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BITCOIN VALUE ANALYSIS BASED ON CROSS-CORRELATIONS

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Abstract

Bitcoin is attracting a steadily increasing interest since its first appearance in 2008. Bitcoin price forecasting would be of great practical interest given its role as a relatively new virtual “currency”. This presupposes the modeling and verification of some kind of relation, causal or not, connecting bitcoin price to other “established” factors of economic interest. Towards this goal, cross-correlation analysis is used in this work to investigate relations between bitcoin price and a set of other factors of economic interest. The years 2013 to 2015 are selected as the temporal basis of this research, because earlier bitcoin prices were practically zero. Results reveal a strong correlation between bitcoin and stock market indices or other economical factor values. SWOT analysis for bitcoin is carried out for the same period of time, based on cross-correlation as well as on existing research results. Bitcoin is seen to possess more benefits than risks, while its strong temporal correlations with other economic indices or prices constitute an opportunity to be further explored towards the goal of bitcoin price forecasting.

Keywords: **Bitcoin; Forecasting; Stock Market Indices; Cross-Correlation; SWOT Analysis**

Mathematics Subject Classification (2010): **60G35 • 62H20 • 62M20 JEL**

Classification: **C22 • E42 • E47**

INTRODUCTION

Bitcoin, along with a set of methods of using peer-to-peer computer networks to generate it, was first proposed as “a system for electronic transactions without relying on trust”, and in the Internet paper signed by its author under the pseudonym of Nakamoto [1].

Early in its life, in 2010, bitcoin has survived an almost fatal software “bug”, after which it has recovered to go up into a bubble during 2013-14. After the bubble was broken, its price is seen to behave modestly to date. Figure 1 shows the rapid growth of bitcoin transactions worldwide, while Figure 2 shows the evolution of the bitcoin-to-USD rates. It would soon be characterized as the “world’s first completely decentralized digital currency” [2-4]. It is exactly the decentralized capacity of bitcoin that has attracted scientific, legislative and regulatory interest, as it has early been realized that anonymous/pseudonymous use may cover legal as well as illegal transactions [5-8].

Bitcoins are created by the highly competitive "mining" process where "miners" create and accumulate bitcoins in reward for services offered to the bitcoin network, such as providing the hardware basis for secure transactions [2,3]. Today it is conceded that bitcoin possesses "the characteristics of money (durability, portability, fungibility, scarcity, divisibility and recognizability) based on the properties of mathematics rather than relying on physical properties (like gold and silver) or trust in central authorities (like fiat currencies) [9].

Major questions of practical consequences regarding bitcoin and its future as a (virtual) "currency" include the following:

- What are the opportunities and threats related to bitcoin?
- Is there a relation or connection between bitcoin price and other commodity values or indices?
- Is it possible to forecast bitcoin price?

Figure 1: Bitcoin transaction numbers per month, years 2009 to 2015. (Source: https://en.wikipedia.org).

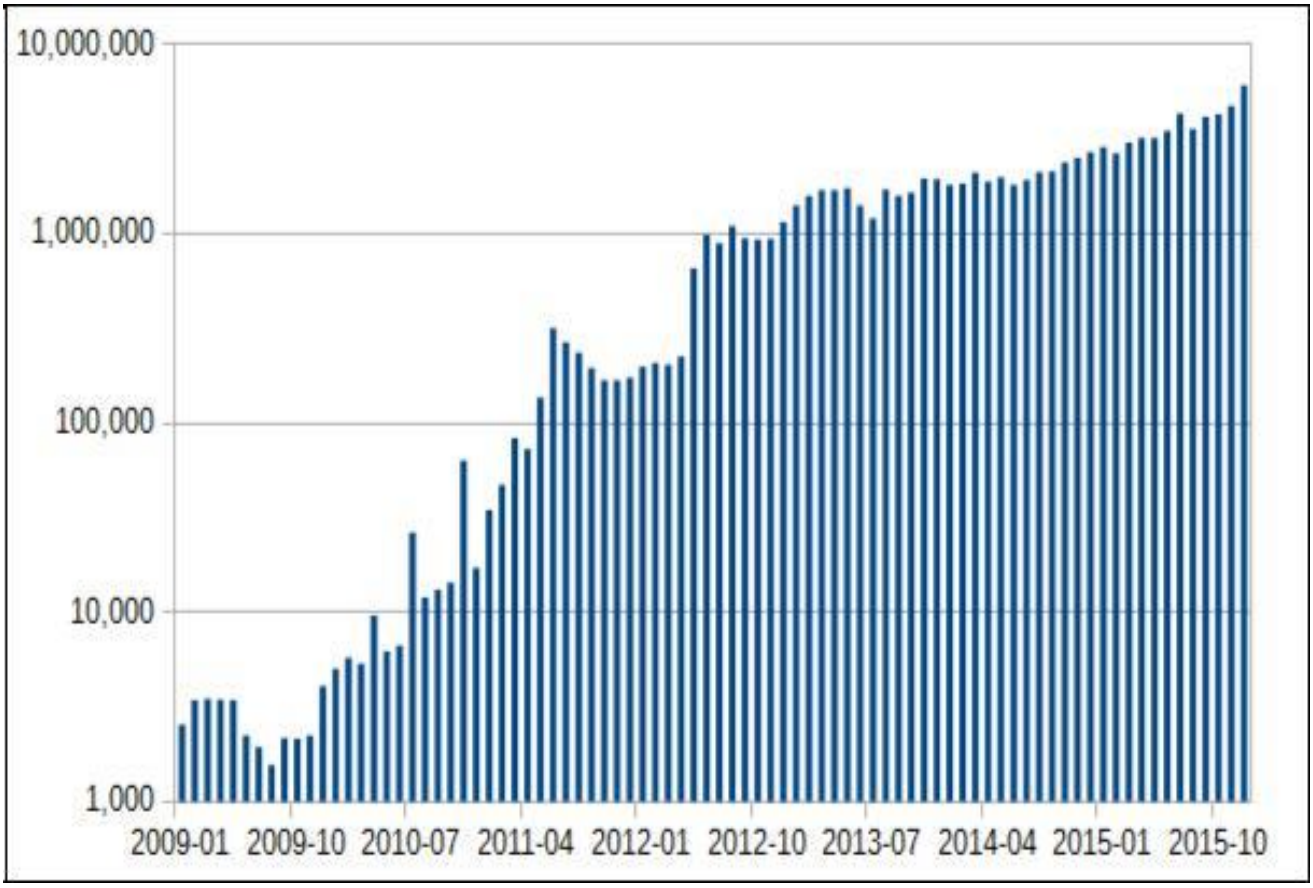
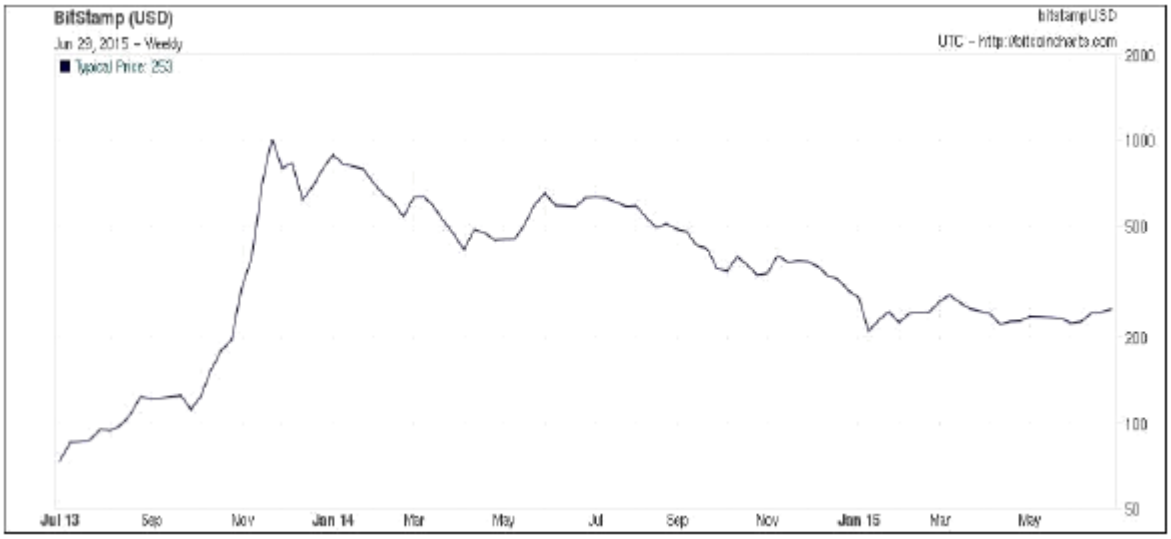


Figure 2: Bitcoin price in USD, years 2013 to 2015. (Source: Bitcoin Charts - http://bitcoincharts.com/charts/bitstampUSD#rg730zigWeeklyztgTzm1g10zm2g10zl)



A first aim of this paper is to explore the character of bitcoin through its correlation with a series of other "established" economic factors, such as gold or crude oil prices or major stock market indices. Cross-correlation between time series, such as the bitcoin price or the prices of other goods or stock market indices, is a standard method to use when searching for similarities shared by two different time series, possibly at lagged time points. It can also be used to locate a given pattern, considered as a shorter time series, within a longer time series. Cross-correlation or auto-correlation is exploited as a measure of similarity in a variety of application fields such as image processing, seismic and geophysical exploration, source localization, astronomical image alignment, surveillance, 3-D imaging, biomedical engineering and many others [10,11].

For two real-valued, discrete-time deterministic signals $\{x(n)\}$ and $\{y(n)\}$, cross-correlation is given by the "inner product" operation at (integer) lag τ:

$$c_{xy}(\tau) = \sum_{n=-\infty}^{\infty} x(n) \cdot y(n+\tau), \tau = 0, \pm 1, \pm 2, \ldots \quad (1)$$

For two real-valued, discrete-time stochastic processes $\{x(n)\}$ and $\{y(n)\}$, assumed to be jointly wide-sense stationary (JWSS), cross-correlation is given by the cross-covariance function, normalized by the standard deviations of the two processes:

$$c_{xy}(\tau) = \frac{E\{(x(n) - \mu_x) \cdot (y(n+\tau) - \mu_y)\}}{\sigma_x \cdot \sigma_y}, \tau = 0, \pm 1, \pm 2, \ldots \quad (2)$$

Where $\mathrm{E}\{\ \}$ denotes the expected value and $\{\mu_x,\sigma_x\},\{\mu_y,\sigma_y\}$ denote the mean and standard deviation of $\{\mathrm{x(n)}\}$ and $\{\mathrm{y(n)}\}$, respectively.

Time series can be treated as one-dimensional discrete-time signals with time being the independent variable. Given the fact that observed (measured) time series values contain signal as well as (additive) noise, time series are considered as stochastic processes and cross-correlation is computed as in eq. (2) with expected values estimated via time averages across observation records of finite length N (in number of samples):

$$\tilde{c}_{xy}(\tau)=\frac{\frac{1}{N}\sum_{n=1}^{N-\tau}(x(n)-\bar{x})\cdot(y(n+\tau)-\bar{y})\}}{s_x\cdot s_y},\tau=0,\pm1,\pm2,\ldots,\pm(N-1) \quad (3)$$

Where means and standard deviations are obtained as time rather than ensemble averages:

$$\bar{x}=\frac{1}{N}\sum_{n=1}^{N}x(n),\bar{y}=\frac{1}{N}\sum_{n=1}^{N}y(n),s_x=\frac{1}{N-1}\sqrt{\sum_{n=1}^{N}(x(n)-\bar{x})^2},s_y=\frac{1}{N-1}\sqrt{\sum_{n=1}^{N}(y(n)-\bar{y})^2} \quad (4)$$

In order to use this last form to cross-correlate time series observation data, two practical considerations arise, as to the time length and the spacing apart of the observations taken. It turns out that it is not necessary that the observations of $\mathrm{x(n)}$ and $\mathrm{y(n)}$ be of equal length N; in order for the results to be meaningful, however, it is important to make sure that both time series are of the same "sampling frequency". This practically means that they contain observations taken at the same regular intervals of time (e.g., daily, monthly, etc.). If necessary, this may be achieved by under-sampling one or both time series down to a common sampling rate.

EXPERIMENTAL CROSS-CORRELATION AND SWOT BITCOIN ANALYSIS

Materials and Methods

The dataset used for experimental auto- and cross-correlation analysis comes from http://bitcoincharts.com/ and https://blockchain.info/pl/charts. Three time series are extracted from these URLs, namely, (i) the price of bitcoin, (ii) the number of bitcoin transactions and (iii) the bitcoin transaction fees. Data correspond to the time period from 17-08-2010 to 25-01-2015, yielding N=1623 observations in each time series, taken on a daily basis. Available data corresponding to the initial period of bitcoin existence, 03-01-2009 to 16-08-2010 or 591 observations (days), are not included because the zero bitcoin value of that period would distort results if taken into the dataset. Analysis is carried out in Matlab R2014a.

Cross-correlations between Bitcoin-related Factors

Cross-correlation results for the three time series mentioned above are shown here. In all cross-correlation plots, values are normalized so that cross-correlation peaks at one (Figure 3). Note that in contrast to auto-correlation, the cross-correlation does not always peak at lag zero; moreover, its value at lag zero may be positive or negative.

Figure 3: Pair-wise cross-correlation between (a) bitcoin prices, (b) bitcoin transaction fees and (c) number of transactions in bitcoin. Horizontal axis: days.

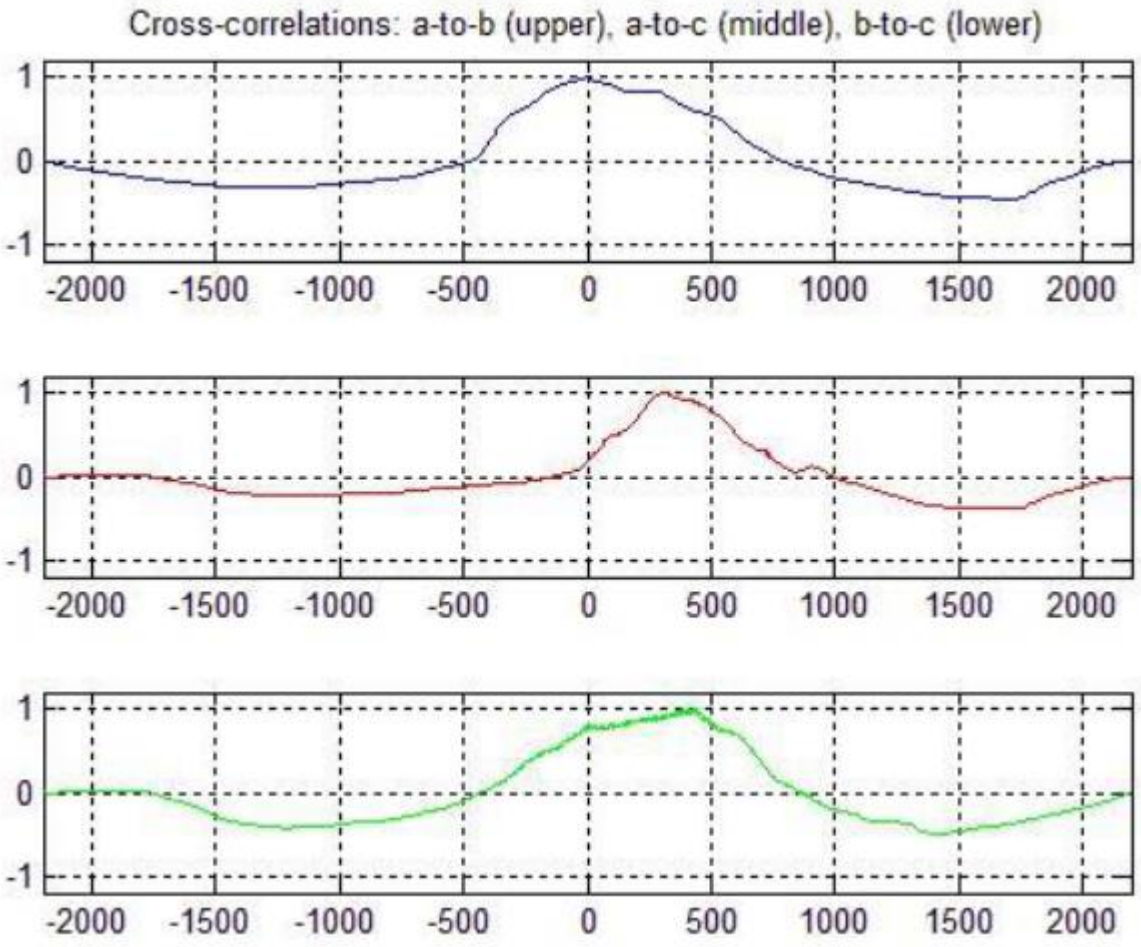


Figure 3 shows pair-wise cross-correlations between (a) the bitcoin price, (b) the bitcoin transactions fees and (c) the number of transactions in bitcoin. Cross-correlation between bitcoin price and bitcoin transactions fees (Figure 3, upper plot) is seen to peak at lag $\tau=0$; moreover, it retains high values for lags up to 250 days, approximately. Such behaviour reveals that these two time series are indeed correlated, i.e. there is an almost linear relation between the number of transactions and the bitcoin price. Cross-correlation between bitcoin price and number of bitcoin transactions fees (Figure 3,

middle plot) is seen to peak around lag τ=300; this also signifies a linear relation between the two factors. Finally, cross-correlation between number of transactions and bitcoin transaction fees (Figure 3, lower plot) is seen to peak around lag τ=400 while it retains very high values between lags τ=0 and lag τ=500, revealing the strongest connection. These results are in agreement to existing research results, e.g., [12,13], where strong correlations between various bitcoin related factors are experimentally revealed.

Cross-correlations between Bitcoin Price and Other Factors

A set of five (5) different economic factors of interest are selected for cross-analysis to bitcoin price. These are

1. NASDAQ index,
2. DAX index,
3. S&P500 index,
4. Gold price and
5. Crude Oil price.

Data for these factors are obtained from URL http://www.investing.com/ for the time period 29-08-2010 to 25-01-2015 (Figure 4). It must be noted that these are weekly averages rather than daily values, yielding a record of 231 data points (observations) for each factor.

Figure 4: Weekly average values of bitcoin price and of the other five (5) selected factors over the 231 weeks period. Blue –Bitcoin price, Green – NASDAQ index, Red – DAX index, Azure – S&P500 index, Violet – Gold price, Yellow – Crude Oil price.

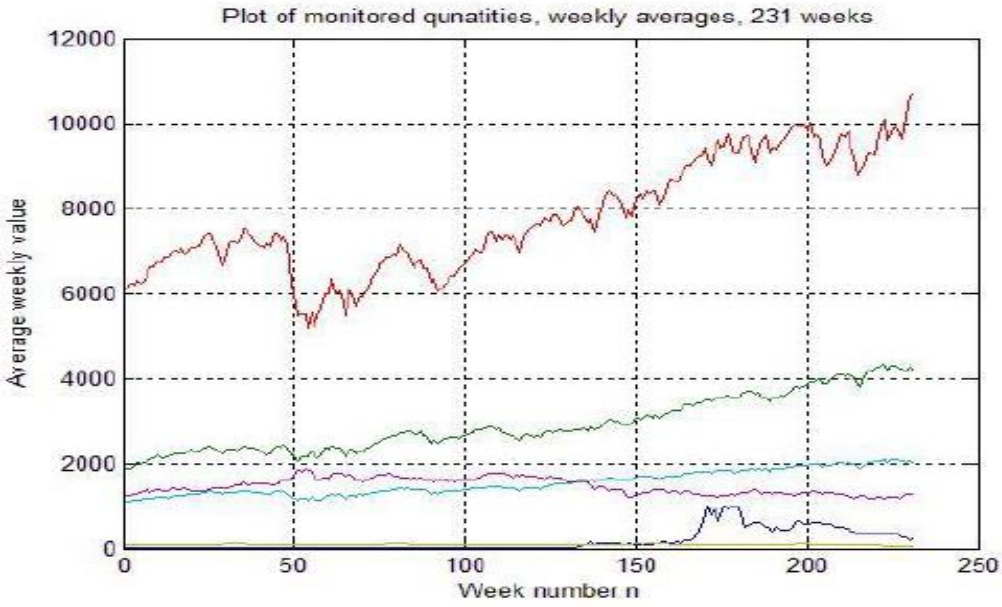


Figure 4 shows the weekly averages of bitcoin price along with all the other five (5) factors over time, for the aforementioned time period of 231 weeks.

The following Figures 5-9 show the pair-wise cross-correlations as functions of time lag τ in number of weeks, between the bitcoin price and each of the other five selected factors of economic interest, namely, NASDAQ index, DAX index, S&P500 index, Gold price and Crude Oil price.

Figure 5: Cross-correlation between bitcoin price and NASDAQ index, weekly averages, normalized to c(0)=1.

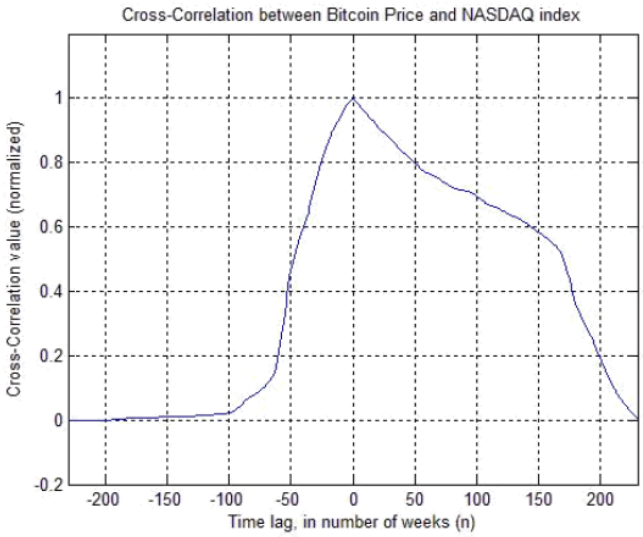


Figure 6: Cross-correlation between bitcoin price and DAX index, weekly averages, normalized to c(0)=1.

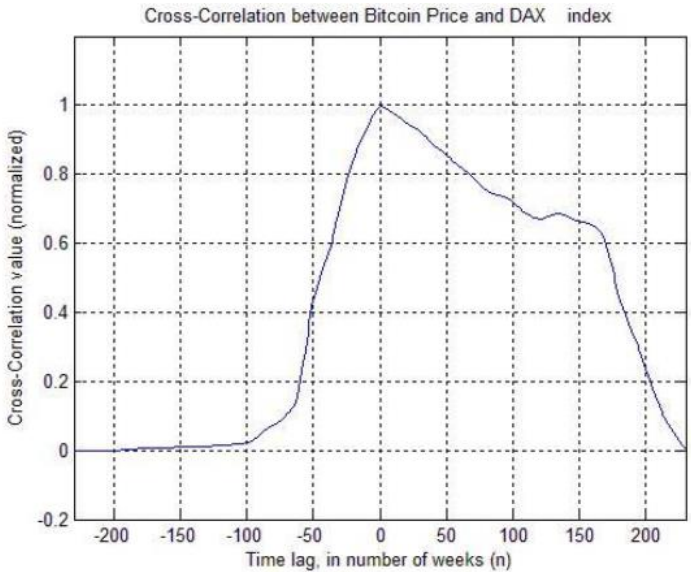


Figure 7: Cross-correlation between bitcoin price and S&P-500 index, weekly averages, normalized to c(0)=1.

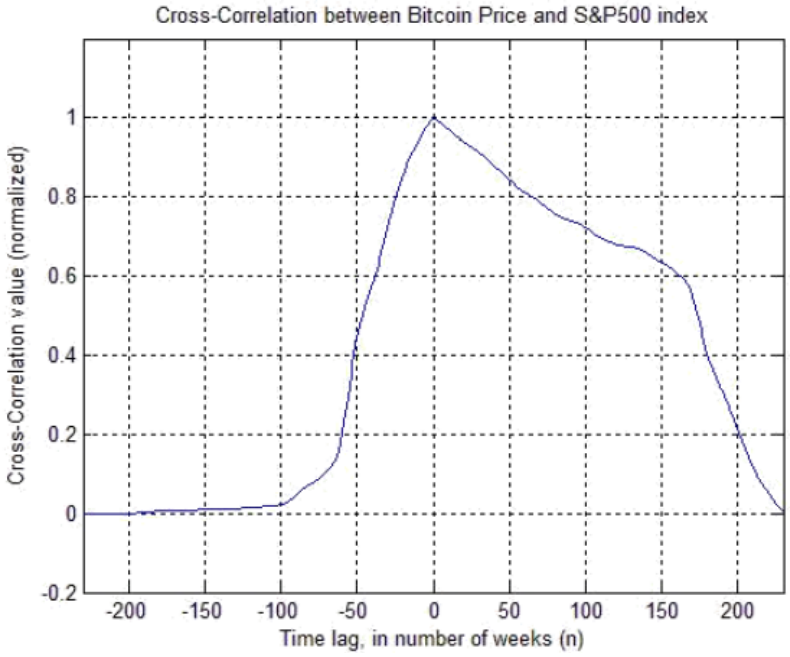
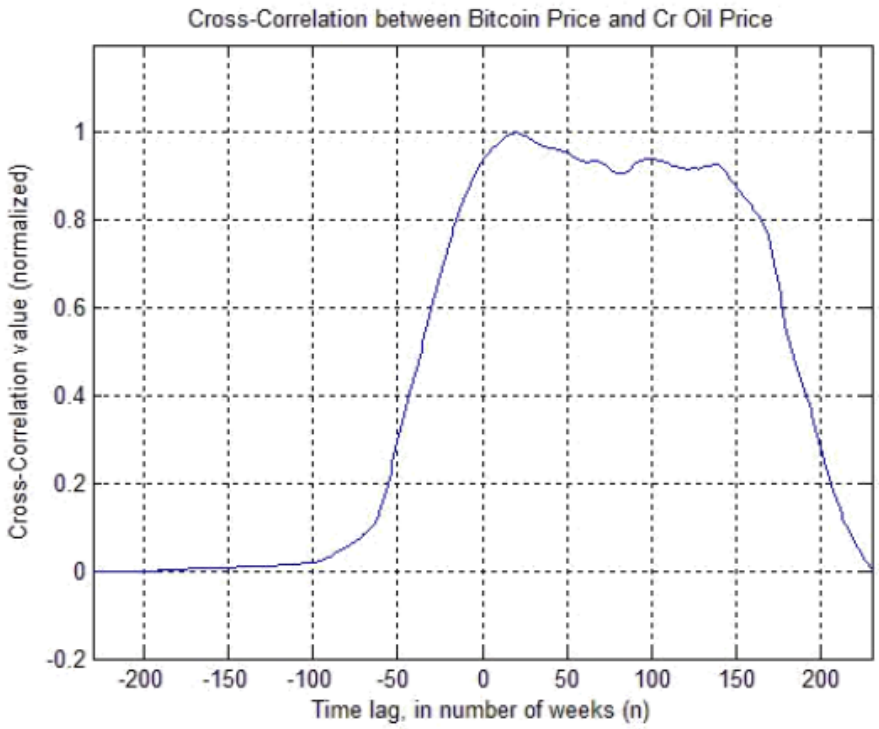


Figure 8: Cross-correlation between bitcoin price and gold price, weekly averages, normalized to c(0)=1.

Figure 9: Cross-correlation between bitcoin price and crude oil price, weekly averages, normalized to c(0)=1.



Figures 5-7 show similarities in the general form of the cross-correlation function: In all three cases, it peaks at zero lag (τ=0) and remains above 0.6 (normalized values) or 60% of the peak value (non-normalized values) for lags up to 150 weeks or approximately 3 years. This behaviour reveals strong correlation between contemporary bitcoin price and major stock market indices.

Figures 8 and 9 show similarities between them, as well: Cross-correlation to gold price peaks at lag τ=95 weeks while that to crude oil price peaks at lag τ=12 weeks. They both remain above 0.8 or 80% of their respective peak values for lags up to 160 weeks or approximately 3 years. This behaviour reveals strong correlation between lagged bitcoin price and gold or crude oil prices.

SWOT Analysis of Bitcoin

The SWOT analysis of bitcoin combines results obtained from existing research, [2-4,8,14,15], with results obtained from the cross-correlation analysis presented above.

- Strengths: Worldwide use; increasing number of users; lack of brokers; low transaction costs; transactions speed; ultimately constant amount of bitcoins in system (anti-inflation mechanism); regulation by market processes; not possible to be regulated by large holders; protection of personal data of all participants.

- Weaknesses: Highly dependent on participants' trust in system; susceptible to speculative bubbles, as that of 2014; no material form; high value fluctuations; susceptible to user errors; decreasing reward for users providing computing power to the system ("miners"); mining using CPU and GPU unprofitable.
- Opportunities: Strong cross-correlations between the numbers of bitcoin transactions and transaction fees and the bitcoin price; very good cross-correlation of bitcoin price with gold and crude oil price; correlation of bitcoin price with contemporary stock market indices like NASDAQ, DAX and S&P500.
- Threats: Exchange rate is impossible to forecast with using standard methods such as the Holt-Winters method or the Indicators method; bitcoin value shows no signs of periodicity; number of users and transactions directly affect bitcoin price.

In summary, SWOT analysis shows that bitcoin has more benefits than risks. It is used worldwide; yet, it is banned from the economies of certain countries. Attempts to regulate the price of bitcoin have all failed. Moreover, it was proved to be hard to predict bitcoin price in future periods using standard models for forecasting, [16]. A noticeable fact is that bitcoin price is very susceptible to its very popularity. Whenever bitcoin would get publicity in the media, its price would increase. This is one characteristic of a speculative bubble. Bitcoin price is also closely related to the amount of users, number of transactions and the amount of transaction fees.

CONCLUSIONS

Bitcoin is a promising yet neither fully understood nor fully matured (virtual) "currency". As such, it concentrates an increasing research interest coming both from the (secure) computer networking world and the economic world. A major concern is that bitcoin price and bitcoin exchange rate to existing currencies have not been predictable to date. As a contribution to the discussion on the emerging bitcoin economy, cross-correlation analysis is carried out in this study between bitcoin-related variables and other standard economic factors like stock market indices or prices of goods. SWOT analysis of bitcoin, based on these as well as on existing research results, shows that benefits are more than risks while the strong correlations revealed in this study constitute considerable opportunities to be further explored towards the goal of forecasting bitcoin price, number of transactions or level of transaction fees in the future.

REFERENCES

1. Nakamoto S (2008) Bitcoin: A Peer-to-Peer Electronic Cash System. Available at: http://bitcoin.org/bitcoin.pdf
2. Brito J, Castillo A (2013) Bitcoin: A Primer for Policymakers. Mercator Center, George Mason Univ, USA.
3. Velde FR (2013) Bitcoin: A primer. Chicago Fed Letter 317: 1-4.

4. Garcia D, Tessone C, Mavrodiev P, Perony N (2014) The digital traces of bubbles: feedback cycles between socio-economic signals in the Bitcoin economy. ETH Risk Center - Working Paper Series 14: 1-16.
5. Barratt MJ (2012) Silk road: Ebay for drugs. Addiction 107: 683.
6. Jacobs E (2011) Bitcoin: A Bit Too Far? Journal of Internet Banking and Commerce 16: 1-4.
7. Barber S, Bayen X, Shi E, Uzun E (2012) Bitter to Better – How to Make Bitcoin a Better Currency. In: Financial Cryptography and Data Security. Springer 399-414.
8. Reid F, Harrigan M (2013) An Analysis of Anonymity in the Bitcoin System. In: Security and Privacy in Social Networks. Springer 197-223.
9. We Use Coins (2015) Available at: https://www.weusecoins.com/en/questions/
10. Gouedard P, Stehly L, Brenguier F, Campillo M, Colin de Vardiere Y, et al. (2008) Cross-Correlation of random fields: Mathematical Approach and Applications. Geophysical Prospecting 56: 375-393.
11. Lewis JP (1995) Fast Normalized Cross-Correlation. Vision Interface 120-126.
12. Kristoufek L (2013) BitCoin meets Google Trends and Wikipedia: Quantifying the relationship between phenomena of the Internet era. Scientific Reports 3: 3415.
13. Kristoufek L (2014) What are the main drivers of the Bitcoin price? Evidence from wavelet coherence analysis, Available at: https://arxiv.org/pdf/1406.0268
14. Bornholdt S, Sneppen K (2014) Do Bitcoins make the world go around? On the dynamics of competing crypto-currencies. Available at: http://arxiv.org/abs/1403.6378
15. Kondor D, Posfai M, Csabai I, Vattay G (2014) Do the rich get richer? An empirical analysis of the Bitcoin transaction network. PLoS ONE 9: e86197.
16. Billings SA (2013) Nonlinear System Identification: NARMAX Methods in the Time, Frequency and Spatio-Temporal Domains. Wiley, ISBN 978-1-118-53556-1.