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The Use of Control Charts in the Study of Bitcoin's Price Variability

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Abstract

The focus of this research is bitcoin's variability and its comparison with the variability of the EURO/USD exchange rate. Virtual currencies have been evolving in a dynamic way in the last few years. Under 600 different virtual currencies, the most successful was bitcoin. Its adherents saw in it an alternative to the traditional means of payments allowing the performance of real-time transactions at low costs. The accessibility, where no financial infrastructure is ensured or where either limited or no international agreements exist between financial and banking institutions was also an advantage. The opponents perceived this as a temporary curiosity with no future. Time confirmed that bitcoin has gained on popularity and the exchange rate to the main currencies rose in a dynamic way. The analysts, however, underline that the bitcoin is too volatile and unpredictable, so it cannot compete against the main currencies. The aim of this research is to compare the bitcoin (BTC) to US Dollar (USD) exchange rate and Euro to USD exchange rate volatility using control charts. The results have shown that BTC/USD exchange rate volatility is strongly affected by unexpected price jumps during the period (2010–2016), an act that significantly distinguishes it from more stable and predictable EUR/USD exchange rate variability.

Keywords: bitcoin, virtual currency, control chart, volatility, exchange rate, BTC/USD, EUR/USD

1. Introduction

Bitcoin is a virtual currency and a quite new phenomenon. It was created in 2008 by Satoshi Nakamoto, who published an article "Bitcoin: A Peer-to-Peer Electronic Cash System" in 2008, in which he described a concept of virtual, decentralized and independent means of payment, which is based on a cryptographic blockchain protocol [1]. His main idea was to build a currency based not on trust but on an algorithm, which cannot be influenced or manipulated. It was thought to be independent of any legal or governmental body. After the first release of

bitcoin, by generating the 'block genesis' in 2009, this currency was gaining rapidly in popularity.

As in September 2015 ca. 667 crypto currencies were established.¹ Among them, bitcoin is considered to be the most popular and the most widely used. According to data published on bitinfocharts.com, bitcoin has the highest market capitalization of more than \$7 billion, representing 89% of the total capitalization of all cryptocurrency. Further down are the Ethereum \$574 million (7.1%), litecoin \$179 million (2.2%) and Dash \$39 million (0.5%). Data published by blockchain.info at the beginning of 2012 indicated that bitcoin had ca. 400 users. This number increased by ca. 970 k at the beginning of 2014 and reached ca. 8.5 m in September 2016 [2].

Within 4 years since its creation, the European Central Bank (ECB) and other financial institutions still have not come to a final conclusion, as to the classification of bitcoin and other cryptocurrencies. They have not recognized virtual currency as money or as a commodity. As such, the current legislation does not regulate events resulting thereof. The official definition of a 'virtual currency' was set up by a European Central Bank in 2012 for the first time, according to which 'a virtual currency is a type of unregulated, digital money, which is issued and usually controlled by its developers and used and accepted among the members of a specific virtual community' [3]. This definition associated virtual currency with a virtual world in a strict sense and the connection to the real economy was nearly neglected. Nowadays, bitcoin is similar to other virtual currencies that can be traded or exchanged for real money and goods and is accepted by many merchants all over the world. That is why in 2016, the International Monetary Fund (IMF) has extended the definition specifying, that 'virtual currencies can be obtained, stored, accessed and transacted electronically and can be used for a variety of purposes, as long as the transacting parties agree to use them' [4].

According to the IMF, the impact of virtual currencies on the real economy and the financial system is limited. It is, however, possible that with the increase of trading volume and acceptability, virtual currencies can become a serious threat to the financial and banking sector. One of the obstacles to the development of bitcoin named by IMF is its unstable variability.

The purpose of this study is to assess the validity of whether the dollar (USD) is more stable than the bitcoin (BTC) using \bar{x} -s and CUSUM control charts. Depending on the outcome thereof, it will evaluate the concerns of sceptics pertaining to bitcoin and its further development and acceptance in the long term. If it turns out that the volatility of bitcoin does not deviate significantly from the volatility of dollar, then the fears of some financial institutions might appear to be valid.

2. Literature review

Bitcoin is gaining much more popularity not only among financiers but also among scientists. However, a limited number of scientific papers pertaining to cryptocurrency have been

¹https://bitinfocharts.com/pl/index_v.html

published. Given the above, the proposed content will be an important contribution to studies of both control cards and bitcoin. Current scientific achievements can be divided into four main fields of interest.

- A general and theoretical background concerning the origin, formation and characteristics of bitcoin, e.g. [5–9].
- A number of reports focusing mainly on issues relating to acquisition (mining), trade and broadly understood security, e.g. [10–15].
- The third large group of articles concerns the regulatory environment, including tax-specific policies and possible solutions that regulate the functioning of cryptocurrency in the financial area, e.g. [16–18]. This group also includes various types of reports, publications or banks, financial institutions and government statements on bitcoin, i.e. European Central Bank [19–21] Congressional Research Service acting on the needs of the US Congress [22, 23], Canadian Central Bank [24–26].
- The last group of papers focuses on the application of quantitative methods in the study of Bitcoin.

Generalized autoregressive conditional heteroscedasticity models (GARCHs) were applied to investigate similarities between bitcoin and both US dollar and gold [27, 28]. It was found that bitcoin-like other cryptocurrency tend to generate bubbles and that they do not have fundamental value [29]. Moreover, bitcoin fluctuations are characterized by sudden jumps and extreme pricing, which is characteristic for immature markets [30]. Autoregressive moving average and log-periodic power law models were applied to show that the price of bitcoin depends on the Chicago Board Options Exchange Index Volatility Index, which is indicative of speculation potential [31]. Other scientists argue that fluctuations in the price of Bitcoin are positively correlated with the amount of BTC users and are determined by the shocks of unknown sources of origin. The latter have an endogenous character and are not generated by the impact of specific variables, such as indexes S&P 500, gold rate against the US dollar or (XAU) and the Shanghai stock exchange index (SSE) [32]. According to Bouoiyour et al. [33], bitcoin's price fluctuations are best characterized by a generalized hyperbolic distribution.

The variability of bitcoin against the dollar in 2015 significantly decreased compared with the preceding period. The authors also claimed that bitcoin can be characterized by excessive asymmetry and the price is prone to the negative shocks negative than positive once.

3. Methodology

Statistical process control (SPC) has found its application in many scientific areas. One of the tools, which are used by the SPC, is control charts (see **Figure 1**). A control chart (CC) is a graphical representation of a process. It presents an average value of the quality characteristics reflected on the chart by a central line (CL). Auxiliary lines, called upper control limit (UCL) and lower control limit (LCL), are used for the presentation of deviations from the mean of the process. Control limits are usually set as three times the standard deviation (3-sigma (σ) limits).

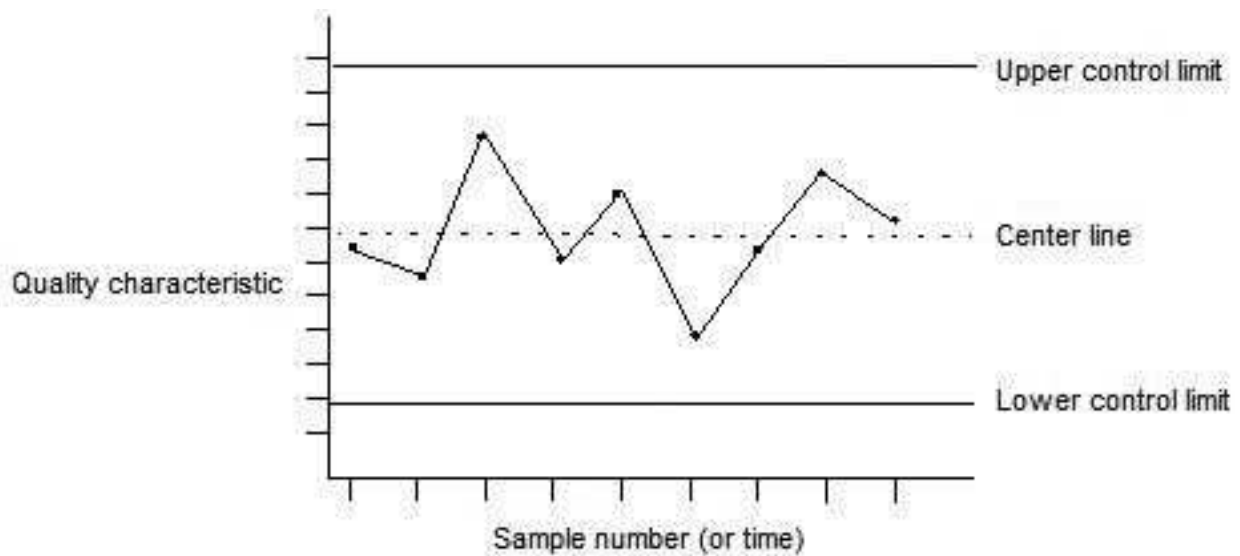


Figure 1. Control chart scheme.

The main idea behind control charts is to monitor an underlying process. If the observations fluctuate in a natural way within set advance control limits and if they do not reveal any specific patterns, then it is said that the process is under control. If, however, the monitored process breaks the established control limits, then it is understood that the process is out of control and specific actions should be launched to return the process under control. For further details considering control charts, please refer to Ref. [34].

SPC uses different types of charts, depending on the type of data used. For the continuous data, the following charts dedicated to variables are used:

- xbar-s charts (controlling the mean and standard deviation of a process),
- xbar-r chart (calculating the mean and the range of a process),
- charts for moving ranges, etc.

For data based on countcharts for attributes are applied, e.g. np chart, p chart, c chart, u chart, etc.

For the purpose of this research, the following control charts will be applied, namely an xbar-s chart and a CUSUM with the moving range chart.

3.1. Xbar-s chart

Xbar-s charts are used to monitor the variation and mean of the process. If the sample size (n) is not constant and is relatively large ($n > 10$), in such a case xbar-s charts are preferable against xbar-R chart.

For the unknown parameters of the s-bar chart and the variable sample size, the central line is defined as an average standard deviation for all samples (Eq. (1))

$$\bar{s} = \sqrt{\frac{\sum_{i=1}^m (n_i - 1) s_i^2}{\sum_{i=1}^m n_i - m}} \quad (1)$$

where m is the number of samples, n_i is the individual sample size and s_i is an individual value of standard deviation for each sample defined as $s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$.

The upper (Eq. (2)) and lower control limit (Eq. (3)), which define the boundaries for the (3σ) -three-sigma control limits are calculated based on the following formulae:

$$UCL = \left(1 + \frac{3}{c_4} \sqrt{1 - c_4^2}\right) \bar{s} \quad (2)$$

$$LCL = \left(1 - \frac{3}{c_4} \sqrt{1 - c_4^2}\right) \bar{s} \quad (3)$$

where c_4 is a constant.

Similarly, the control limits are determined for the xbar chart, which accompanies the s-chart. The central line is calculated as an average value of the individual averages (Eq. (4))

$$CL = \bar{\bar{x}} = \frac{\sum_{i=1}^m n_i \bar{x}_i}{\sum_{i=1}^m n_i} \quad (4)$$

The three-sigma control limit is determined by the upper control limit (Eq. (5)) and the lower control limit (Eq. (6)) in the form:

$$UCL = \bar{\bar{x}} + \frac{3\bar{s}}{c_4\sqrt{n}} \quad (5)$$

$$LCL = \bar{\bar{x}} - \frac{3\bar{s}}{c_4\sqrt{n}} \quad (6)$$

It is assumed that the underlying process is under control if it varies between defined control limits. The breach of any of the control limits points at the process being out of control.

3.2. CUSUM and MR chart

Moving range chart enables to plot the sum of ranges of the adjacent pairs of observation within the investigated period. The central line (see Eq. (7)) is calculated as an average range of k -samples and the control limits (see Eqs. (8) and (9)) are set as m -times deviation from the average process range.

$$\bar{R} = \frac{\sum_{i=1}^k R_i}{k} \quad (7)$$

$$LCL = \bar{R} - md_3\hat{\sigma} \quad (8)$$

$$LCL = \bar{R} + md_3\hat{\sigma} \quad (9)$$

where R_i is a range in sample i , k is the number of samples, m is a multiplier chosen to establish control limits, usually set to 3 and d_3 is a constant and $\hat{\sigma}$ is an estimated variance of a process.

CUSUM control charts plot the cumulative sum of deviation from the assumed target value (see Eq. (10)).

$$C_i = \sum_{j=1}^i (\bar{x}_j - \mu_0) \quad (10)$$

where C_i is a cumulative sum, \bar{x}_j is mean of a process in sample j , average and μ_0 is target value.

If the process is under control, then a cumulative sum (C_i) follows a random walk process with mean equals 0 [35]. It is assumed that the process is out of control, if the average values drift from the target value. If the values move in the positive direction, then the upper cumulative sum is written as in Eq. (11).

If, however, they move into the negative values, then the lower cumulative sum is defined as in Eq. (12). Finally, if the process exceeds the decision interval, which is contained between the positive and negative sum, then it is assumed, that the process is out of control:

$$C_I^+ = \max\left(0, \bar{X}_i - (\mu_0 + K) + C_{i-1}^+\right) \quad (11)$$

$$C_I^- = \max\left(0, (\mu_0 + K) - \bar{X}_i + C_{i-1}^-\right) \quad (12)$$

where k is a target value, $C_0^+ = C_0^- = 0$, C_i is cumulative sum for sample i .

4. Results

4.1. BTC/USD

The main goal of this research was to compare the variability of two exchange rates: bitcoin to US Dollar (BTC/USD) and Euro to US Dollar (EUR/USD). The average exchange rates for the quarterly data between 2010 and 2016 will be taken into consideration. The final result of the appliance of the xbar-s chart for BTC/USD is presented in **Figure 2**.

It is visible that the process is out of control and the layout of the chart is strongly affected by the significant volatility exchange rate increase in 2013. In the period before, it was a long run

of very low prices. After the peak in 2013, the level of the exchange rate has never reached a comparable value. Taking the above into consideration, the whole investigated period should be divided into consistent and disjoint periods, i.e. the covering time before the positive price shock, namely the year 2013 and the period after 2013. An attempt to analyse the whole period can be misleading due to the faultily estimated control lines understood as a process average and standard deviation.

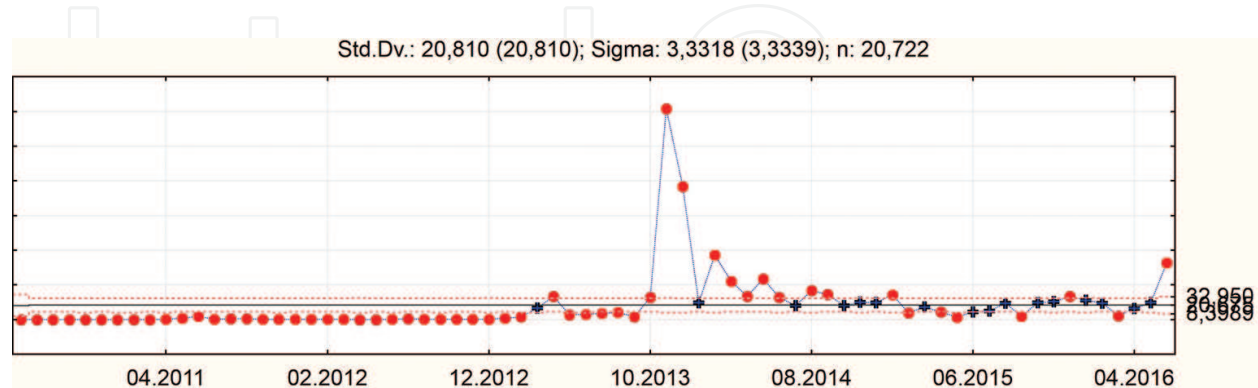


Figure 2. xbar-s chart BTC/USD 2010-2016.

The first studied period was the initial phase of the development of bitcoin. Within that time, the exchange rate has changed significantly, starting from 0.08 USD for 1 BTC, reaching 13.51 USD for 1 BTC at the end of 2012. The xbar-s chart (Figure 3) has generated the CL at the level of 0.62. The layout of the chart suggests that the process being out of control in the period reaching April 2011, when the average volatility was significantly under the LCL equalling to 0.31.

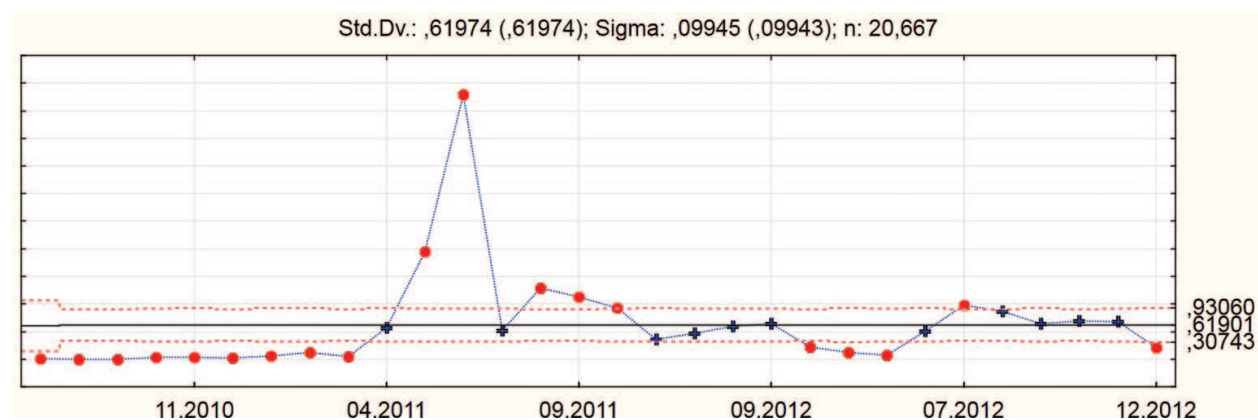


Figure 3. xbar-s chart BTC/USD 2010-2012.

This is justified, as within that time, the price was significantly lower than in other periods. Small changes in prices had almost no effect on volatility. The numbers for May and June have breached the UCL, which equals to 0.93. This peak was connected with strong price jumps, up to 18.50 USD for BTC. The other periods were relatively stable.

A permanent breach of control limits on both sides of CL may be observed, but the deviations are not essential. It is worth to mention that between the years 2010–2012, the graph may imply

a pattern. The observed standard deviations tend to move in the same direction almost every 4 months. The extension to the bitcoin volatility analysis gives the MR chart (**Figure 4**) and CUSUM chart for the standard deviation (**Figure 5**). At the beginning of the investigated process, the exchange rate volatility was dropping constantly. Commencing in April 2011 it is starting to grow, in par with the price increase. After a strong peak in price, which has also a solid and positive effect on price volatility, the bitcoin faced a volatility decrease at the end of 2011, after which the process started to normalize. This phase lasted until the next shock at the end of 2012, where the volatility has started to grow again.

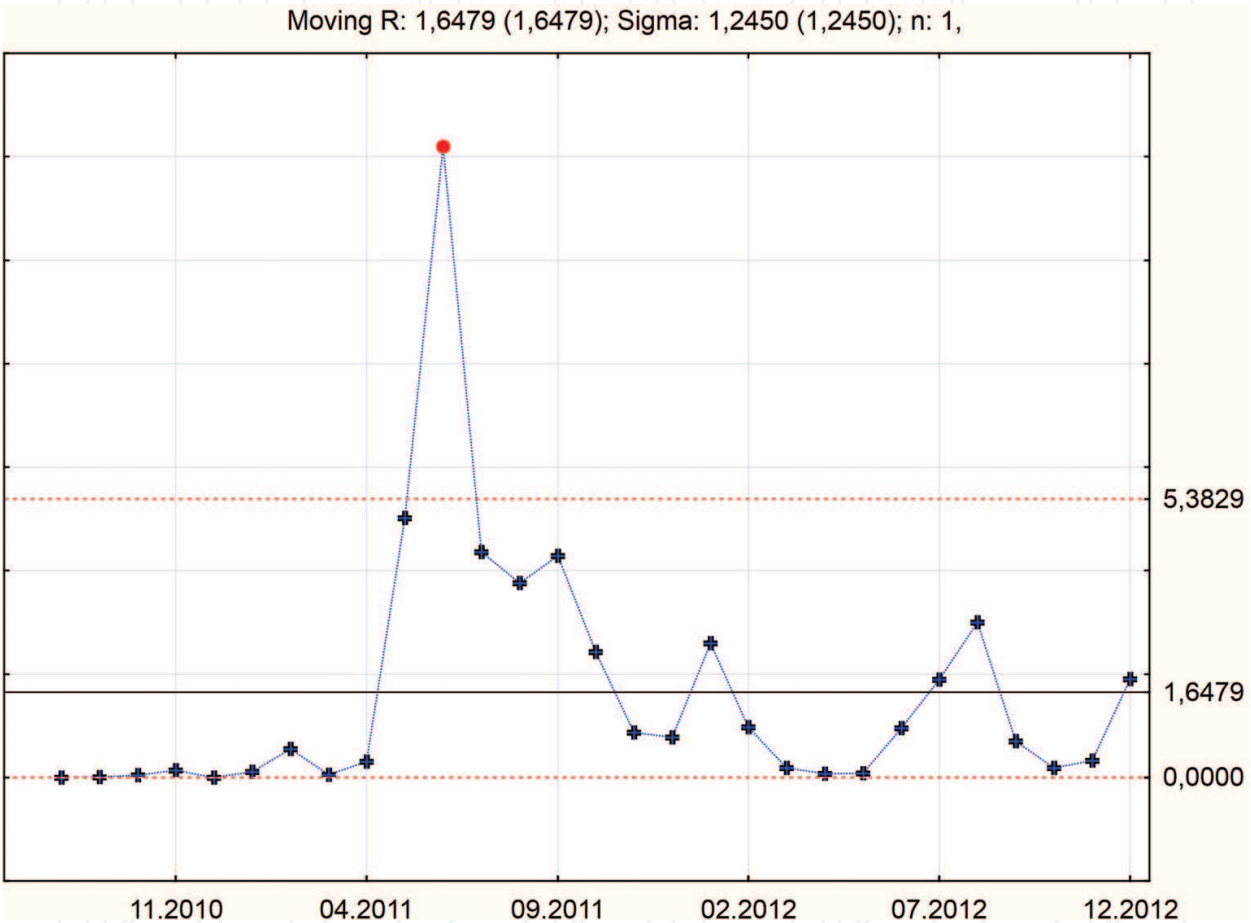


Figure 4. MR chart BTC/USD 2010-2012.

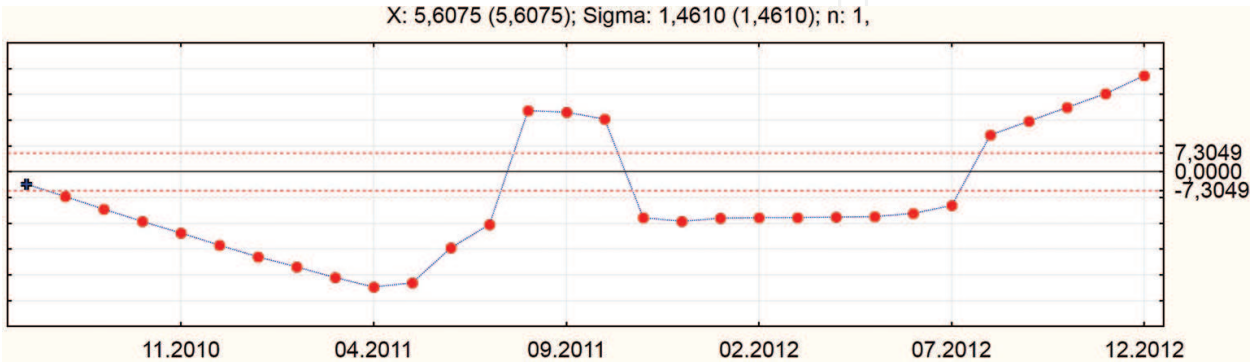


Figure 5. CUSUM BTC/USD 2010-2012.

In 2013, the BTC/USD sudden price jump was observed, which has affected the average price volatility strongly. Throughout the year 2013, the exchange rate was developing steadily (see **Figure 6**). The jump took place between October and November. In this period, exchange rate has risen from 155 to 870. The average price volatility for the year 2013 equals to 51.87. If only the first 10 months of the year were considered, then the CL would be at the level of 12.65.

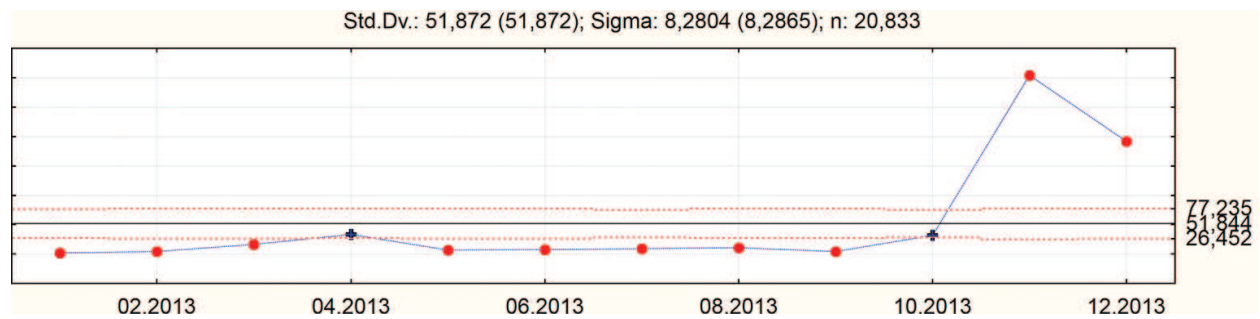


Figure 6. xbar-s chart BTC/USD 2013.

Moreover, the MR chart (**Figure 7**) shows that within the period between January and October 2013 ranges have fluctuated at the zero line until the exchange rate jumps, which caused an increase of almost 150, thereby, the whole process is said to be significantly out of balance.

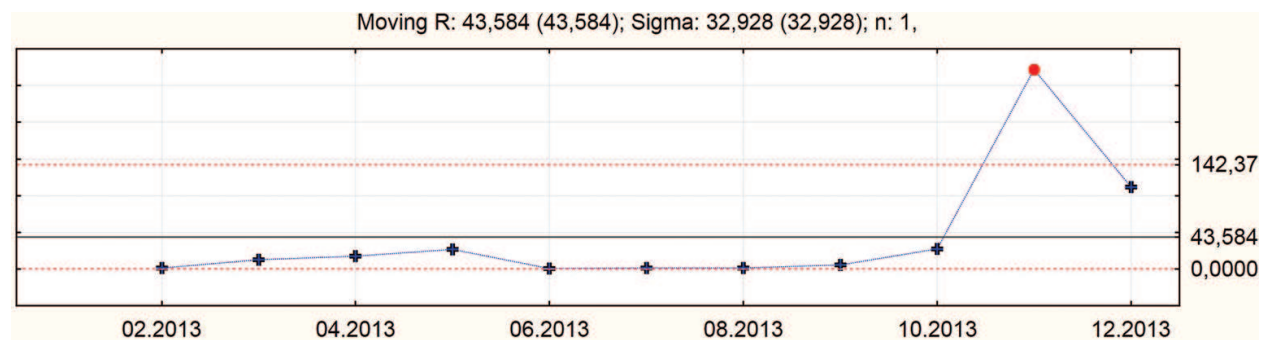


Figure 7. MR chart BTC/USD 2013.

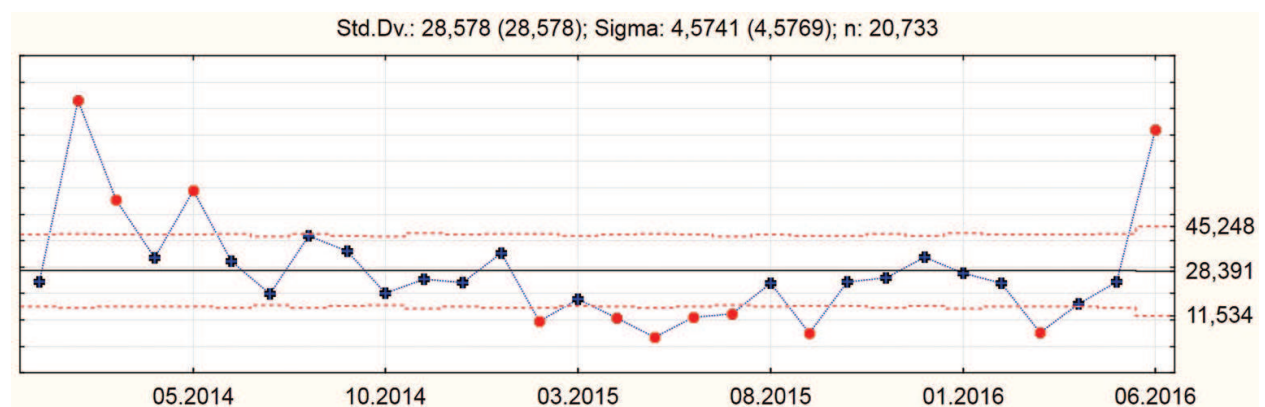


Figure 8. xbar-s chart BTC/USD 2014-2016.

Bitcoin development during the period (2014–2016) was more stable compared to the previous years. The value for the central line in s-chart (**Figure 8**) has declined to 28.4 compared with the year 2013. At the beginning and at the end of the investigated period the price fluctuations

were observed. In January 2014, the exchange rate has reached the level of 649, which was the continuation of the price increase from the year 2013 and in 2016, when the price reached again the limit of 687 US Dollars for a Bitcoin.

The s-chart has produced warning signals concerning a high volatility between February and May 2014 and for June 2016 by breaching the UCL (45.25), as well as signals for low volatility between March and September 2015 by breaching the LCL (11.53). This downturn shift in price was also reflected by the CUSUM chart (**Figure 9**).

These have caused a shift in a process, which was followed by the constant movement with the decreasing tendency of deviations from the process mean until the end of the considered period.

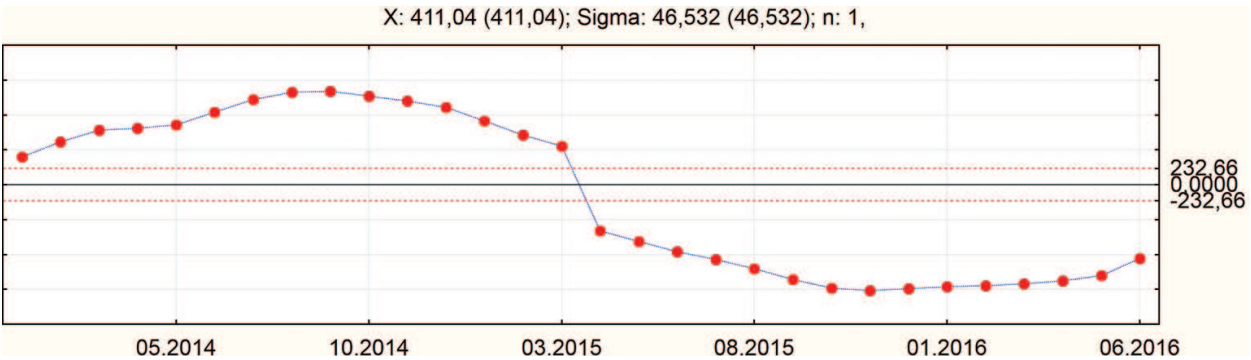


Figure 9. CUSUM chart BTC/USD 2014-2016.

4.2. EUR/USD

The USD/EUR exchange rate volatility seems to be more stable within whole investigated period (see **Figure 10**) compared to the results for BTC/USD (**Figure 2**). The CL generated by the s-chart was at the level of 0.012. The volatility during the years 2010 and 2011 passes the UCL. Global financial crisis has impacted EUR/USD exchange rates strongly. After the crisis hit Greece in 2009 it has moved on and inadvertently affected other European countries, e.g. Spain and Italy. This was the most significant and long-lasting process disruption signalled by the control chart. The other breaches, which appeared in 2014 and at the beginning of 2015, are very close to the LCL (= 0.0052) and UCL (= 0.02). The deviation from CL seems to be not substantial, especially considering the process standard deviation at the level of 0.002.

This development was also reflected by the CUSUM chart (**Figure 11**), where mainly the above average values for the standard deviation were signalled in the year 2010 and the beginning of the year 2011. The rest of the process despite the visible downturn trend remained between the UCL (0.029) and LCL (-0.029).

The central line, which reflects the average standard deviation for the entire process equals 0.1272. If the time after 2013 was considered, then the average standard deviation would be equal to 0.1040, hence both results were at a comparable level.

The EUR/USD exchange rate volatility starting from June 2010 was in the downward trend, which ended in December 2014. The s-chart has produced warning signals for points beyond

the control limits, which were set at a level of 0.02027 for the UCL and 0.00516 for the LCL, respectively. The first signals were produced for the period between August 2010 and October 2011. Strong fluctuations in this time were caused by weak economic data mainly from the United States. It is worth to mention that this was the period short after the economic crisis, when most of the world economies were unstable.

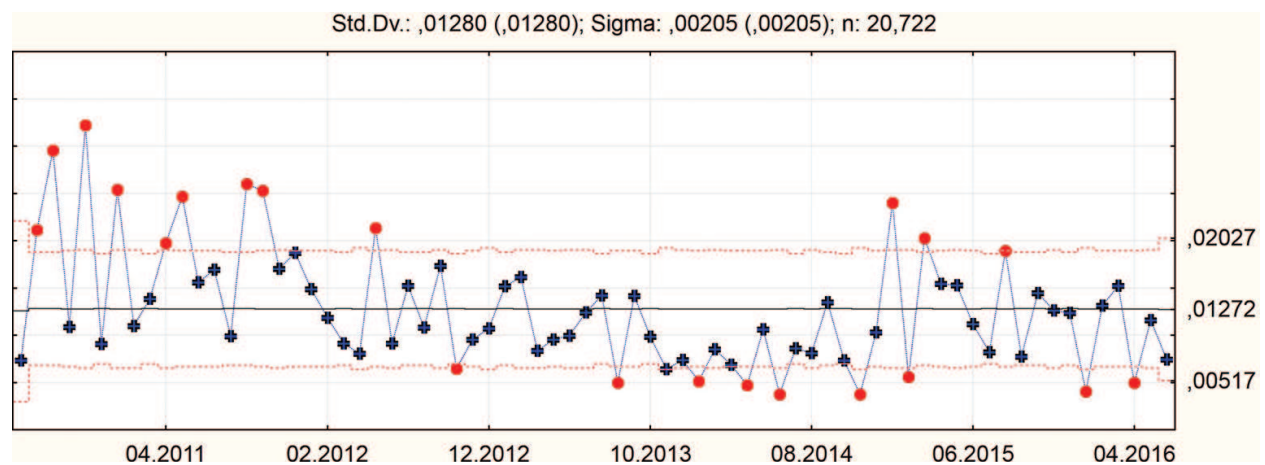


Figure 10. xbar-s chart EUR/USD 2010-2016.

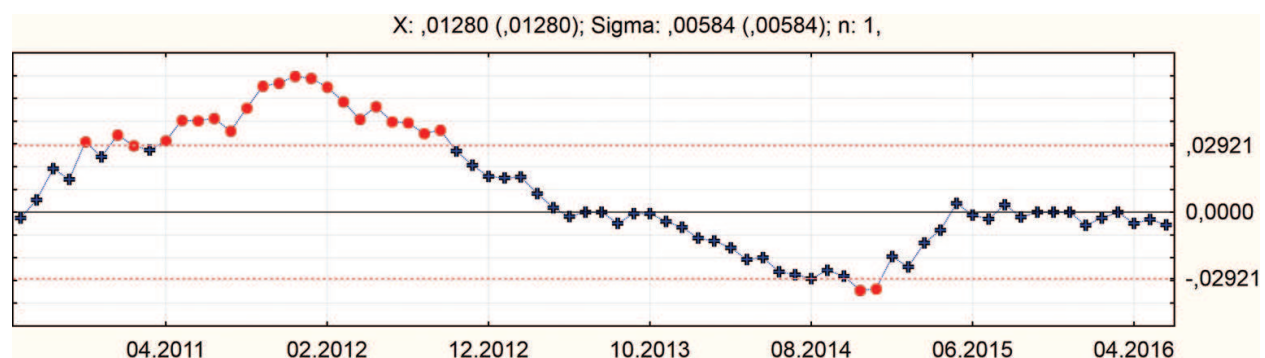


Figure 11. CUSUM chart EUR/USD 2010-2016.

5. Conclusion and further work

Bitcoin, a virtual currency, seems to be a promising alternative to a traditional means of payment. According to a survey published by the IMF, bitcoin has many advantages like low transition costs. It offers the possibility to make transactions with countries with weak financial infrastructure and might contribute to transferring developed technologies and solutions to undeveloped countries. At this point, it is worth mentioning that the idea on which the bitcoin is based has a huge potential in many areas, such as banking, accounting, data gathering and transfer, etc. At the same time, it is not without flaws. Reports and surveys concerning bitcoin mention money laundering issues, low recognisability and lack of stability.

In this chapter, an attempt was made to compare the exchange rate volatility between EUR/USD and BTC/USD. The analysis has shown that the EUR/USD exchange rate volatility is

much more stable compared to the BTC/USD exchange rate. In the entire investigated period, the average exchange rate volatility was at the level of 0.013. The first period after the world crisis, when the international economy was unstable and USA has published economic reports below market expectations, the exchange rate volatility has recorded an increase and charts have produced warning signals for the process being out-of-control. In the remaining period, the exchange rate volatility development did not behave in an unpredictable pattern. The downward trend is visible, but no significant shocks were observed. The lack of sudden fluctuations characterises mature economies.

BTC/USD exchange rate volatility is developing in a completely different way. **Figure 2** shows three establishing phases of this virtual currency; the first one before 2013, when the price level and the overall recognition were nearly zero. The average volatility was equal to 0.6. This value was affected by the price increase from June 2011. In the year 2013, another strong price jump was visible, when the exchange rate has risen from 155 to 870. The third period under consideration was also susceptible to price shocks, namely at the beginning of 2014 and in June of 2016. This unexpected price increase has strongly affected the average exchange rate volatility of BTC/USD. What is positive, the declining tendency in volatility can observe.

In 2013, the average process volatility including outliers caused by price jumps was equal to 51.8, between 2014 and 2016 it has decreased to 28.4. The xbar-s chart and MR-chart for BTC/USD have showed that except for the above-mentioned price fluctuations the process was most of the time under control. It is worth noting at this point that the range between the upper and lower control limits for the bitcoin is broad, which was caused by the extreme price movements. Because of this lack of stability, it is difficult to model bitcoin behaviour. As such, an attempt to forecast its future behaviour based on its past values would be impossible.

The lack of BTC/USD exchange rate predictability and its excessive volatility causes that at least at this stage of development bitcoin cannot threaten the traditional and regarded as stable, currencies such as USD or EUR. It is also associated with a small recognisability and is still limited to a number of places where it can be exchanged or traded. The bitcoin's founder Satoshi Nakamoto said that he is not sure if the bitcoin in this form will survive, but he is convinced that virtual currencies will exist in the future, in this form or in a different one, due to the increasing loss of confidence and trust among the business partners [36].

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