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Economic, technological and social drivers of cryptocurrency market evolution and its managerial impact

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Economic, technological and social drivers of cryptocurrency market evolution and its managerial impact

Thomas Holtfort¹/Andreas Horsch²/Joachim Schwarz³

Abstract

Cryptocurrencies, such as Bitcoin, have caused intense discussions during recent years among market participants according to new options (such as payment or financing alternatives) and new risks (such as price volatility) involved. Despite being considered by various actors of private households, companies, financial, monetary, and political institutions, a theory-based understanding of this innovation and knowledge of their evolution is still limited. On a basic level, this holds for differences between cryptocurrencies on the one hand and traditional currencies, like paper money, gold or special assets, on the other. On a market level, factors driving the prices of cryptocurrencies appear to be of seminal meaning, in particular against the backdrop of recent market turmoil. Therefore, the paper conducts an empirical analysis of the five biggest cryptocurrencies (measured by market capitalization) with regard to their evolutionary development, price behaviour, and their impact for managers.

Keywords: cryptocurrencies, innovation, evolutionary economics

JEL Classification: E42, O30

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1 Introduction

Blockchain technology and cryptocurrencies, such as Bitcoin or Ethereum, have attracted substantial attention recently. Besides being considered by corporate managers as new payment and financing options, they gained increasing acceptance by private households, financial, monetary, and political institutions (see *Gangwal/Longin*, 2018). It has even been suggested that cryptocurrencies could have a disruptive impact in the Schumpeterian sense on the financial system as a whole (see e.g. *Tapscott/Tapscott*, 2016).

Cryptocurrencies are a new type of digital currency systems built on computer and decentralized (peer-to-peer) network architecture (*Ammous*, 2018; *Li/Wang*, 2017). Bitcoin as the leading cryptocurrency (by awareness and market capitalization, see *coinmarket.com*) was created in 2007 to serve as an innovative means of payment (see *Nakamoto*, 2007). Bitcoin differs from traditional currencies in two ways: first by the method of creation, which is based on computerized processes known as blockchain (the blockchain contains blocks of validated transaction records to track the ownership of every bitcoin, see *Antonopoulos*, 2014; *Li/Wang*, 2017), and second by their ability to operate without the control or oversight of a private entity or governmental organization (*Dominguez et al.*, 2019). During the last ten years, Bitcoin has become increasingly debated and widespread, and also suggested to be a future alternative to fiat money and classical payment systems of banks (*Antonopoulos*, 2014; *Reuse et al.*, 2019). Nevertheless, the acceptance of cryptocurrencies turned from euphoria to skepticism in the wake of recent market turmoil.

Against this backdrop, one seminal question asks for the evolutionary drivers of the emergence and further evolution of cryptocurrencies, in how far they differ from other (currency) concepts, and which are the factors driving their prices, i.e. exchange rates denominated in traditional currencies such as the US dollar. The paper therefore analyzes different technological, economic and social determinants of cryptocurrency evolution and their relevance for the price behavior of the five largest cryptocurrencies (Bitcoin, Ethereum, Ripple, Bitcoin cash and Litecoin; size measured by market capitalization as of end-2018, see *coinmarketcap.com*). Accordingly, the paper contributes to the analysis of the cryptocurrency market by a demarcation to similar (currency) concepts, an analysis of influencing factors, the usage of an evolutionary approach and the delineating of implications for managers.

After distinguishing cryptocurrencies from related (monetary) concepts and terms based on a literature review (chapter 2), chapter 3 examines the evolutionary development of the

cryptocurrency market. The fourth chapter provides a description of the dataset and an introduction of the independent and dependent variables used in the quantitative analysis of cryptocurrency prices. Chapter 5 shows the results, before the sixth chapter concludes.

2 Literature review and delimitation of cryptocurrencies

Blockchain technology and cryptocurrencies have impacted various academic fields already (which will be partly relevant later in the analysis of the influencing factors), such as (financial) economics (see e.g. *European Central Bank*, 2012; *Gans/Halaburda*, 2013; *Yermack*, 2013; *Glaser et al.*, 2014; *Hays*, 2016; *Georgeson*, 2018), business information science (see e.g. *Babaioff et al.*, 2012; *Böhme*, 2013; *Eyal/Sirer*, 2013; *Li/Wang*, 2017) and jurisprudence (see e.g. *Murphy et al.*, 2017; *Reed et al.*, 2017). According to our focusing on factors influencing the price behavior of cryptocurrencies, we hereafter consider mainly papers with this reference. The *European Central Bank* (2012) focuses on the impact of digital currencies on the use of fiat money, while *Gans/Halaburda* (2013) evaluate the economics of private digital currencies. *Yermack* (2013) analyzes changes in Bitcoin prices against fiat currencies and concludes that Bitcoin price volatility undermines its usefulness as an alternative currency. *Glaser et al.* (2014) examine whether users are interested in cryptocurrencies rather as a new investment to complete their portfolios or as a new currency allowing for alternative payment techniques. *Hays* (2016) analyzes cryptocurrencies from the evolutionary perspective of (monetary) Austrian theory and states that although bitcoin is not the perfect medium of exchange or store of value, it nevertheless has the potential to become the first global money to fulfill both functions simultaneously. *Georgeson* (2018), who follows an Austrian approach, too, elaborates that cryptocurrencies can be an alternative to fiat money as long as trust exists. From a technological point of view, *Babaioff et al.* (2012) argue that the current Bitcoin protocols do not provide an incentive for transactions, whereas *Böhme* (2013) analyzes what can be learned from Bitcoin regarding internet protocol adoption. *Eyal/Sirer* (2013) show that individual mining⁴ is not incentive-compatible and that a strategy for mining bitcoin in groups can lead to higher revenue for miners. *Li/Wang* (2017) confirm the relevance of technological factors for the Bitcoin-USD exchange rate.

⁴ Mining is done by specialized computers and means to process every Bitcoin transaction by miners. Miners achieve this by solving a computational problem which allows them to chain together blocks of transactions (see *Antonopoulos*, 2014; *Ammous* 2018).

The selection of papers presented above show that the cryptocurrency topic has been considered much more intensively by economic science since 2012 (one reason could be the consequences of the financial and euro crisis in 2007 and 2011, see e.g. *Subramanian*, 2015). Likewise, it can be derived that the cryptocurrency market has been influenced in particular by economic (e.g. trading volume, see *Yermack*, 2013; *Glaser et al.*, 2014) and technological (e.g. mining, see *Eyal/Sirer*, 2013; *Li/Wang*, 2017) factors (beside legal factors, which will not be further explored in this paper, as the legal status of cryptocurrencies remains to be clarified). Additionally, social factors, like e.g. the public reception and acknowledgement of cryptocurrencies, should be taken into consideration for understanding market processes and market structures (see in more general *Tucker*, 2008; *Li/Wang*, 2017). This view has also been supported recently by the research approach of called “narrative economics” (see *Shiller*, 2017), which refers to the relevance of narratives for market and intra-corporate processes. Accordingly, a greater prevalence of narratives (e.g., information from newspapers or social media) about cryptocurrencies could greatly affect its prices (and even contribute to price bubbles or crises). Economic, technological and social influencing factors will be therefore included in our subsequent empirical analysis of cryptocurrency market evolution.

In order to better understand what cryptocurrencies are and how they work, a distinction from comparable or competing concepts, like traditional (paper or other) money/currencies, gold and special assets, is conducted using different criteria based on further literature (see table 1).

insert table 1 around here

It can be derived from table 1 that cryptocurrencies so far have little in common with traditional money/currencies, particularly referring to haptics, anonymity, store of value and system cost (see also *Federal Reserve*, 2018; *Hern*, 2018; *Li/Wang*, 2017; *The Motley Fool*, 2017). Thus, in contrast to money, cryptocurrencies are invisible means of payment, which are produced anonymously and decentrally by market participants called miners and not by central banks. Further differences to traditional money are the (so far non-existent) store of value on the one hand, and high the particularly high electricity costs of mining activities caused by the the necessary computing power on the other hand. Likewise, cryptocurrencies show differences to gold with regard to haptic and production cost, but on the other hand the term “mining” (production of the resource) can be used analogously (see *Artigas*, 2010; *Divine*, 2016; especially on “cryptocurrency mining”, see *Vigna/Casey*, 2016; *Romano/Schmid*, 2017). With

regard to diversification, price bubbles and market anomalies, cryptocurrencies have more in common with a speculative asset, like e.g. stocks (see also *Gangwal/Longin, 2018; Sharma et al., 2019*). It can even be said that regarding the risk-return ratio, cryptocurrencies are a kind of alternative investment like hedge fund certificates or commodities which could be advantageous for diversification effects in portfolios due to low correlations with traditional asset categories (on the term “alternative investment”, see *Cumming et al., 2014*).

In order to obtain a better understanding of the inherent functioning of the cryptocurrency market, especially its influencing factors, which could help understand cryptocurrency price behavior until today, it is important to look more precisely at the development since 2007, conducting an evolutionary analysis.

3 Evolutionary development of cryptocurrencies

The subsequent chapter tries to interpret and characterize the development of the cryptocurrency market (with a special focus on Bitcoin as the first and leading cryptocurrency) from an evolutionary point of view. Evolutionary economics fully emerged in the 1980s, focusing the role of knowledge, its transformation and its limitations for the economy (*Nelson/Winter, 1977, 1978, 1982, 2002*). However, the basis of evolutionary economic thinking can be found much earlier, in particular within contributions of economists of the Austrian School, such as the works of *Menger (1871)*, *Veblen (1898)*, *Marshall (1898)*, *Schumpeter (1911)*, *Mises (1940)*, and *Hayek (1945)*, who elaborated seminal economic concepts which today are pillars of evolutionary economics. *Menger (1871, 1883)* is considered the founder of the Austrian school, which adopted an approach that differed substantially from that of neoclassical economic theory, as it focused on the idea of evolutionary creation of knowledge, as well as considering the dynamic uncertainty of economic processes – instead of modelling equilibria on perfect markets. It was *Veblen (1898, p. 373)* who introduced the term *evolutionary economics*, and he did so in recognition of the fundamental fact that the nature of the modern economy could be captured most adequately by referring to its dynamic. In addition, *Marshall (1898)* emphasized the importance of economics’ evolutionary biology, while *Schumpeter (1911, 1935, 1942 and 1954)* placed the rivalrous character of competition processes and the moment of the creatively destructive entrepreneur at the center of his reflections. *Mises (1940, 1949)*, who continued the tradition of Menger’s Austrian school, pointed out the need for a decentralized

information system, which is crucial to the functioning of the markets and thus renounced central planning. Finally, *Hayek* (1945, 1973, 1976 and 1979) saw, further elaborating the groundbreaking concepts of the Austrian school, the essence of the modern market economy in the distinctive complexity, accelerated evolution and unequal distribution of knowledge.

Further important works of evolutionary tenor, which appear particularly relevant in the context of cryptocurrencies, can be considered the regression theorem of *Mises* (1912) and the theory of institutional change of *North* (1990). Mises reflected about the definition of money and its initial appreciation due to non-monetary use, while North pointed out the design of formal and informal rules (e.g. culture) and its influence on economic processes.

The following figure 1 therefore focuses on relevant events of the evolution of the cryptocurrency market between 2007 (start of the Bitcoin concept) and 2018 and points out economic, technological and social drivers of this market on the one hand, and the development of market capitalization of Bitcoin as the leading cryptocurrency on the other hand.

insert figure 1 around here

Figure 1 in conjunction with the literature review in chapter 2 suggests that especially economic, technological and social triggers could have a strong influence on the evolution and development of the cryptocurrency market (including processes, structures and rules) and its price movements (taking the price development of Bitcoin in figure 1 as representative of all other mentioned cryptocurrencies). Regarding Bitcoin, there was a kind of first mover advantage by the innovative blockchain technology and the novelty of the idea of this decentralized concept (see *Gandal/Halaburda*, 2014). This invention took place during the financial crisis in order to develop a decentralized and anonymous currency (which can cause a non-monetary added value like trust in the sense of Mises and thus more acceptance, see also *Georgeson*, 2018). During the following years, the invention developed into an innovation by new technological processes (e.g. mining), increasing acceptance (e.g. by firms, courts, political institutions and individuals) and economic relevance (e.g. evolving of price quotations and subsequent price increases due to higher demand or new exchange markets). These evolutionary processes incentivized economic agents to deal with this innovation and to start changes in the economy. The changes can be seen (derived from figure 1) e.g. at the level of knowledge (e.g. the social forum Bitcoin.org was created in 2008) and narratives in the society (which can push the demand for cryptocurrencies and therefore prices, as was seen at the end of 2017, see *Shiller*,

2017), payment processes (in 2015 worldwide 160,000 companies accepted bitcoin, which can lead to a new kind of payment culture; see also *Valente et al.*, 2018), new business ideas as a consequence of the Bitcoin concept (such as e.g. Elliptic in 2014 with the first insured Bitcoin storage service worldwide), further competition of cryptocurrencies by Litecoin, Ripple, Ethereum and Bitcoin cash, new processes of corporate financing by Initial Coin Offerings (as part of an ICO, units of a newly issued cryptocurrency are sold to investors in exchange for either government-issued currencies or other cryptocurrencies, see *Chohan*, 2017), new financial products including cryptocurrencies (e.g. Bitcoin futures or diversified cryptocurrency funds in 2017) and finally an evolving of risks (or lack of trust, such as e.g. Mt. Gox in 2014) leading to new rules elaborated by courts or standard-setting institutions (for the relevance of formal rules in evolutionary economics, see *North*, 1990).

It seems obvious that the invention and innovation of the Bitcoin concept resulted in an imitation of this concept by other cryptocurrency entrepreneurs. Therefore competition is not limited to Bitcoin vs. traditional money/currencies, but also includes a competition between different cryptocurrencies (on the “competition of private currencies” in evolutionary economics, see the seminal contributions of *Mises*, 1912; *Hayek*, 1945, 1976 and further according to the regression theorem *Davidson/Block*, 2015; *Hays*, 2016; *Georgeson*, 2018). The reason for the emergence of these further cryptocurrencies is partly due to their promise of technological advantages compared with Bitcoin (e.g. Bitcoin cash has a higher scalability than Bitcoin, and Ethereum includes an integrated platform for blockchain transactions, see for example *Coincentral*, 2017; 2018). Important in the sense of evolutionary economics, however, is not the pure existence of such potential benefits, but also the respective discovery and implementation by alert entrepreneurs (e.g. *Vitalik Buterin* with Ethereum), who turn the abstract opportunity into real market processes and even competitive advantage (on the concept of the alert entrepreneur, see the seminal contributions of *Kirzner*, 1973, 1979 and 1997).

Finally, it can be stated that the evolution of the cryptocurrency market was accompanied by intense price movements which by the end of 2017 even led to a price bubble (see the statements of *Shiller* according to Bitcoin in figure 1; a price bubble means that the prices of particular assets are way above their intrinsic value, see *Shiller*, 2000). Such immense price fluctuations are not only important for investors in the portfolio context, but also have a deep impact on managers who are responsible for firm processes – and their impact on market processes. Accordingly, it is more difficult to plan and organize ICOs as financing options in an environment of very volatile prices. Likewise, cryptocurrencies could be more useful in corporate treasury processes if prices are reliable. According to Hayek and the Austrian school

the price is a collector and sender of information (see *Hayek*, 1945). Thus, the price bubble in the cryptocurrency market at the end of 2017 has indicated on the one hand a sign of scarcity in this market, but also unequal distributed knowledge due to probably less informed investors, which were still willing to pay the high prices at the end of 2017.

While figure 1 already presents important events according to different economic, technological and social influencing factors and thus possible starting points for an explanation of cryptocurrency market evolution and the associated price behavior, a thorough empirical analysis seems inevitable to reach solid conclusions. Consequently, the subsequent chapter provides a derivation of data, research hypotheses and methods.

4 Data, hypotheses and methods

As outlined in the previous chapters, possible economic, technological and social factors have influenced the evolution of the cryptocurrency market in particular. Nevertheless, managers should develop a deeper understanding of these driving factors on pricing behavior of this market innovation, which could be relevant in the context of ICO financing, firm payment processes, financial risk management, corporate treasury or other corporate investments (e.g. cryptocurrency funds or futures).

The main data source for our empirical analysis of the pricing behavior (measured by the exchange rate of the respective cryptocurrency and the USD) of the five biggest cryptocurrencies as of end-2018 is the website www.coinmarketcap.com (see table 2 of the Appendix; for using the data of this website in other studies see e.g. *Frey/Cheah*, 2016; *Gkillas/Katsiampa*, 2018). Besides, we retrieved data on economic, technological and social influencing factors from other relevant websites (e.g. blockchain.info or the Federal Reserve Bank) respectively from Google and Wikipedia, which can also be found in table 2 of the Appendix. Using these factors, we formulated testable hypotheses regarding possible favorable drivers of cryptocurrency prices.

For the purpose of testing whether technological factors affect the behavior of cryptocurrency prices, we focus the mining process. As the mining of Bitcoins incurs significant costs of e.g. hardware purchase, maintenance and electricity, prices should reflect such costs (see *Li/Wang*, 2017; respectively more general for the influence of the mining cost on commodity prices, see *Shafiee/Topal*, 2010). Although it is impossible to track the actual costs incurred by individual miners, mining difficulty is considered a good proxy of the average mining cost of miners (see

Li/Wang, 2017). In the Bitcoin system, the measure of this mining difficulty indicates the average amount of calculation (measured with an average of 10 minutes) required to find a valid hash (hash means a value that unites a lot of information in itself, which are assigned by a special function, see *blockchain*, 2019).

At the same time, however, it can be assumed that the relationship between mining difficulty and mining cost depends on the efficiency of mining technology (by the same amount of investment in equipment and electricity more computing power for mining is generated). Mining technology improved significantly over the years, e.g. at Bitcoin the adoption of more advanced mining devices makes hash calculation faster while requiring less electricity (see for example *Cointelegraph*, 2018). Subsequently, the impact of mining difficulty on cryptocurrency prices could be weaker as mining technology evolves. Thus, the subsequent hypotheses connecting technical factors and the prices of the five biggest cryptocurrencies can be derived:

Hypothesis 1a: There is a positive correlation between mining difficulty (measured by the hashing power that has to be deployed by the network of miners) and prices of cryptocurrencies (measured by the exchange rate in USD).

Hypothesis 1b: The impact of mining difficulty on cryptocurrency prices ceases over time (measured as a moderating effect of time on the relationship between mining difficulty and price).

As they are currencies, the exchange rate of cryptocurrencies should follow predictions of economic theories (e.g. the theory of purchasing power parity according to which the long-term real purchasing power in any two countries should be equivalent, despite any difference in the nominal currency, see *Castillo-Maldonado/Perez-Macal*, 2013; *Cheung et al.*, 2005; *Dornbusch*, 1976). Related to this rationale, price monetary models emphasize the relevance of macroeconomic factors such as, e.g. Gross Domestic Product (GDP), interest rate and inflation (see e.g. *Ho*, 1993; *McCallum*, 1994). As well, cryptocurrencies can lead to diversification effects in portfolios, as their risk-return ratio differs from traditional (financial) asset classes (such as stocks, see *Gangwal/Longin*, 2018; *Schmidt*, 2017) so that the movement of the stock market could influence prices of cryptocurrencies due to capital shifts with regard to portfolio risks.

Furthermore, due to the difficulty to measure the use of cryptocurrencies by market participants, it is difficult to define and measure the cryptocurrency economy's inflation rate⁵ (Li/Wang, 2017). Discretionary monetary policies are also absent in an economy with cryptocurrencies. Meanwhile, cryptocurrency supply follows a fixed schedule of production (mining) and is subject to natural deflation due to the limited storage space of the blockchain (see *Böhme et al.*, 2015). According to the technical cap (resulting from the underlying computing algorithm) of the total amount of the respective cryptocurrency in circulation, current cryptocurrency supply may indicate the relative scarcity of future supply, which is reflected by cryptocurrency prices. Finally, there has been discussion about the buying and selling of cryptocurrencies being driven by speculative trading (see *Bouoiyour/Selmi*, 2015; *Cheah/Frey*, 2015), which is analogously observed in commodity, security and foreign exchange markets (see e.g. *Gilbert*, 2008; *Vitale*, 2000). As a new currency system, cryptocurrencies have attracted enormous media attention. Yet the market has lacked proper understanding of the technology and there has been no consensus about the prospects, which turned the cryptocurrency market into a target of speculative investments (*Glaser et al.*, 2014; *Li/Wang*, 2017), as could be observed in late 2017. A common approach to capture the impact of speculative trading on prices is to employ market activity indicators, such as e.g. the trading volume, in an exchange price model (see *Brooks/Katsaris*, 2003; *Robles et al.*, 2009; *Li/Wang*, 2017). Thus, the subsequent hypotheses linking economic factors and the prices of the five biggest cryptocurrencies can be derived:

Hypothesis 2a: The price of cryptocurrencies (measured by the exchange rate in USD) reacts to macroeconomic factors like US GDP, US inflation, US interest rate and the US stock market.

Hypothesis 2b: The price of cryptocurrencies (measured by the exchange rate in USD) reacts to the total number of the respective cryptocurrency in use.

Hypothesis 2c: The price of a cryptocurrencies (measured by the exchange rate in USD) reacts to the trading volume of the respective cryptocurrency.

The third relationship (besides technical and economic factors) we examine is the one between social indicators, like the number of worldwide Google searches for keywords like “Bitcoin, Ethereum” etc., and the number of worldwide Wikipedia searches for the keyword “the respective cryptocurrency” on the one hand (these sources are commonly and frequently used

⁵ Bitcoin inflation is controlled by halving the amount of bitcoins that can be drawn in a given unit of time at specific times. As a result of the number of mines cut in half, the number of bitcoins on offer will decrease, while demand is unlikely to change (see *Kaskaloglu*, 2014).

by people to obtain information, see e.g. *Kristoufek, 2013*), and the prices of the five biggest cryptocurrencies on the other. The rationale is, as already mentioned in Chapter 2, that public recognition, e.g. in the form of search intensity, social media mention and with it narratives, reflects the expressed intention of information retrieval and learning about cryptocurrencies (see *Ball, 2013; Li/Wang, 2017; Wu/Brynjolfsson, 2014*). Thus, the subsequent hypothesis can be derived:

Hypothesis 3: There is a positive correlation between public recognition and interest (measured by the number of worldwide Google searches and the number of worldwide Wikipedia searches for the respective cryptocurrency) and prices of cryptocurrencies (measured by the exchange rate in USD).

As there are five different dependent variables (the prices of the five biggest cryptocurrencies), we apply five different models, one for each dependent variable. Another five models, one for every cryptocurrency, have been fitted to test for hypothesis 1b, for which the moderating effect of time on the relationship between mining difficulty and the cryptocurrency's prize has been added to the initial five models. The time variable has been normalized on the interval of 0 (first day in the data set) and 1 (last day in the data set). However, not all determinants are available for the five different cryptocurrencies. Mining difficulty is only available for Bitcoin, Ethereum and Bitcoin Cash, and the total number of the respective cryptocurrency in circulation (cryptocurrency supply) is only available for Bitcoin and Ethereum. This procedure results in eight models to be fitted.

Before starting the analyses, we have to consider the (in)completeness of data. To clarify the respective problem, we take Bitcoin pars pro toto for all the cryptocurrencies. Prices, trading volume and the S&P 500 stock market index are available on a daily basis, e.g. for every day without weekends and public holidays. On the other hand, macroeconomic indicators like US GDP, US inflation and US interest rate are available on a monthly or quarterly rate, but they are valid for every day within the month respective quarter, so the same value has been taken for every trading day. In contrast, mining difficulty and cryptocurrency supply are only reported every second day including weekends and public holidays, and it is not reasonable to assume, that if mining had been done every day, the same value for mining difficulty and cryptocurrency supply holds as the day before. Furthermore, data for the number of Wikipedia searches are only available starting from July 2015. Consequently, complete data sets on all components were available for every second trading day in the time window from July 1st, 2015 until the September 30th, 2018 which sums up to 394 data points. However, the final number of

observations is lower due to occasionally occurring missing data. Similar situations hold for the other four cryptocurrencies.

The first step in any time series analysis is an inspection of stationarity, whether the series has a constant mean, variance and covariance over time, or if the series violates any of these three conditions. For this, the Augmented Dickey Fuller Test (ADF Test) has been applied, with its results reported in table 3.

insert table 3 around here

For every variable in the model, the table contains the corresponding values of the ADF test statistic and its p-value for both the variable itself and their first difference (*Greene, 2011*). The results of the ADF test show that for all five cryptocurrencies, some of the independent variables are stationary and others are non stationary time series, thus meaning a mix of $I(0)$ and $I(1)$ time series. For Ethereum, the cryptocurrency supply is neither $I(0)$ nor $I(1)$.

For non stationary time series, ordinary time series regression analyses are not appropriate because this can result in spurious correlations and inconsistent estimates (*Greene, 2011*). It is possible to perform the time series regression for the first differences instead but only if the time series are not cointegrated. Therefore, cointegration has to be examined. Common tests for cointegration are e.g. the tests of Engle and Granger (*Engle/Granger, 1987*) or the Johansen-Test (*Johansen, 1991*). These tests all require a set of $I(1)$ time series, but table 3 shows that there are also $I(0)$ time series present. A more suitable approach is the bounds procedure of Pesaran, Shin, and Smith (*Pesaran et al., 2001*). This procedure has been integrated into the autoregressive distributed lag (ARDL) models framework and tests the null hypothesis of no long run equilibrium relationship between the dependent and independent variables, no matter if the underlying time series are $I(0)$, $I(1)$, or mutually cointegrated. If the aforementioned null hypothesis is rejected, the nature of the long run relationship can be taken from the underlying ARDL model (see the example in *Pesaran et al., 2001* for this approach). This procedure has been implemented in the R package dynamac (v0.1.10, *Jordan/Phillips, 2019*) which has been used for the analyses. However, as this procedure requires at most $I(1)$ time series, the cryptocurrency supply for Ethereum has been omitted from the analysis.

To apply the procedure, an appropriate vector error correction model (VECM) has to be specified, which requires a lag to be chosen. There is a balance between choosing it large enough to handle the serial correlation problem and at the same time small enough so that the model is not over-parameterized in regard of the limited amount of data available especially for the cryptocurrency Bitcoin cash (for this approach see e.g. *Pesaran et al. 2001, p. 307*). This

leads to a time-lag of 12⁶ for the Litecoin model and a lag of 8 for all other models, based on the results for the Akaike Information Criterion, and the Lagrange Multiplier statistic for the serial correlation test. As a result, the preconditions of the bounds procedure, uncorrelated and normal distributed residuals (graphically examined by histograms), were met. Finally, a trend and an intercept are also included in the models.

insert table 4 around here

Table 4 yields the results of the bounds test procedure for the eight models. For the two models for Bitcoin and the Ripple and Litecoin models, the F-statistic exceeds the critical value if all variables are I(1) meaning that no matter how many variables are I(0) or I(1), there exists a long run relationship between the Bitcoin, Ripple and Litecoin price and the independent variables. For Ethereum and Bitcoin cash, the F-statistic exceeds only the critical value if all variables are I(0) but not for I(1). This indicates that the time series exhibits a slow adjustment towards the long-term relationship (see e.g. *Li/Wang*, 2017 for the interpretation).

5 Results

Tables 5 to 8 show the results for both Bitcoin, Ethereum and Bitcoin cash models on the one hand and the models for Ripple and Litecoin on the other hand. All four tables display the nature of the long run relationships and can therefore be used for the testing of the hypotheses elaborated above. For Bitcoin, there exists a significant positive effect of mining difficulty which supports hypothesis 1a. Thus, the market price of Bitcoin does anchor in mining cost. The decline of this effect over time is only significant at the 10% level, but this still supports hypothesis 1b. Therefore it can be assumed that bitcoin mining technology has become more efficient recently. For Ethereum and Bitcoin cash, however, the effect of mining difficulty on the price of the cryptocurrency is not significant meaning hypothesis 1a has to be rejected. The same applies to hypothesis 1b for both cryptocurrencies, as the interaction term is not significant. It is important to note that significances and most of the effect sizes for the models with and without the interaction term are similar for all the three cryptocurrencies. This supports the robustness of the models. For Ripple and Litecoin, there were no data for mining difficulty available so that the first hypothesis cannot be tested.

insert tables 5 to 8 around here

⁶ The time lag means, how many terms have to be back down to test for serial correlation.

Trading volume, cryptocurrency supply and macroeconomic indicators do not show any significant effects on the Bitcoin prices meaning that the hypotheses 2a, b and c are not supported by the empirical results (although a weak influence of the trading volume and the US inflation can be observed).

For Ripple, Litecoin and Bitcoin cash, the situation is different, as the trading volume has a significant positive effect on the cryptocurrency's price. To confirm that this effect is real and not a result of the fact that some of the variables available for bitcoin are missing here (mining difficulty and cryptocurrency supply), a model for Bitcoin has been fitted without the two mentioned variables which results in a significant positive effect of trading volume on the Bitcoin price. So it is reasonable to assume that the significant positive effect of the trading volume on the Ripple resp. Litecoin and Bitcoin cash price will disappear if information on mining difficulty and cryptocurrency supply were available, which means that hypothesis 2c cannot be confirmed either.

For Ethereum and Litecoin, there is also a significant positive effect of the S&P 500 on the prices. A similar comparison with the Bitcoin model as described above yields that this effect cannot be explained by the missing variables which gives some weak support for hypothesis 2a, but only for Ethereum and Litecoin. Google and/or Wikipedia searches are positively significant in all considered models giving strong support for the third hypothesis. Thus, the approach of "narrative economics" of Shiller and related to this the relevance of public recognition of cryptocurrencies are strongly confirmed.

In the following, the hypothesis effects are summarized again for the sake of clarity.

insert table 9 around here

6 Conclusion

In this paper we empirically examine various drivers of cryptocurrency exchange rates of the five biggest cryptocurrencies measured by market capitalization with the help of an evolutionary approach. We find that economic, technological and social factors are relevant on the one hand for the evolution of the cryptocurrency market since the financial crisis in 2007, and on the other hand as drivers for the prices. The empirical data show that above all trading

volume, mining difficulty and views on social media platforms are significant triggers on the cryptocurrency prices.

Accordingly, the following managerial implications can be deduced from the literature and the empirical data/hypotheses:

- Cryptocurrencies can influence financial decision-making processes (e.g. payment solutions) of managers in the future
- Cryptocurrencies are up to now more an alternative (speculative) asset in the context of asset management/corporate treasury
- Cryptocurrencies offer new options of firm financing (e.g. ICO)
- Cryptocurrency prices are influenced by various factors (e.g. social media views)
- Cryptocurrencies react different to various price drivers (e.g. Bitcoin vs. Ethereum)
- Cryptocurrency prices are in the case of Bitcoin less affected by mining difficulty over time
- Cryptocurrency prices are not influenced by the cryptocurrency supply
- Cryptocurrencies require managers to rethink their internal and external processes to be more innovative (e.g. usage of blockchain technology)
- Cryptocurrencies lead simultaneously to new risks for managers (e.g. data security)

However, the paper also has limitations, which can be found in the non-consideration of the regulatory perspective of cryptocurrencies and the non-existent analysis of legal influencing factors on the prices. By future (rather legal than economic) research, also the legal status of cryptocurrencies should be further explored.

Appendix

Tables and Figures

Please insert the following tables and figures into the text as indicated on the previous pages.

Criteria	Cryptocurrencies	Fiat Money/Currencies	Gold	Special Assets (e.g. stocks)
(de-)centralization of supply	Bitcoin opened the door to decentralized (and therefore anonymous) cryptocurrencies, meaning that money is not created by central/monopoly or other intermediaries (such as central banks) but is carried out using a complicated calculation algorithm with high system costs (<i>Scaillet et al.</i> , 2017; <i>Schmidt</i> , 2017). Functions of money are not completely fulfilled (e.g. unit of account and store of value, see <i>Gangwal/Longin</i> , 2018)	Money is primarily produced and controlled by central banks (<i>Friedman</i> , 1968) and defined by three functions: intermediary of exchanges, unit of account and store of value (see <i>Barnes</i> , 2000),	Compared to money, supply is less centralized, more decentralized available and in contrast to cryptocurrencies used in many electronics and medical appliances due to its durable conductive properties (see <i>American Bullion</i> , 2017).	Assets like stocks or bonds are emitted each by firms but decentralized tradable at stock or bond exchanges (see <i>Bodie/Kane</i> , 2017).
portfolio characteristic	The risk-return ratio of cryptocurrencies (including skewness and kurtosis of returns) differs (by being higher) from that of traditional asset classes (see e.g. <i>Gangwal/Longin</i> , 2018) shows low correlation to them and thus could foster diversification effects.	Money in the sense of liquidity can lead to diversification effects in total portfolios (see <i>Bodie/Kane</i> , 2017).	As a commodity, gold can lead to diversification effects in portfolios due to its low correlation to traditional assets (see <i>Artigas</i> , 2010).	Different asset classes can achieve diversification effects in the sense of Markowitz (<i>Markowitz</i> , 1952; <i>Sharpe</i> , 1992). Stock prices are known to show market anomalies similar to cryptocurrencies (see e.g. <i>Caparole/Plastun</i> , 2017 and 2018; <i>Kurihara/Fukushima</i> , 2017).
cash flow relevance	Unlike traditional financial assets (e.g. stocks and bonds) cryptocurrencies do not generate financial cash flows (dividends or interest) so that no estimation of a fundamental value is possible (<i>Gangwal/Longin</i> , 2018).	Money has no cash flow unless it is invested in an asset (see <i>Bodie/Kane</i> , 2017).	Similar to cryptocurrencies, gold does not cause any cash flow unless sold (see <i>Divine</i> , 2016).	Cash flows occur as dividends or debt service (see <i>Bodie/Kane</i> , 2017).
risk aspects	Since there is no haptic in cryptocurrencies, unlike money and gold, this must be replaced by a high level of trust (see <i>Schmidt</i> , 2017; see also <i>Khatwani</i> , 2018 for the conditions of trust). Similar to traditional assets cryptocurrencies can produce price bubbles (e.g. Bitcoin at the end of 2017).	Money can be devalued by inflation and is legal tender in the respective country in contrast to cryptocurrencies, which nobody is legally obliged to accept as a means of payment (see <i>The Motley Fool</i> , 2017).	Gold is typically considered a kind of safe haven in times of crisis (e.g. <i>Baur</i> , 2006) what could it have in common with cryptocurrencies despite market price risk (see <i>Gangwal/Longin</i> , 2018).	Due to irrational behavior of the investors especially stock prices can cause a speculative bubble (e.g. the dot. com bubble, see <i>Shiller</i> , 2000). Furthermore, stocks are subject to a market risk (see <i>Markowitz</i> , 1952).

Table 1: Distinguishing cryptocurrencies

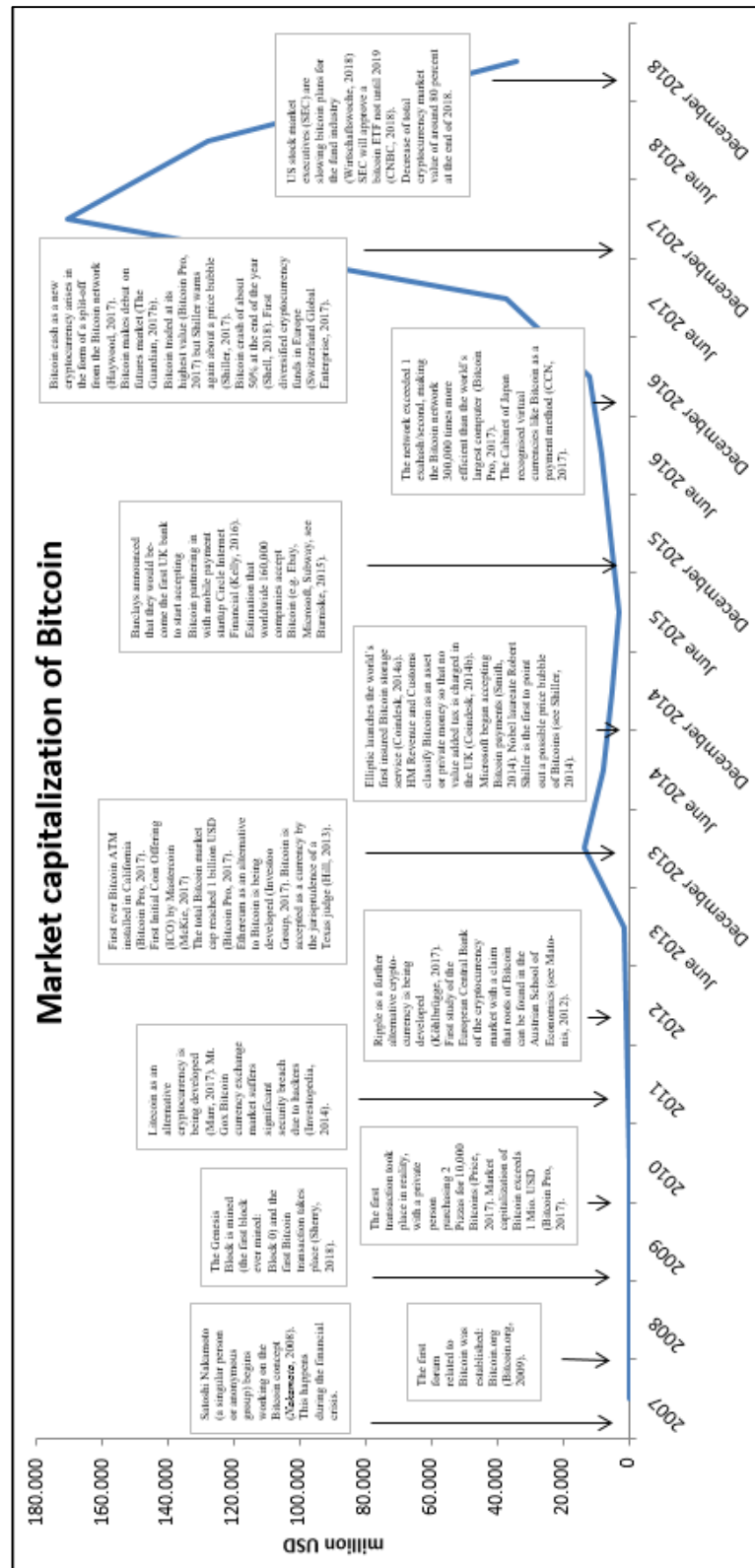


Figure 1: Market capitalization of Bitcoin and evolutionary development of the cryptocurrency market from 2007 to 2018⁷

⁷ Data for the market capitalization of Bitcoin are only entirely available since 2013 (in 2010 the market capitalization was 1 mill. USD). This is the reason for the change in the inscription of the abscissa from 2013.

Variable name	Definition	Data source
Dependent variables:		
Price of the respective cryptocurrency: Bitcoin, Ethereum, Ripple, Bitcoin cash and Litecoin	Daily exchange rate in USD of the respective cryptocurrency.	coinmarketcap.com
Explanatory technical variable:		
Mining difficulty	The hashing power that has to be deployed by the network of miners	blockchain.com
Explanatory economic variable:		
US GDP	Quarterly US GDP	Federal Reserve
US inflation	Monthly US inflation rate	usinflationcalculator.com
US interest rate	Daily US federal interest rate	Federal Reserve
US stock market	Daily price of the S&P 500 Index	Federal Reserve
Cryptocurrency supply	Total amount of cryptocurrency in circulation	blockchain.com
Trading volume	Daily trading volume of the respective cryptocurrency	coinmarketcap.com
Explanatory social variables:		
Number of worldwide Google searches	Monthly Google Trends Index on the term "respective cryptocurrency"	Google Trends
Number of worldwide Wikipedia searches	Daily Wikipedia pageview on the term "respective cryptocurrency"	Wikipedia pageview analysis

Table 2: List of dependent and independent variables

Currency	Variable	ADF	Lag parameter	P-value	ADF first difference	Lag parameter	P-value
Bitcoin	Price	-2,65	12	0,304	-11,46	12	0,010
Bitcoin	Trading volume	-2,27	11	0,462	-16,62	11	0,010
Bitcoin	Mining Difficulty	6,26	9	0,990	-7,67	9	0,010
Bitcoin	Cryptocurrency supply	-0,56	9	0,979	-3,62	9	0,031
Bitcoin	Google Searches	-3,02	12	0,145	-11,96	12	0,010
Bitcoin	Wikipedia Searches	-3,34	10	0,063	-11,91	10	0,010
Ethereum	Price	-2,19	10	0,499	-9,93	10	0,010
Ethereum	Trading volume	-3,59	10	0,033	-12,01	10	0,010
Ethereum	Mining Difficulty	-1,69	10	0,709	-9,17	10	0,010
Ethereum	Cryptocurrency supply	-1,48	10	0,797	-1,64	10	0,732
Ethereum	Google Searches	-2,11	10	0,531	-9,71	10	0,010
Ethereum	Wikipedia Searches	-3,58	10	0,035	-14,71	10	0,010
Ripple	Price	-3,42	12	0,051	-13,52	12	0,010
Ripple	Trading volume	-4,23	11	0,010	-17,14	11	0,010
Ripple	Google Searches	-3,43	12	0,049	-11,65	12	0,010
Ripple	Wikipedia Searches	-5,38	10	0,010	-11,16	10	0,010
Bitcoin Cash	Price	-1,76	6	0,678	-6,78	6	0,010
Bitcoin Cash	Trading volume	-4,09	6	0,010	-10,19	6	0,010
Bitcoin Cash	Mining Difficulty	-3,06	6	0,130	-8,67	6	0,010
Bitcoin Cash	Google Searches	-2,55	6	0,344	-6,87	6	0,010
Bitcoin Cash	Wikipedia Searches	-4,24	6	0,010	-11,24	6	0,010
Litecoin	Price	-2,79	12	0,245	-14,27	12	0,010
Litecoin	Trading volume	-5,32	11	0,010	-16,65	11	0,010
Litecoin	Google Searches	-4,34	12	0,010	-11,96	12	0,010
Litecoin	Wikipedia Searches	-4,92	10	0,010	-12,89	10	0,010
All Currencies	US Inflation	-4,20	12	0,010	-11,99	12	0,010
All Currencies	US Interest rate	-0,33	12	0,989	-13,34	12	0,010
All Currencies	US GDP	-3,39	12	0,056	-11,67	12	0,010
All Currencies	SP 500	-2,23	10	0,479	-12,41	10	0,010

Table 3: Results of the ADF test

Model	dependent variable	moderator no / yes	Number of observations	AIC	BIC	LM teststatistic	LM test p-value	F-statistic	Significant for I(0)	Significant for I(1)	interpretation
1	Bitcoin	no	364	4501,846	4883,959	1,414	0,234	5,124**	yes	yes	Long run relationship exists
2	Bitcoin	yes	364	4498,981	4884,840	0,066	0,798	4,809**	yes	yes	Long run relationship exists
3	Ethereum	no	657	5877,928	6287,806	0,122	0,727	4,205**	yes	no	Inconclusive
4	Ethereum	yes	657	5879,922	6294,256	0,121	0,728	3,928*	yes	no	Inconclusive
5	Ripple	no	689	-2586,891	-2218,280	0,064	0,800	26,676***	yes	yes	Long run relationship exists
6	Bitcoin Cash	no	164	1712,172	1980,810	0,689	0,407	3,685*	yes	no	Inconclusive
7	Bitcoin Cash	yes	164	1711,490	1983,048	0,717	0,397	3,848*	yes	no	Inconclusive
8	Litecoin	no	687	3758,159	4270,620	0,010	0,921	5,301**	yes	yes	Long run relationship exists

Table 4: Results of the bounds test procedure

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level. Statistical significance of the F-statistics of the bounds test is derived from Table C1.v in Pesaran et al. (2001). The table contains a lower bound and a higher bound at each significance level, dependent of the number of lags in the vector error correction model. The lower bounds are critical values when all variables are I(0), while the higher bounds are critical values when all variables are I(1). Given a mixture of I(0) and I(1) variables, the critical value should be between the two bounds.

Variable	Model 1: Excluding moderator			Model 2: Including moderator		
	Coefficient	t-statistic	P-value	Coefficient	t-statistic	P-value
Trading volume (fd)	5,73E-08	1,434	0,153	5,75E-08	1,446	0,150
Mining difficulty (fd)	2,17E-09	2,767	0,006***	1,54E-09	1,803	0,073*
Cryptocurrency supply (fd)	0,006	0,768	0,443	0,006	0,735	0,463
Google searches (fd)	22,93	3,367	0,001***	22,64	3,342	0,001***
Wikipedia searches (fd)	0,004	2,254	0,025**	0,004	2,178	0,031**
US inflation	-157,3	-1,285	0,200	-201,4	-1,622	0,106
US interest rate (fd)	-440,7	-0,926	0,356	-287,0	-0,597	0,551
US GDP (fd)	-2,009	-0,029	0,977	-2,745	-0,040	0,968
SP 500 (fd)	-0,151	-0,172	0,863	-0,200	-0,229	0,819
Bitcoin Price (lagged)	-0,214	-3,18	0,002***	-0,215	-3,201	0,002***
Mining diff. * time				6,59E-09	1,818	0,070*

Table 5: Results of the ARDL-model for bitcoin

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level; fd denotes that the first differences have been used; lagged denotes a time lag of one day.

Variable	Model 1: Excluding moderator			Model 2: Including moderator		
	Coefficient	t-statistic	P-value	Coefficient	t-statistic	P-value
Trading volume (fd)	2,06E-09	0,779	0,437	2,07E-09	0,781	0,435
Mining difficulty (fd)	1,92E-05	1,167	0,244	1,96E-05	1,132	0,258
Google searches (fd)	0,699	2,451	0,0146**	0,698	2,441	0,015**
Wikipedia searches (fd)	2,96E-04	0,489	0,625	2,94E-04	0,485	0,628
US inflation	-3,372	-0,635	0,526	-3,348	-0,629	0,530
US interest rate (fd)	-17,90	-0,636	0,525	18,10	-0,639	0,523
US GDP (fd)	-2,967	-0,598	0,550	-2,966	-0,598	0,550
SP 500 (fd)	0,263	4,274	0,001***	0,263	4,269	0,001***
Ethereum Price (lagged)	-0,006	-3,171	0,002***	-0,006	-2,062	0,040**
Mining diff. * time				-1,72E-06	-0,072	0,942

Table 6: Results of the ARDL-model for Ethereum

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level; fd denotes that the first differences have been used; lagged denotes a time lag of one day.

Variable	Model 1: Excluding moderator			Model 2: Including moderator		
	Coefficient	t-statistic	P-value	Coefficient	t-statistic	P-value
Trading volume (fd)	6,99E-08	1,981	0,054*	6,77E-08	1,912	0,062*
Mining difficulty (fd)	2,85E-04	-0,417	0,679	-1,98E-03	-1,030	0,309
Google searches (fd)	0,980	0,391	0,698	1,030	0,411	0,683
Wikipedia searches (fd)	1,15E-03	1,788	0,080*	0,012	1,915	0,062*
US inflation	-77,35	-0,379	0,706	-94,61	-0,461	0,647
US interest rate (fd)	236,7	0,627	0,534	287,7	0,753	0,455
US GDP (fd)	-161,5	-0,271	0,788	-401,1	-0,618	0,540
SP 500 (fd)	0,775	1,102	0,276	0,866	1,218	0,229
Bitcoin Cash Price (lagged)	-0,638	-3,592	0,001***	-0,682	-3,710	0,001***
Mining diff. * time				2,57E-03	0,943	0,351

Table 7: Results of the ARDL-model for Bitcoin cash

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level; fd denotes that the first differences have been used; lagged denotes a time lag of one day.

Variable	Ripple			Litecoin		
	Coefficient	t-statistic	P-value	Coefficient	t-statistic	P-value
Trading volume (fd)	3,11E-11	7,145	0,001***	8,23E-09	6,820	0,001***
Google searches (fd)	0,001	3,924	0,001***	0,120	2,187	0,029**
Wikipedia searches (fd)	7,09E-04	13,16	0,001***	1,69E-03	5,373	0,001***
US inflation	-2,04E-04	-0,030	0,976	-0,637	-0,701	0,484
US interest rate (fd)	0,027	0,711	0,477	2,496	0,525	0,600
US GDP (fd)	-0,006	-0,921	0,357	-0,276	-0,332	0,740
SP 500 (fd)	2,66E-05	0,347	0,729	0,019	2,088	0,037**
Ripple / Litecoin Price (lagged)	-0,172	-8,092	0,001***	-0,044	-3,597	0,001***

Table 8: Results of the ARDL-model for ripple and litecoin

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level; fd denotes that the first differences have been used; lagged denotes a time lag of one day.

	Bitcoin	Ethereum	Ripple	Bitcoin Cash	Litecoin
Hypothesis 1a	significant effect	no effect	n.a.	no effect	n.a.
Hypothesis 1b	weak effect	no effect	n.a.	no effect	n.a.
Hypothesis 2a	effect, but not significant for inflation	significant effect for the stock market	no effect	no effect	significant effect for the stock market
Hypothesis 2b	no effect	no effect	no effect	no effect	no effect
Hypothesis 2c	effect, but not significant	no effect	significant effect	significant effect	significant effect
Hypothesis 3	significant effect	significant effect	significant effect	significant effect	significant effect

Table 9: Hypotheses and statistical effects

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