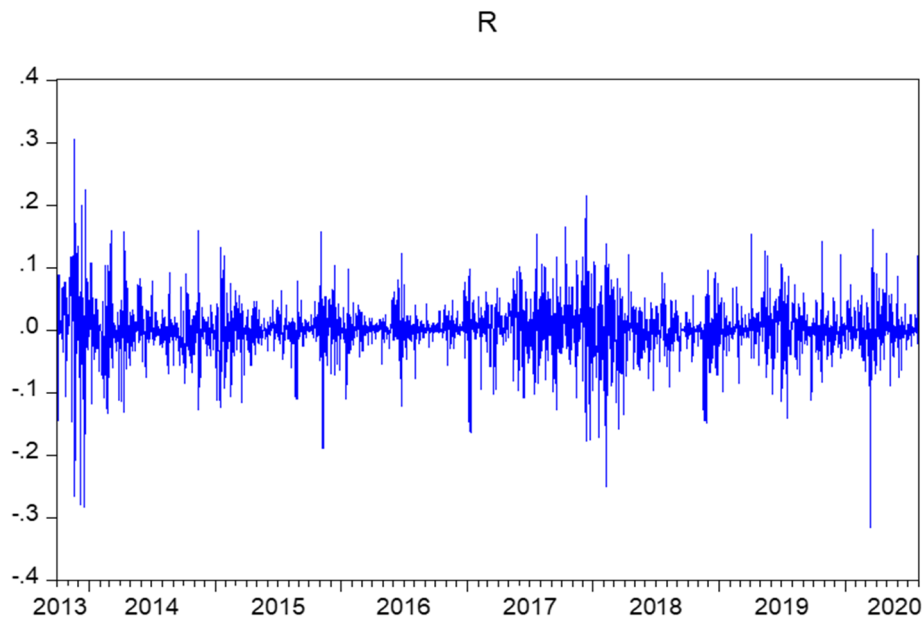

Figure 3. Bitcoin daily rate of return r volatility graph.

Figure 3 is the volatility diagram of the daily rate of return r of Bitcoin. The figure illustrates that fluctuation of daily rate of return (r) shows obvious time-varying, clustering and sudden characteristics. From the figure, it clearly shows that Bitcoin daily return in period of 2013 had strongly volatility. Because in 2013 European sovereign debt crisis (ESDC) brought financial crisis, people pay attention on currency which was not overvalued as safe-haven property. Apart from this, the volatility of daily return in 2013 was the strongest in whole sample time. After that time, the volatility gradually reduced, then it suddenly grew up in Jan. 2014–Jan. 2015. However, until mid of 2015, the volatility slowly decreased. Then the volatility repeated to be up and down again from beginning of 2015 to end of 2016. Interestingly, volatilities crowded in 2017–2018. Combining Figure 2 and Figure 3, two graphs show that Bitcoin daily price changed frequently between 2017 with 2018. Because Bitcoin halving and other reasons, there are a great number of investors who focused on it and invested it, leading to daily returns enormously changing in the time. The volatility of returns of Bitcoin firstly rose up in 2017, but it quickly decreased in 2018. After that, the volatility kept to be up and down in 2019. Specially, because COVID-19 virus and trade war between with China and the USA in 2020, economy of all over the world show a down-trend tendency. Therefore, Bitcoin still as a safe-haven asset to hedge negative shocks.
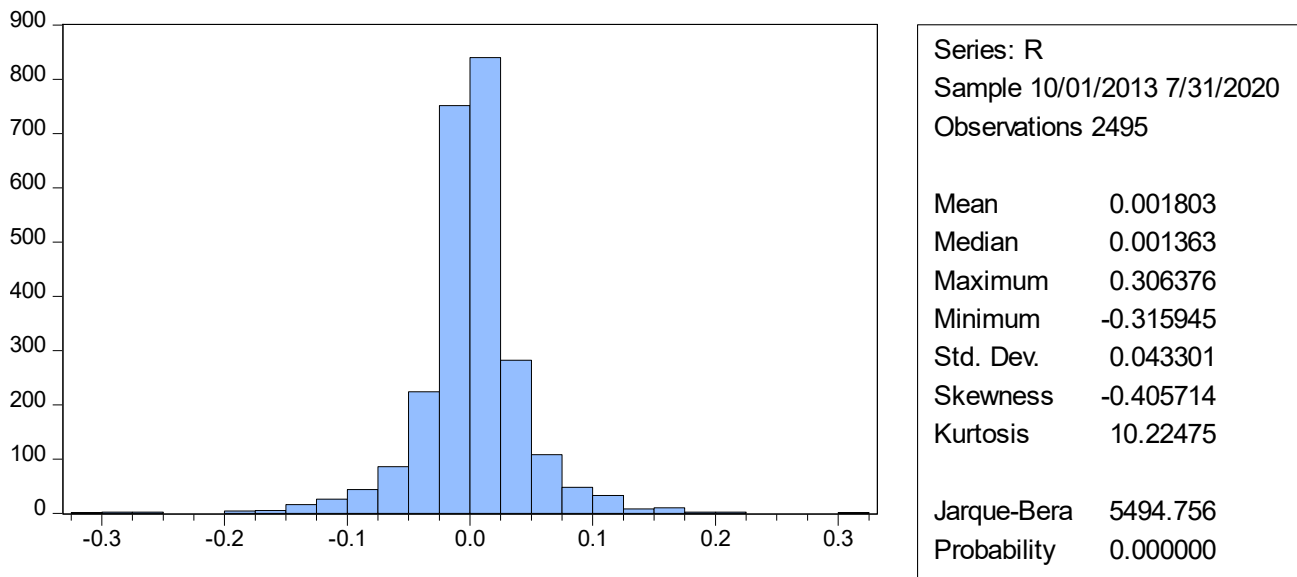
Figure 4. Histogram of Bitcoin's return rate (r).

It can be seen from Figure 4 that, during the sample period, the average value of Bitcoin daily return (r) is 0.1803%, and standard deviation is 4.3301%, and skewness is −0.405714, and the left skew kurtosis of 10.22475 are much higher than the normal distribution of kurtosis 3. The daily rate of return (r) shows a characteristic of sharp peak and thick tail. his feature is confirmed its normality test. Besides, J-B statistic is 5494.756. The rate of return (r) is significantly different from the normal distribution at a very small level, that is, if the sequence uses F test or all the test methods based on the normal distribution statistical method cannot test the return sequence.

3.3. Stability test of Bitcoin return rate series

Unit root method, the most common method in stationarity testing, proposed by two American statisticians who are DA Dickey and WA Fuller in the 1970s. It is to judge whether the autocorrelation coefficient is equal to 1. method. After nearly 30 years of research in academia, this method is finally summarized as ADF test, that is, Augmented Dickey-Fuller test method.

From the above descriptive statistical analysis, it can be seen that the return rate series fluctuates around the mean, and there is no trend (R Mean = 0.001803). Therefore, the ADF unit root test is performed on the sequence, and 4 lags are selected, with an intercept term and no trend term. The test results are as follows:

Table 1. Test of the stability of the rate of returns.

		t-Statistic	Prob.*
Null Hypothesis: R has a unit root			
Exogenous: Constant			
Lag Length: 4 (Fixed)			
Augmented Dickey-Fuller test statistic		−20.736	0.000
Test critical values:	1% level	−3.433	
	5% level	−2.863	
	10% level	−2.567	
*MacKinnon (1996) one-sided p-values.			

From the unit root test result, it can be seen that the t value of the bitcoin return rate series is −20.736, which is much smaller than −3.433 at the 1% level. Ho is rejected, indicating that the bitcoin return rate r obeys the I (0) process, that is, there is no unit the root is a stationary time series.

4.   Methodology

4.1.   ARCH model

In econometrics, autoregressive conditional heteroscedasticity (ARCH) model, a statistical model for time series data, describes variance of the current error term or innovation as a function of the actual sizes of the previous time periods' error terms. Normally, the variance is related to the squares of the previous innovations. The ARCH model is appropriate when the error variance in a time series follows an autoregressive (AR) model. ARCH models are commonly employed in modeling financial time series that exhibit time-varying volatility and volatility clustering, for example, periods of swings interspersed with periods of relative calm. ARCH-type models are sometimes considered to be in the family of stochastic volatility models, although this is strictly incorrect since at time t the volatility is completely pre-determined (deterministic) given previous values.

Using ARCH model to model a time series, ϵ_t expresses returns or residuals of returns and σ_t, a time-dependent standard deviation, characterizes the typical scale of the terms. In addition, z_t is random variable with a strong white noise process.

$$\epsilon_t = \sigma_t z_t \tag{2}$$

The series σ_t^2 is modeled by:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 \epsilon_{t-2}^2 + \cdots + \alpha_{q-1} \epsilon_{t-q-1}^2 + \alpha_q \epsilon_{t-q}^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 \tag{3}$$

where > 0, and $\alpha_i \geq 0$, i > 0.

4.2. GARCH models

4.2.1.   GARCH and ARMA models

Generalized autoregressive conditional heteroskedasticity (GARCH) model transforms from an autoregressive moving average (ARMA) model, when ARMA model is assumed for the error variance.

GARCH (p, q) model is a normal GARCH model. p is order of the GARCH terms. α^2 and q is the order of the ARCH terms ϵ^2.

Equation of GARCH (p, q) model is:

$$y_t = x_t'b + \epsilon_t \tag{4}$$

$$\sigma_t^2 = \omega + \alpha_1\epsilon_{t-1}^2 + \cdots + \alpha_q\epsilon_{t-q}^2 + \beta_1\sigma_{t-1}^2 + \cdots + \beta_p\sigma_{t-p}^2 = \omega + \sum_{i=1}^{q}\alpha_i\,\epsilon_{t-i}^2 + \sum_{i=1}^{p}\beta_i\,\sigma_{t-i}^2 \tag{5}$$

4.2.2.   GARCH (1,1) model

Nonlinear Asymmetric GARCH (1,1) (NAGARCH) is a model with the specification:

$$\sigma_t^2 = \omega + \alpha(\epsilon_{t-1} - \theta\sigma_{t-1})^2 + \beta\sigma_{t-1}^2 \tag{6}$$

$\alpha > 0$, $\beta \geq 0$, $\omega > 0$ and $\alpha(1 + \theta^2) + \beta < 1$, which ensures the non-negativity and stationarity of the variance process. This model reflects a phenomenon commonly referred to as the "leverage effect", signifying that negative returns increase future volatility by a larger amount than positive returns of the same magnitude.

4.2.3.   EGARCH model

The exponential generalized autoregressive conditional heteroskedastic (EGARCH) model is another form of the GARCH model. Formally, an EGARCH (p, q):

$$log\sigma_t^2 = \omega + \sum_{k=1}^{q}\beta_k\,g(Z_{t-k}) + \sum_{l=1}^{p}\alpha_k\,log\alpha_{t-k}^2 \tag{7}$$

where $g(Z_t) = \theta Z_t + \lambda(|Z_t| - E(|Z_t|))$, the conditional variance is σ_t^2, coefficients are ω, β, α, θ, λ. Standard normal variable or come from a generalized error distribution is Z_t. The equation for $g(Z_t)$ allows the sign and the magnitude of Z_t to have separate effects on the volatility. Since $log\sigma_t^2$ may be negative, there are no sign restrictions for the parameters.

4.2.4.   Asymmetry

About Asymmetry, there are a lot of sufficient evidences to show that negative shocks generate more effects than positive shocks in stock market (Glosten et al., 1993; Bollerslev et al., 2007). There are two theories which have been used to illustrate this negative return and volatility relationship in equities. Firstly, volatility feedback (Campbell and Hentschel, 1992) is one of the theories. This theory shows that the expected increase in volatility increases the required return on equity, leading to a fall in equity prices. In other words, a positive shock to volatility leads first to lower equity returns, which in turn increases the time-varying risk premium. However, the negative change of expected return

tends to be more severe than the positive change of expected return, which leads to the phenomenon of asymmetric volatility. Secondly, leverage hypothesis is another. The leverage hypothesis shows that when ratio of stock and valuation of company decrease but ratio of debt and valuation of company increase, risk of company stock will rise up in dropping valuation of company. This negative relation leads to a spike in the stock volatility (Black, 1976; Duffee, 1995).

Contrary to stocks, the volatility of gold returns has the opposite reaction to negative shocks which means that positive shocks of the same degree produce more volatility than negative shocks (Baur, 2012). Baur (2012) believes that for a commodity, such as gold, such a positive return-volatility relationship cannot be properly explained by leverage effect or volatility feedback (Bollerslev et al., 2007), but is related to a safe-haven asset. When the price of gold rises in the downward movement of the market, investors interpret it as an increase in the uncertainty of the macroeconomic environment, thus transferring the uncertainty and volatility of the stock market to the gold market. In contrast, if gold prices fall during a stock market rally, this uncertainty of volatility is also transmitted to the gold market by investors. With the Commodity Futures Trading Commission (CFTC) accepting bitcoin as a commodity, any evidence of a positive reaction-volatility relationship in the bitcoin market is likely to point to a safe-haven property. These evidences can be used to expand the usefulness of Bitcoin as a hedge against stock market turbulence (Dyhrberg, 2015).

5. Results

5.1. ARCH effect test

5.1.1. Selection of lag order and determination of mean value equation

This article uses time series, which means equation of Bitcoin's return rate (r) takes the following form:

$$r_t = c_0 + \sum_{i=1}^{n} c_i r_{t-1} + \varepsilon_t \tag{8}$$

Regression is performed on the lags 1, 2, 3, and 4 respectively, and the results are shown in Table 2.

Table 2. Selection of autoregressive order.

Lag	AIC	F-statistic
1	−3.44017	1.184208
2	−3.444386	1.266232
3	−3.445114	0.025164
4	−3.446444	4.118333

According to the judgment of AIC that is the smallest and F-statistics that is the most different item in lag 4 with others, Table 2 clearly shows the lag 4 period is the best, so the lag order is selected as 4. Thus, the formula can be written as:

$$r_t = c_0 + c_1 r_{t-1} + c_2 r_{t-2} + c_3 r_{t-3} + c_4 r_{t-4} + \varepsilon_t \tag{9}$$
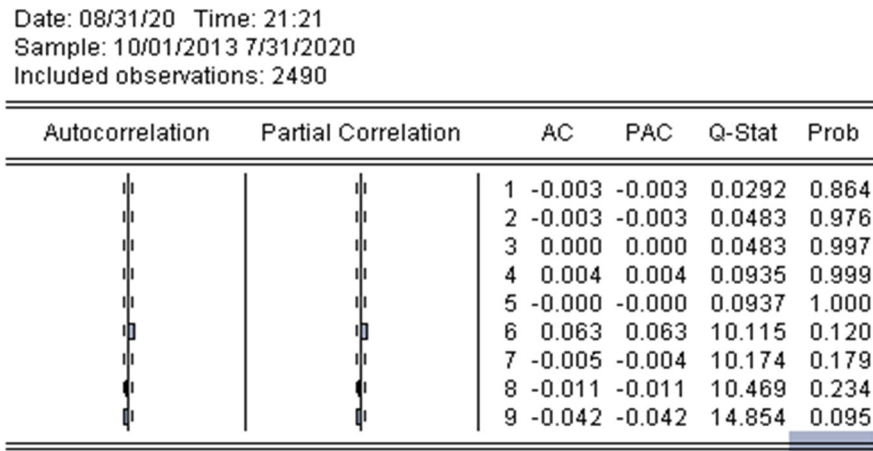
5.1.2. Autocorrelation test of residual series


```
Date: 08/31/20  Time: 21:21
Sample: 10/01/2013 7/31/2020
Included observations: 2490
```

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.003	-0.003	0.0292	0.864
		2	-0.003	-0.003	0.0483	0.976
		3	0.000	0.000	0.0483	0.997
		4	0.004	0.004	0.0935	0.999
		5	-0.000	-0.000	0.0937	1.000
		6	0.063	0.063	10.115	0.120
		7	-0.005	-0.004	10.174	0.179
		8	-0.011	-0.011	10.469	0.234
		9	-0.042	-0.042	14.854	0.095

Figure 5. The AC value and PAC value of the autocorrelation coefficient of the residual term of Bitcoin returns (r).


```
Date: 08/31/20  Time: 21:24
Sample: 10/01/2013 7/31/2020
Included observations: 2490
```

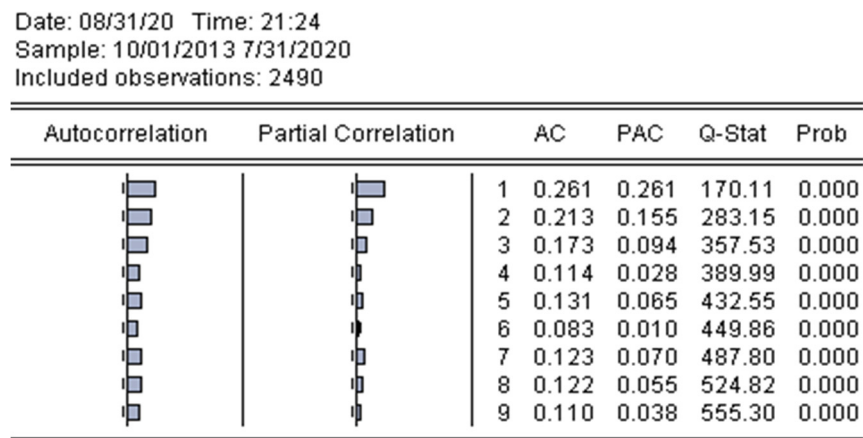| Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.261	0.261	170.11	0.000
		2	0.213	0.155	283.15	0.000
		3	0.173	0.094	357.53	0.000
		4	0.114	0.028	389.99	0.000
		5	0.131	0.065	432.55	0.000
		6	0.083	0.010	449.86	0.000
		7	0.123	0.070	487.80	0.000
		8	0.122	0.055	524.82	0.000
		9	0.110	0.038	555.30	0.000

Figure 6. The autocorrelation coefficient AC value and PAC value of the residual square of the Bitcoin returns (r).

Draw sequence residuals and residual squared autocorrelation graphs. From Figures 4 and 5, we can see that there is no significant autocorrelation in the residual term of the Bitcoin return (r), but the residual squared has significant autocorrelation.

5.1.3. Make a linear graph of the squared residuals
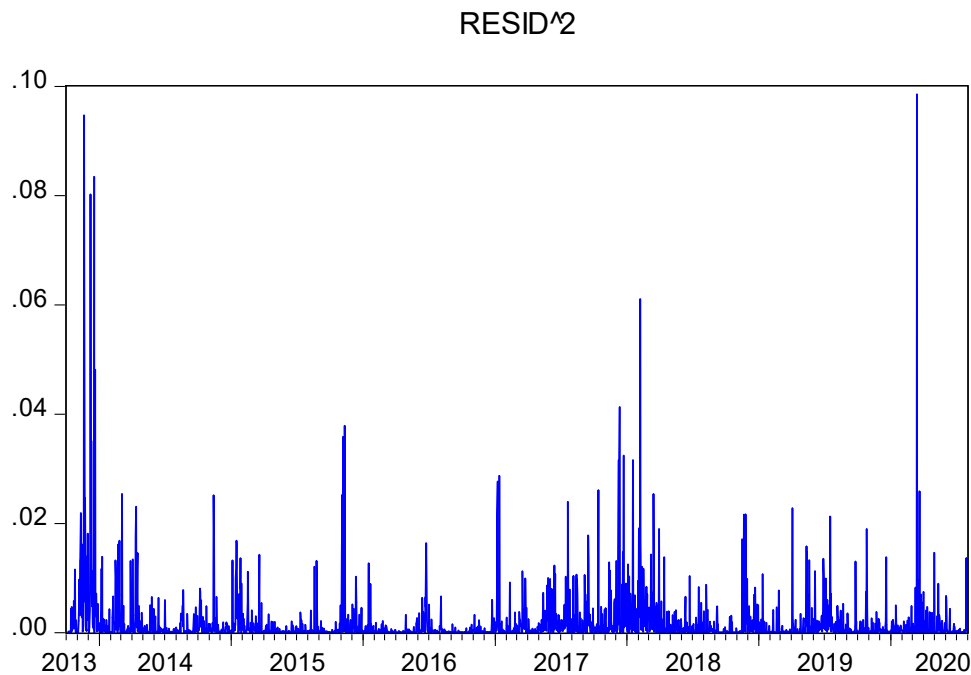

Figure 7. Bitcoin returns (r) residual square line graph.

Draw a line graph of the squared residuals. It can be seen from the figure that the fluctuation of the residual ε_t^2 of the regression equation has the phenomenon of "grouping": Fluctuations are very small in some longer periods of time, and larger in other longer periods of time, that is, they have obvious temporal variability and clustering. This shows that the residual sequence has a high-order ARCH effect, which is suitable for modeling with GARCH models. The graph shows that residuals ε_t^2 in 2013–2014 crowed together with high volatilities, which means that there were a great number of people to invest Bitcoin with crazy emotions in the period of the time. Apart from this, "grouping" phenomenon suddenly came up again in 2017–2018. It can be explained by halving of Bitcoin that resulted in overvaluation of Bitcoin and bubble of Bitcoin that leaded investors to rapidly sell their bitcoins, so that volume of transactions of Bitcoin was really large. In 2020, although "grouping" phenomenon is not very obvious, volatility keeps a high level. To sum up, mean of volatility of Bitcoin always keeps a high level and fulminant buying and selling of Bitcoin crowd in a period of time.

5.1.4. Perform ARCH-LM Test on the residual (lag 9th order)

Table 3. ARCH-LM test on the residual of Bitcoin return.

Heteroskedasticity Test: ARCH			
F-statistic	35.50890	Pro. F (9,2472)	0.0000
Obs*R-squared	284.1393	Pro. Chi-Square (9)	0.0000

ARCH-LM test is performed on the residuals of serial linear regression, and the test object of the F statistic is the joint significance of the squared residuals of all lags. The Obs*R2 statistic is the LM test statistic, which is the number of observations T multiplied by the test regression R2. Given the

significance level α = 0.05 and the degree of freedom 9, the value of LM is 284.1393 greater than the critical value of 16.9190, and the concomitant probability P is 0.0000, which is less than 0.05. The null hypothesis is rejected. It shows that there is obvious heteroscedasticity in the return sequence, and the residual has strong ARCH effect. Therefore, it is reasonable for this article to use the GARCH model to simulate the data of Bitcoin's returns rate.

5.2. ARCH effect test

5.2.1. Research on the volatility of Bitcoin returns

The estimation results of GARCH (1,1) model are shown in Table 4:

Table 4. GARCH (1, 1) model estimation results.

Dependent Variable: R
Method: ML-ARCH (Marquardt)–Normal distribution
Sample (adjusted): 10/03/2013–7/31/2020
Included observations: 2491 after adjustments
Convergence achieved after 21 iterations

	Coefficient	Std. Error	z-Statistic	Prob.
C	0.001034	0.000666	1.554104	0.1202
R (-4)	−0.008808	0.020909	−0.421273	0.6736
Variance Equation				
C	0.000076	0.00000553	13.74898	0.0000
RESID (-1) ^2	0.189179	0.013256	14.27126	0.0000
GARCH (-1)	0.785817	0.012448	63.12982	0.0000

$$r_t = 0.001034 - 0.008808\gamma \tag{10}$$

（1.554）（-0.421）

$$\sigma_t^2 = 7.6 \times 10^{-5} + 0.189179\varepsilon_{t-1}^2 + 0.785817\sigma_{t-1}^2 \tag{11}$$

（13.749）（14.271）（63.130）

Log Likelihood = 4731.619 AIC = −3.795 SC = −3.783

From this model, it can be seen that in the conditional variance equation of Bitcoin's return rate, both the ARCH and GARCH terms are highly significant. This significance indicates that the volatility of the return rate series has clustering characteristics. And dependent variable is R and sample time is from October 6th, 2013 to July 31th, 2020, which includes 2491 observations after adjustments. Besides, convergence achieved after 21 iterations. Sum of the ARCH term and the GARCH term of the Bitcoin rate of return is 0.974996 < 1, which meets the constraints on the parameters. But, since the sum of the two coefficients 0.974996 is very close to 1, it can be shown that the impact of the shock on the conditional variance is not transient but a permanent process. Then the impact can be inferred from this feature to play an important role in future predictions, so GARCH (1,1) is a smooth process. However, the conditional variance shows that the influence of past fluctuations is limited, and its influence on the future is gradually attenuating to 0, which is called MEAN-REVERSION.

5.2.2. *Research on the asymmetry of Bitcoin returns*

The estimation results of the TRACH model are shown in the following table:

Table 5. TARCH model estimation results.

Dependent Variable: R
Method: ML-ARCH (Marquardt) – Normal distribution
Sample (adjusted): 10/06/2013 7/31/2020
Included observations: 2491 after adjustments
Convergence achieved after 25 iterations

	Coefficient	Std. Error	z-Statistic	Prob.
C	0.001039	0.000724	1.434527	0.1514
R (-4)	−0.00876	0.021361	−0.4101	0.6817
Variance Equation				
C	7.6E−05	5.56E−06	13.67519	0.0000
RESID (-1) ^2	0.18969	0.016727	11.34065	0.0000
ARCH (1) * (RESID(-1) < 0)	−0.001122	0.015673	−0.071609	0.9429
GARCH (-1)	0.78587	0.012451	63.11544	0.0000

$$r_t = 0.001039 - 0.00876\gamma \tag{12}$$

$$(4.435) \quad (-0.410)$$

$$\sigma_t^2 = 7.60 \times 10^{-5} + 0.18969\varepsilon_{t-1}^2 - 0.001122\varepsilon_{t-1}^2 d_{t-1} + 0.78587\sigma_{t-1}^2 \tag{13}$$

$$(13.675) \quad (11.340) \quad (-0.072) \quad (63.115)$$

Log Likelihood = 473.620 AIC = −3.794 SC = −3.780

From Table 5, dependent variable is R and sample time is from October 6th, 2013 to July 31th, 2020, which includes 2491 observations after adjustments. In the TARCH model, the leverage effect term is described by (RESID < 0) * ARCH (1) in the model. The coefficient estimate of the ARCH(1)*(RESID(−1) < 0) (That is, the $\varepsilon_{t-1}^2 d_{t-1}$ in the model) term is negative and not significant ($\beta = -0.001122$, p > 0), which shows that the special price fluctuation does not have a "leverage effect".

The estimation results of the EGRACH model are shown in the following table:

Table 6. EARCH (1, 1) model estimation results.

Dependent Variable: R
Method: ML-ARCH (Marquardt) – Normal distribution
Sample (adjusted): 10/06/2013 7/31/2020
Included observations: 2491 after adjustments
Convergence achieved after 37 iterations

	Coefficient	Std. Error	z−Statistic	Prob.
C	0.001052	0.000646	1.629147	0.1033
R (-4)	−0.025538	0.020908	−1.221422	0.2219
Variance Equation				
C	−0.691107	0.03877	−17.8256	0.0000
ABS (RESID (-1)/@SQRT (GARCH (-1)))	0.336807	0.017652	19.08078	0.0000
RESID (-1)/SQRT (GARCH (-1))	−0.001903	0.008307	−0.229028	0.8188
LOG (GARCH (-1))	0.930196	0.004365	213.0794	0.0000

$$r_t = 0.001052 - 0.025538\gamma \tag{14}$$

$$(1.629) \quad (-1.221)$$

$$Log\ (\sigma_t^2) = -0.691107 + 0.336807 \left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| - 0.001903 \left(\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right) + 0.9682\ log(\sigma_{t-1}^2) \tag{15}$$

$$(-17.826)\quad(19.081)\quad(-0.229)\quad(213.079)$$

As can be seen from the above table, dependent variable is R and sample time is from October 6th, 2013 to July 31th, 2020, which includes 2491 observations after adjustments. In the EGARCH model, the coefficient of the asymmetric term RESID(-1)/@SQRT(GARCH(−1)) is significantly less than zero (β = −0.001903, p > 0.05), indicating that Bitcoin during the sample period. There is no leverage effect in the rate of return. Whether there are negative shocks or positive shocks, the shocks will only bring an impact of α = 0.336807.

6. Conclusions

To sum up, result of GARCH (1,1) model shows that returns and volatility of BTC have clustering characteristics. Combining Figure 7, BTC's returns and volatility sharply increased in the period of 2013–2014, 2017–2018 and 2019–2020. There were some serious evidences happened in the time. European sovereign debt crisis happened in 2013–2014, Trade War between China and the USA started from 2017–2018 and COIV-19 came up during 2019–2020, which all lead financial crisis to all over the world. Interestingly, financial markets' returns declined in the financial crash, but returns and volatility of BTC rose up. This phenomenon can be explained by reduction of interest rate and monetary excessing. Because central banks of countries in our world issue more and more currencies to hedge risks of economic depression with low interest rate, people have more money. However, they want to reduce inflation effect, so investments are conducive to help them. Due to issuing more

currencies, BTC can be a low valuation asset to be invested, so it is concerned by capitals from every country. This is why BTC returns and volatility show clustering feature in serve periods. Besides, by GARCH (1,1) model, we found that shocks affecting conditional variance is a long-term process, so this finding can be used to predict returns and volatility of BTC in the future. However, conditional variance is limited to influence future returns and volatility of BTC and its effect gradually decrease, which can effectively explain why BTC's returns and volatility reduce after financial crisis and crashes.

Furthermore, the paper uses TARCH and EGARCH models to analyze, because GARCH (1,1) model cannot explain "leverage effect" that is an asymmetric effect in returns and volatility research. By results of TARCH and EGARCH models, they clearly illustrate that BTC's returns and volatility do not exist "leverage effect", which means returns and volatility of BTC is a symmetric relationship. But figure of returns and volatility understandably shows an asymmetric effect between positive and negative shocks, for example, when negative shock, COIV-19, came up in 2019–2020, BTC's returns and volatility sharply increased. But, before COIV-19 happening, positive shock brought lower change in its returns and volatility. As an asset BTC should show similar characteristics with other assets, such as stock, bond and gold. However, it illustrates a revised phenomenon, comparing with stock. Similarly, gold returns and volatility appear resemble trend (Baur, 2012). In addition, CFTC accepted BTC as a commodity in Oct. 2015. After that, Anne (2016) indicated that gold and bitcoin have significant correlation, so revised asymmetry of BTC cannot easily explain by "Leverage Effect". Based on this critical thinking, the paper quotes conception of safe-haven property. Safe-haven property is an asset can offer defensed protection in order to hedge risk in financial crisis. Between 2013–2014, 2017–2018 and 2019–2020, BTC played a role of a safe-haven property, so financial institutions and other investors can add Bitcoin into their investment portfolios to efficiently avoid and hedge financial risk.

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Conflict of interest

The authors declare no conflicts of interest in this paper.

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