THE SCARCITY OF MONEY: THE CASE OF CRYPTOCURRENCIES

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Abstract

Five years after the introduction of the peer-to-peer payment system and digital currency bitcoin, cryptocurrencies have flourished and become a global phenomenon. Concerns regarding the impact of cryptocurrency on financial stability and the conduct of monetary policy have drawn regulatory scrutiny and formal policy stances on this emerging phenomenon. The main purpose of the present research is to determine whether cryptocurrencies are scarce and can, by this virtue, be regarded as money. Cryptocurrencies such as bitcoin and litecoin are programmed to have supply scarcity, however the fact that myriad digital coins can be created effortless by emulation raises the question of whether the total combined supply of this potential money is indeed scarce or not. The primary focus of the paper is to determine empirically if the two main cryptocurrencies, bitcoin and litecoin are actually perceived by the market as being different. In order to determine whether bitcoin and litecoin are perceived as similar or not by the market, I conduct an empirical analysis using daily closing price and trade volumes data from major exchanges Bitstamp and BTC-e. I calculate correlations on a monthly and weekly frequency to investigate price co-movement and its dynamics. Complementarity and substitutability for the entire sample and for 4 separate subsamples is formally analyzed through the calculation of direct price elasticities and of cross-price elasticities of volume. I show that in spite of negligible fundamental differences that would lead us to believe that the two cryptocoins are interchangeable and fungible to a great extent, the empirical landscape is more complex, with fair evidence in favor of substitutability, i.e. them being effectively perceived as different monies. The implication of this finding is that the supply scarcity of any individual coin is not placed under question by the potentially infinite aggregate supply of all cryptocurrencies. Cryptocurrencies can posses scarcity, and, other properties left aside, can be regarded as money.

Keywords: cryptocurrency, money scarcity, currency competition

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1. Introduction

Five years after its introduction as the peer-to-peer payment system and digital currency, Bitcoin has rapidly become a global phenomenon, traded online on non-stop exchanges, subject to several spectacular bubbles, accusations of facilitating illicit activities and organized crime, Congress investigations, court rulings and several major central bank bans. Innovative as a payment method that is completely decentralized and authority-free, bitcoin is hailed by many as the future of money.

Since 2009, cryptocurrencies have flourished; more than 300 altcoins have emerged in bitcoin's wake and have shifted significant amounts of capital to the cryptocoin "mania". Concerns regarding the impact of cryptocurrency on financial stability and the conduct of monetary policy, as well as connections with illicit activities have drawn regulatory scrutiny and formal policy stances on this emerging phenomenon. The U.S. Federal Reserve, the ECB and the People's Bank of China, among others, have all issued statements, conducted research and taken action in response to this emerging market reality.

The question whether crytocurrency is money and can affect central bank monetary policy and also the stability of the financial system as more and more capital is directed toward these highly volatile assets is of great policy relevance.

1.1. Thesis statement

The main purpose of the present research is to determine whether cryptocurrencies are scarce and can, by this virtue, be regarded as money. For a commodity/object/token/artifact to be money, it requires, among other attributes, to come in scarce supply. Cryptocurrencies such as bitcoin and litecoin are programmed to have supply scarcity, however the fact that myriad digital coins can be created effortless by emulation and these coins bear striking resemblance to the existing ones raises the question of whether the total combined supply of this potential money is indeed scarce or not. If not, it can be inferred that cryptocurrencies cannot possibly achieve the status of money.

The primary focus of the paper is to determine empirically if the two main cryptocurrencies, bitcoin and litecoin, which share great technological similarity, are built on the same inelastic supply philosophy and thus appear to be identical in fundamentals are actually perceived by the market as being different. It will be shown that in spite of negligible fundamental differences that would lead us to believe that the two cryptocoins are interchangeable and fungible to a great extent, the empirical landscape is more complex, with fair evidence in favor of substitutability, i.e. them being effectively perceived as different monies.

My analysis leads me to believe that we cannot reject the possibility that bitcoin and litecoin are perceived by the market as different types of monies. Findings are rather conflictive and time dependant. Correlation seems to jump from positive to negative on almost a weekly basis, which leads us to believe that no real conclusion of complementarity or substitutability can be drawn for the entire period as a whole. When breaking down the analysis into subperiods, I notice that the overall relationship is mainly driven by bubble events, when the cryptocoins price correlation becomes very strong. I interpret this in the following way: during times of great "hype" around cryptocurrencies, i.e. when they compete together against other asset classes more so than against each other, both their prices go up riding a wave of cryptocurrency enthusiasm. In normal times correlation can even turn negative.

The ultimate test for complementarity/ substitutability, the cross price elasticities of volume, suggests that the two cryptocurrencies are rather substitutes to each other, as the market perceives them as being different types of money.

As a conclusion, despite their fundamental similarity, the market perception surrounding the two cryptocurrencies is rather mixed, with evidence that cannot completely rule out substitutability. The implication of this finding is that the supply scarcity of any individual coin is not placed under question by the potentially infinite aggregate supply of all cryptocurrencies. Cryptocurrencies can posses scarcity, and, other properties left aside, can be regarded as money.

Assessing whether bitcoin or altcoins are currencies or money in the broad sense does not fall within the scope of my thesis. Here I solely concentrate on scarcity as a defining feature of money. Bitcoin's suitability as a means of exchange, store of value and unit of account has already been analyzed at different points of its history; furthermore, empirical studies have looked into the financial properties of the cryptocoin such as liquidity, volatility, etc. Emerging from previous literature seems to be an agreement that bitcoin, at the moment, is not a currency, but has certain degrees of moneyness and can be regarded as a form of money, but its fulfillment of some of the definitory functions of money is so far lackluster. Existing literature compares cryptocurrency to both fiat money, which derives its scarcity from government monopoly over the money supply and to commodity-like money, which are literally scarce by nature.

1.2. Methodology

In order to determine whether bitcoin and litecoin are perceived as similar or not by the market, I conduct an empirical analysis using daily closing price and trade volumes data from major exchanges Bitstamp and BTC-e. The time series comprises little over 600 observations spanning over almost 2 years, from litecoin launch in August 2012 until March 2014. I calculate correlations on a monthly and weekly frequency to investigate price co-movement and its dynamics; alternating signs for correlations are rationalized through a bubble/non-bubble framework. Complementarity and substitutability for the entire sample and for 4 separate subsamples is formally analyzed through the calculation of direct price elasticities and of cross-price elasticities of volume. Quantitative information and statistics are rather difficult to compile for most altcoins; bitcoin and litecoin, as market leaders, are fortunate exceptions and data availability is a main criteria for restricting my research to these two alternative cryptocurrencies.

1.3. Contribution and thesis structure

Computer science and investment literature aside, there is very little scholarly work on the economics of bitcoin, much less with regards to the question of bitcoin as money. Most of the available information can be found on web sites, blogs, news articles, but very little of the analysis is structured and rigorous. The few studies that do engage the question of cryptocurrency as money is limited to considering mostly moneyness properties such as liquidity, velocity, volatility, adoption rate, etc. There is virtually no literature on the scarcity property of cryptocurrency, needless to say none that investigates cryptocurrency competition by looking at actual competing cryptocoins bitcoin and litecoin. My goal through this paper is to answer the scarcity question by empirical analysis, using the most recent data available.

I structure my thesis in a way that first sets the conceptual framework for analysis, with introductions for bitcoin and litecoin and definitions for money, scarcity and currency competition. Literature on cryptocurrency as money and money scarcity is then engaged to identify the state-of-play and to explain the contribution of my research. The empirical analysis that follows is an investigation into market perceptions, and my findings are discussed in light of my conceptual framework and as a source for policy implications. Following this Introduction (Chapter 1), the thesis explores the concept of cryptocurrency, introduces bitcoin and signals the “altcoin”, i.e. major bitcoin competitors and afterwards reviews both existing literature on bitcoin as money as well as regulator stances on the issue of digital money worldwide (Chapter 2). Subsequently, the paper draws on the concepts of money scarcity and currency competition, establishing both definitions as well as visiting the existing literature (Chapter 3). Chapter 4 comprises of the actual empirical analysis and provides the most significant evidence in drawing the Conclusions and formulating the Policy implications (Chapter 5).

2. Cryptocurrencies: economic literature and policy stances

2.1. What is bitcoin?

Bitcoin is a digital currency created in 2009 by a computer programmer using the pseudonym Satoshi Nakamoto. It has no physical manifestation (exists only as computer codes), it is open source (computer code is open to all) and peer to peer (transactions do not require authorization by a third party like Paypal, Skrill, Visa, but are rather verified through the resolution of complex algorithms by powerful computers). Bitcoin is a private currency, i.e. it is not the creation of a central bank; although not the first private currency, it is the first one so far to run in a completely decentralized manner – there is no central authority performing system functions or dictating the money supply, but these functions are performed by all users.

Bitcoin is produced by “mining”, i.e. miners place the computing capacity of their machines in the service of verifying transactions to complete the common record, the “block chain”, being rewarded for solving complex algorithm with currency. “Whereas gold miners compete in finding, extracting and purifying the metal, bitcoin miners compete to solve an extraordinarily difficult puzzle every 10 minutes around the clock by using brute-force number-crunching capacity” (Grinberg, 2012, p.4). The analogy to gold does not stop in the circles of bitcoin miners and enthusiasts. In a formal report prepared in December 2013 by the Congressional Research Service (Elwell et al. 2013) in the wake of bitcoin’s most spectacular price movement, specialists have warned that cryptocurrencies with inelastic supply are reminiscent of the gold standard period of 1880-1914, when deflationary bias drove interest rates high, causing periodic bank crises and high output volatility, prompting the creation of the Federal Reserve system in 1913, which would ultimately manage an elastic, fiat dollar money supply.

What is peculiar about bitcoin as money is that its supply is programmed to increase at a decreasing rate and then halt at an upper limit. Indeed, the number of bitcoins awarded for each puzzle solution is halved every four years, with mining complexity increasing to mirror the amount of coins mined. Today, there are about 7.5 million bitcoins in existence and 50 bitcoins are awarded every 10 minutes or so; by 2030, the number of bitcoins will approach the absolute maximum, 21 million, which programming protocols guarantee that no individual or management committee has the power to manipulate (Grinberg, 2012). To a great extent, the valuation of bitcoin is dependent on whether current and future users truly believe in the absence of any technological workaround to this cap. Despite the arguably low cap, bitcoin is suitable for small transactions and low concentration due to its divisibility to eight decimal places, with the smallest unit of account named satoshis.

Even abstracting from the fact that is has its own unit of account, bitcoin is an amazingly innovative payment system technology that enables users to bypass some of the shortcomings of traditional payment processors and of the transnational banking system. Bitcoin draws its advantages from the fact that it has no third party intermediary to verify buyer and seller interaction, which considerably reduces transaction costs (Vaishampayan, 2014). Unlike cash money, transactions are not fully anonymous, but pseudonymous, with a transaction record being created in the common ledger, available to all users at the same time.

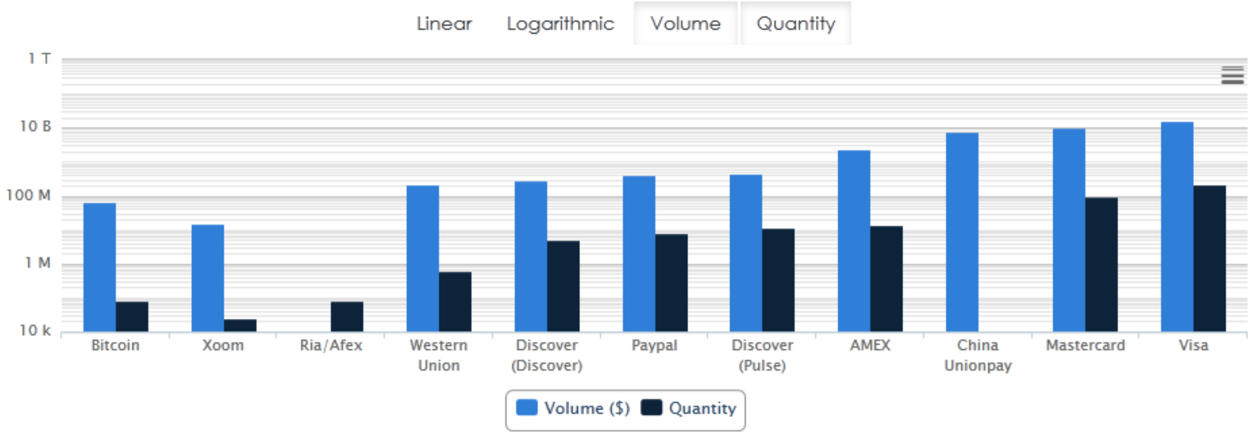
Bitcoin is a fiduciary currency. Like other fiduciary currencies, and in contrast to commodity-based currencies (such as gold coins), bitcoin has no intrinsic value, and derives its value from the belief that they will be accepted at any time by a counterparty. Unlike government fiat, Bitcoin is not legal tender, it lacks the support of deposit insurance schemes, nor is it backed by any government or any other legal entity, nor is its supply determined by a central bank (Velde, 2013, p.2). The bitcoin exchange rate to other cryptocurrencies or fiat is not pegged or managed in any way, but determined real-time, 24/7 by the supply and demand on global exchanges, where trading is brokerage-free.

As of yet, the scale of bitcoin usage remains small in comparison to traditional electronic payments systems such as credit cards and the use of dollars as a circulating currency; however, more and more merchants are accepting it as a legitimate means of exchange. Bitcoins are being exchanged daily for the purchase of various non-digital goods and services, such as food, tickets, travel services, electronic equipment and cars. In November 2013, the total number of Bitcoins in circulation was approaching 12 million, compared to about 2 million coins from a year earlier. Its current market capitalization exceeds $20 billion. During 2013, Bitcoin daily transaction volume was situated in a range of between $20 million and $40 million, representing about 40,000 daily transactions. This compares to (Velde, 2013, p.1):

- the U.S. money supply (M2) was about $10.8 trillion (about 1,000 times larger.); daily transactions in dollars on global foreign exchange markets averaged over $4 trillion
- Visa total dollar volume was $6.9 trillion, with an average number of daily individual transactions of near 24 million.

As of May 2014, daily transaction volume had reached $66MM, roughly 1/3 and 1/5 of Western Union and Discover volumes, with about 60,000 transactions or about 1/10 of WE transactions. This comes to show that bitcoin is not yet comparable to traditional merchant and remittance payment systems, but is hardly negligible on this global market.

Graph 1: Daily USD volume and number of transactions for market leaders in payment systems, March 2014



Source: http://www.coinometrics.com/bitcoin/btix, accessed June 2, 2014.

2.2. Bitcoin's crypto-competitors

After bitcoin's launch in 2009, over 300 alternative currencies, or altcoins, have emerged to ride the wave of enthusiasm surrounding this new technology. While most of them are "garage start-ups", curiosities without global ambitions, some have benefited from heightened investor attention and even consumer adoption. In the following I will introduce the six top altcoins of 2013 (Bradbury, 2013) and their present market value based on figures spanning 306 currencies from 704 markets, from coinmarketcap.com.

- **Litecoin (LTC)**. Market cap: $ 308,265,259. First mined in Dec. 7, 2011.

Named by some as the silver to bitcoin's gold (Neal, 2014), litecoin is considered the main alternative to bitcoin and is indeed the coin with the highest market capitalization after bitcoin, but the value of its supply is 24 times less than the estimated $ 7,294,753,289 for BTC. Its success is an early proof of a nearly-identical coin being able to penetrate the market despite the network advantages of the already established first-mover and leader (The Genesis Block, 2014).

Litecoin was designed as nearly identical to bitcoin, but with a few technical and monetary differences: it uses a different proof of work algorithm (scrypt as opposed to bitcoin's SHA), chosen specifically so that average miners would be able to gain currency with simple home computers; the LTC protocol targets lower average block times (2.5 minutes versus 10 for BTC); additionally, its final supply, although also limited, is set at 84 million, compared to the 21 million of BTC (Stacke, 2013).

- **Peercoin (PPCoin).** Market cap $ 47,215,407.

Peercoin distinguishes itself significantly from the anti-inflationist ideals of cryptocurrencies by not having a limit on the amount of coins that can be created. By using proof-of-stake, an alternative to the proof-of-work mechanism used by bitcoin, Peercoin's algorithm automatically produces more coins based on the holdings a person already has, thus maintaining an annual inflation rate of 1%. According to developer Sunny King, a pseudonym echoing that of Satoshi Nakatomo, this is intended to achieve long-term mining energy efficiency and more cost-competitiveness in payment processing. The constant, uncapped rate of growth for the money supply would alleviate the concerns that cryptocurrencies might trigger a deflationary spiral (Krugman, 2011) if adoption became widespread.

- **Namecoin**. Market cap: $ 20,381,687

Namecoin is a typical example of a bitcoin copycat; it can hardly be argued that this altcoin has any significant differences over the market leader. Namecoin is built as a modified version of the bitcoin software and has the same mining complexity. Moreover, the currency functions on a merged mining basis with bitcoin and clients can be configured to check both blockchains when performing proof-of-work tasks. Designed to enable users to store and transmit pairs of keys and values cryptographically, in an entirely decentralized domain name system, the altcoin has lost a number of positions in the market cap ranking after identification of a technical flaw in late 2013.

- **Worldcoin.** Market cap: $ 1,328,414

The goal for Worldcoin ever since its launch would be to turn into the global cryptocurrency of choice for merchants, consumers and remittances, with one of the fastest confirmation times for transactions, 60 seconds (Bradbury, 2013). In 2013, Worldcoin and partners feathercoin and phenixcoin attempted to join forces in creating a common promotion platform, United Open Currencies Solutions (UNOCS) that would increase their visibility on the market and their chances to compete the established cryptocurrencies.

- **Feathercoin.** Market cap: $ 2,896,844

Feathercoin was also a relative newcomer to the market, having been launched in April 2013. As a response to a 51% attack attempted on the altcoin, it boasts an innovative feature built into the client code and called advanced checkpointing, which grants extra security to the blockchain. Moreover, feathercoin benefits from its own eBay-style marketplace and the possibility of placing metadata in the block chain, that would assist with file transmission (Bradbury, 2013).

- **Dogecoin.** Market cap: $ 30,142,049. First mined Dec.6, 2013.

Dogecoin is the latest arrival in this shortlist of altcoin, alternative cryptocoins and it was initiated as a way of ridiculing the cryptocurrency phenomenon by adopting the famous internet “doge” meme and a picture of Shiba Inu as its emblem. On a more serious note, it is worth noticing that the altcoin rapidly emerged as one of bitcoins top contenders, building a strong Reddit community and excelling in the marketing game, not least by buying advertisement space on NASCAR vehicles. Dogecoin however does not only build a comparative advantage in marketing, but rather has appealing technological features that make it stand out of the altcoin group: most coins in circulation (over 28 billion), highest average trading and the highest mining reward (each block containing 526,226 dogecoins).

2.3. Are cryptocurrencies money? Economic studies

Before launching into an empirical analysis of cryptocurrency, it is important to understand how well digital currency fits the description of money by reviewing both existing literature that poses this question and also the most recent rulings of courts and regulators on the same matter.

My purpose in exploring the literature addressing the question of bitcoin as money is to understand the implications of previous research on my current research topic, the scarcity of cryptocurrency. As we will see, agreeing that, so far, cryptocurrencies are not quite currencies, existing literature compares them to both fiat money, which derives its scarcity from government monopoly over the money supply and commodity-like money, which are literally scarce by nature. I will first summarize a definition of money, after which I will review the (scarce) literature on bitcoin as money, as well as the state of play in regards to regulators' and authorities' approach to cryptocoins.

The most commonly accepted definition of money is that of a record or an object/artifact generally accepted for the payment of goods/services and for the repayment of debt; this definition encompasses three broad functions, which had already been outlined by William Stanley Jevons in *Money and the Mechanism of Exchange* (1896, pp.14-19): first and most importantly, money is a medium of exchange, second, it is a store of value, and third, it is a unit of account.[1]

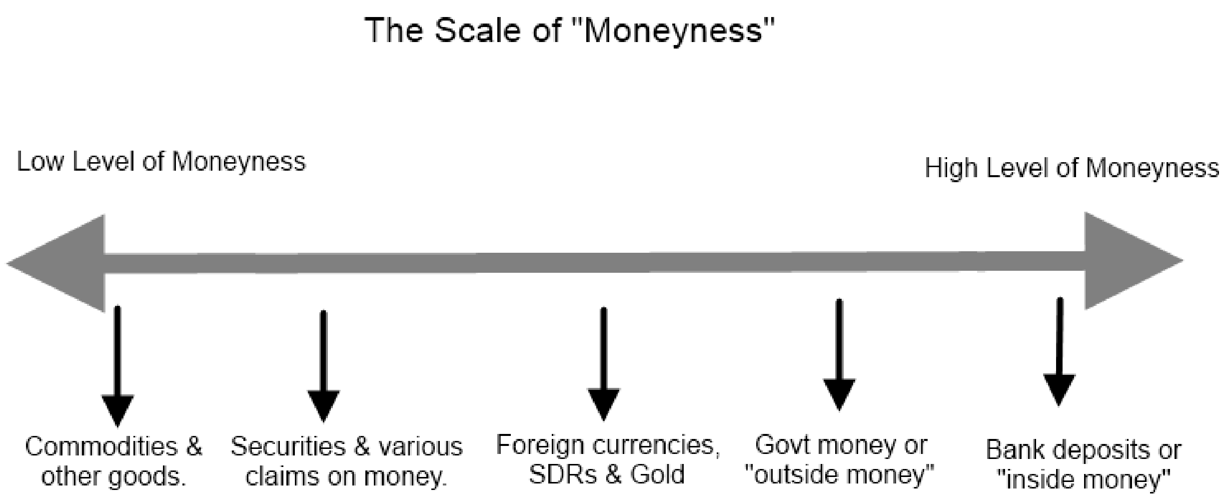
1. Medium of exchange: usage as intermediate for the exchange of goods and services, avoiding several inefficiencies of a barter system, including the double coincidence of wants. Barter only allows for simple, direct trade, but modern economies cannot be imagined without the use of money.
2. Unit of account: numerical unit of measurement of market value, a benchmark/ standard of relative worth that acts as a necessary prerequisite for the formulation of commercial agreements. If prices within an economy are set in a specific currency and this currency enables consumers to measure the relative value of goods and services and firms to keep track of their assets and liabilities and make investment decisions, than that currency is considered a unit of account. This is an important distinction, as not all mediums of exchange are necessarily units of account.
3. Store of value: money is easily stored, saved and retrieved; its value, for the most part, is predictable and does not fluctuate wildly; money that fluctuates wildly, usually as caused by hyperinflation, has a short lifespan and is typically replaced by other money, either internally or externally (dollarization). Rising price levels make money an imperfect means of transferring purchasing power from the present to the future, but constant, low levels of inflation are generally acceptable and do not qualify as wild fluctuations.

Mainstream economics views money as uniquely specified as a measure of abstract value (Keynes 1930; Grierson 1977; Hicks 1989; Hoover 1996 cited Ingham, 2004); and a means of storing and transporting this abstract value (Knapp 1973 [1924] cited Ingham, 2004).

[1] Textbook definitions of today refer to these 3 functions. See Krugman, Paul R. (1984) or Mankiw, Gregory (2010).

Mises (1912 cited Surda 2012) or Schlichter (2011 cited Surda 2012) argue, however, that this definition either does not make a strong enough separation between functions (or that these functions may even be in conflict) or makes a separation were doing so is artificial. They point out that the single definitory feature of money, from which all else is derived and secondary, is the medium of exchange. In referring to Hicks' theory of money (1935 cited Hayek 1999), Hayek stresses out that money can be better understood as a continuum, with various forms of money exhibiting varying degrees of moneyness in relation to these functions: there is no money and non-money, but rather moneyness of various currencies. Currency as an adjective would be a more appropriate term than the noun money, as objects can have various degrees of "currency" across space and institutional arrangements.

Graph 2: The scale of "moneyness"



Source: http://monetaryrealism.com/understanding-moneyness/, accessed June 4, 2014

Depending on its degree of moneyness, or currency, money can come in different forms. Money has emerged historically as a spontaneous market creation under the form of commodity money, but its most widespread and uncontestable form today is that of fiat money, without any intrinsic value other than the value people attribute it. Government enforced fiat money is a legal tender, no one being able to refuse it as a means of settlement. Fiat money, whether paper or electronic, is the norm of our age, but commodity backed and

100% commodity money were used for the most part of human history. The first thought that crosses our mind upon mentioning commodity money is of course gold or silver, but money can take amazingly different shapes. For instance, cigarettes were used as money in WWII POW camps and even underground economies in the Soviet Union. Having been supplied by the Red Cross with various goods such as food, clothing, cigarettes and others, the prisoners of war arrived at an ingenious system of overriding the limitations of bartering these goods and adopted cigarettes as a “universal” means of exchange. Cigarettes were the ideal commodity money in their captive predicament: they were easily transportable, had intrinsic value, allowed accounting and relative pricing and were commonly accepted for exchange even by non-smokers: a shirt cost about 80 cigarettes, doing someone’s laundry cost about 2 per item (Radford, 1945 cited Mankiw 2010, p.82) This comes to show that for something to be money, mainstream adoption is not a necessary requirement; put differently, if usage of an object for money is common within a specific community, the size of that community is not as relevant. Generating trust in large anonymous markets is an important effect of money. If bitcoin or altcoins were used solely by online communities for making exchanges, holding on to value or pricing goods of services, this would not disqualify cryptocurrency as potential money; yet bitcoin usage, although still limited, spans now across countries and industries. However, for a form of money to warrant attention, claim relevance to real modern economies and even survive the test of time, the magnitude of its adoption is crucial.

Having established that we can evaluate whether an object or artifact is money either by searching for three core properties or by assessing whether our object has some degree of moneyness and can be likened to other forms of money on a moneyness scale, we can now reviews existing literature and regulator stances on the question of bitcoin/cryptocurrency as money.

Motivated by bitcoin's spectacular appreciation in December 2013, when it was valued at a staggering 1200$ just four years after it was first exchanged publicly for no more than a few cents, David Yermack (2013) launches the question of whether bitcoin can be considered a real currency. Reasoning that its exchange rate volatility, incomparably higher than that of mainstream fiat currencies makes it a poor unit of account and store of value, while its zero daily correlation with major currencies makes it impossible to use for forex risk management/ hedging, added to the fact that bitcoin lacks adoption by the banking system and has no access to deposit insurance schemes, Yermack goes on to conclude that bitcoin cannot be considered a currency (2013, p.4). Arguably, deposit insurance and adoption by the banking system fall beyond the classical definition of money, however insurance schemes and layers upon layers of regulation do make fiat money less susceptible to fraud, theft and hacking, warranting more trust from the public, which in turn is a key feature of money. However, if we were to rely solely on the Mises or Schlichter definition of money as primarily a means of exchange and strip away the secondary effects of storing value and accounting, the verdict would be less clear-cut, as Yermack agrees that bitcoin does satisfy the means of exchange property and does so increasingly, with a growing number of merchants, online stores and shops but also small remittance users are adopting bitcoin as an alternative to classical payment systems such as bank wires, cards or Western Union/ Paypal money transfers. His last argument on the deflationary potential of bitcoin's fixed supply disqualifying it as credible currency (and this argument is quite common among economists and pundits alike at present; see Krugman, 2011; Elwell et al., 2013; O'Brien, 2013) is rather illogical, as he actually goes on to compare it with the concerns voiced in the 19th century over gold's deflationary nature, and it is very hard to argue against gold being money.

Bergstra and Weijland (2014) argue that bitcoin can be considered a "money-like informational commodity". Originating in an informatics approach to the ontology of monies, the authors agree that rather than a binary variable taking values yes or no, moneyness is a matter of degree. They part from the premise that an artifact could be money, in principle, if it displays a high degree of moneyness, but can only be considered money-like if its functionality resembles that of money just to a certain extent. The authors reject the classification into the class of cryptocurrencies primarily because bit/altcoins have not gained the status of currency. Including cryptocoins in the informational commodity category is justified by the process of commodification, defined as: "the process by which objects and activities come to be evaluated primarily in terms of their exchange value in the context of trade in addition to any use-value such commodities might have" (Watson and Kopachevsky, 1994 cited Bergstra and Weijland, 2014, p.15). Money-likeness and commodity-likeness as argued throughout their paper would indeed set up and interesting comparison between the market behavior of cryptocoins and that of gold/silver, arguably a closer comparison than matching bitcoin with fiat currencies.

What I consider the deepest dive into the question of bitcoin as money, both from a theoretical and empirical standpoint is Surda (2012). In spite of the empirical analysis being to some extent outdated as time series to be analyzed have expanded ever since, the theoretical analysis is well grounded and holds for cryptocurrency in general. Surda argues that although not money, bitcoin can be considered a medium of exchange, and investigates the literature to find concepts that would anchor this odd category: he finds them in Mises (1999 cited Surda 2012) as secondary media of exchange, demanded by the public to reduce the costs of cash holding and in Rothbard's (2004 cited Surda 2012) concept of quasi-money, money-like commodities that are so marketable that they rise close to the status of money. Furthermore, a classification of bitcoin is made possible in reference to Selgin's (2012 cited Surda 2012) term "quasi-commodity money" as a base money that does not have non-monetary applications (such as gold or silver have), but is scarce in nature, idea that is reflected by Schlichter's (2012b cited Surda 2012) comparison of the cryptographically limited supply of bitcoin and the time and computing power dedicated to its mining with the mining process of precious metals. As far as the inelasticity of its supply is concerned, indeed bitcoin would be closer to commodity money than to fiat money, which is specifically intended to have an elastic supply. The conclusion that emerges from the empirical analysis is that currently the liquidity of bitcoin is lower than that of fiat currencies, and this in turn affects the cryptocoin's property as a store of value: if bitcoin is to compete traditional currencies and become money, its liquidity needs to increase by widespread adoption, leading to a stabilization of its exchange rate (Surda, 2012, p.37).

Selgin (2013) categorizes bitcoin as an inelastic synthetic commodity money, a type of money with features of both commodities and fiat money, that enable a high degree of macroeconomic stability without oversight from any monetary authority.

Table 1: The money matrix

		Nonmonetary Use?	
		Yes	**No**
Scarcity	**Absolute**	Commodity	Synthetic Commodity
	Contingent	Coase Durable	Fiat

Source: Selgin (2013), p.5

Selgin defines the upper-right quadrant of the money matrix (see Table 1) as synthetic commodity money, objects which lack nonmonetary use, but are absolutely scarce rather than contingently scarce. In other words, money that does not have nonmonetary value (such as bitcoin's cryptographical codes have no intrinsic value), but can only be reproduced at a positive and rising marginal cost or not at all (Selgin, 2013, p.8). For the author, bitcoin's increasing at a decreasing rate and ultimately capped supply, simulating the difficulty of gold mining, but immune to supply side shocks induced by mining technology innovations, fits well with the criteria of increasing marginal costs. It is extremely interesting to investigate whether reproducibility at low costs would include replication through seemingly identical alternative cryptocurrencies.

2.4. Regulatory perception

Bitcoin has been receiving increasing attention from regulators around the world ever since its launch in 2009. The main factors that have drawn regulator scrutiny have to do with bitcoin's potential as a payment method and the disruptive character of its innovation, the fact that its pseudonimity enables and empowers usage by criminal networks and agents involved in illicit activities, its highly speculative nature and the risks it implies for investors and, perhaps most importantly, its monetary effects on the real economy and on the effectiveness of central bank's monetary and supervisory policies.

Regulator perception can be analyzed from several perspectives, with distinction being drawn between what courts and legislators perceive the cryptocoin to be and the central bankers' approach to the topic.

From a legal standpoint, Bitcoin is receiving mixed recognition as a potential form of money. In the U.S., the SEC successfully convinced a federal district court that bitcoins are money; this appears to be the first ruling addressing the question of whether digital currency issued without the backing of a government or other official entity is to be legally considered money and the court reasoned that because bitcoins are used as money to purchase goods or services and can be exchanged for conventional currencies, they are money (Elwell et al., 2013).[2] In Europe, German courts have ruled that bitcoin is considered a "unit of account" and "private

[2] Securities and Exchange Commission v. Shavers, 2013 WL4028182, No. 4:13-CV-416 (E.D. Tex. Aug. 6, 2013).

money" (Dillet, 2013), while Dutch courts have concluded that bitcoin is not money, but rather a different asset class (Rizzo, 2014).

Outside the courts, non-monetary regulators have made crucial investigations and decisions into the nature of bitcoin and cryptocurrencies. The U.S. Senate Committee on Homeland Security and Governmental Affairs held a first hearing on bitcoin in 2013 when the price of the cryptocurrency peaked at 1,200$; government official testified that virtual currencies without government backing have important roles to play as commercial payments systems. In part, the somewhat benign attitude of U.S. regulators (when compared to Chinese or Russian counterparts) towards bitcoin and its like stems from the great transparency of the blockchain, the common ledger of transactions, which offers a good online audit trail for any necessary investigations (Yermack, 2013). Of great significance was the recent decision of the Internal Revenue Service (which has come under intense scrutiny and may possible be revised in the future) of treating bitcoin as "property" not as currency for tax purposes. This has been interpreted by some as a potential threat to the expansion of bitcoin as a payment systems and discouraging news for consumers (Vaishampayan, 2014); moreover, it has been criticized for lacking bite, as due to the digital nature of mining and trading, users will simply move to offshore jurisdictions (Eisenbeis said in a recent note cited Vigna, 2014), bypassing IRS's reach.

Of course, markets are heavily affected by declarations, appraisals and decisions of central banks and the bitcoin market is no exception; quite the contrary, the price of bitcoin has shown exceptional sensitivity to changes in stance by the Fed, ECB/EBA or the People's Bank of China.

In the United States, in a November 2013 letter to Congress, the then Chairman of the Federal Reserve, Ben Bernanke, warned of the risk virtual currencies posed for investors, but nonetheless emphasized the great potential these innovations hold for lowering transaction costs and improving the state of payment systems. More importantly, Bernanke stated that the Fed does not claim any authority in regulating or supervising the entities involved with cryptocurrencies, which was perceived as a crucial decision for the early phase of a currency initiated, among other things, for the purpose of overriding the traditional Federal Reserve System.

In the European Union, the ECB (2012) has published a comprehensive and thorough study on virtual currency schemes and their potential impact on central bank objectives. The ECB includes tokens such as bitcoin or the Linden dollar in the category of virtual currencies, a type of digital, unregulated money which is issued and controlled by private developers/companies and used/ accepted within a specific online community. A clear distinction is being drawn between virtual currency and electronic money: while the latter, with Paypal or Skrill as examples, has a legal foundation with stored funds expressed in the same unit of account (a fiat currency like USD, EUR), the former represents its own, special unit of account (BTC, LTC) (ECB, 2012, pp.16-17). The study also argues that bitcoin would not fall under the framework of neither the Electronic Money Directive (2009/110/EC), nor the Payment Services Directive (2007/64/EC) (ECB, 2012, p. 43). Of greatest interest to monetary authorities are the so-categorized Type 3 currencies, which are not only used to buy virtual goods and services, but can also have various degrees of interaction with the "real" economy and are exchanged freely against fiat currencies at rates determined by supply and demand. The ECB acknowledges that type 3 may be implemented to compete with traditional currencies, thus warranting central bank scrutiny and reviews existing literature on potential effects of virtual currency on monetary policy, including papers by Peng and Sun (2009 cited ECB, 2012) and the BIS (2012, cited ECB 2012), which argue that the real money supply might be affected by virtual currency schemes, forcing central banks to incorporate these form of money into monetary statistics. The ECB study concludes however that due to their limited usage, at the moment virtual currencies do not pose a threat for price stability and financial stability, yet this situation might change if adoption increases significantly.

More recently, the European Banking Authority, aiming to harmonize macroprudentiality across the EU, as well as the Bundesbank have issued warnings about potential losses that speculating in this highly-volatile investment can bring.

In opposition to the favorable (or at least neutral) attitude displayed by the Fed and ECB, the Chinese central bank (PBoC) has recently decided to ban certain bitcoin related activities. This occurred as a significant change from an initial position of cautious neutrality, whereby the PBoC was not banning bitcoin outright, but rather was simply voicing the desire to control speculation in digital currency in the same manner as controlling real estate bubbles and loans in the "shadow banking" sector (Casey cited Vigna, 2014). Bitcoin found, for understandable reasons, a very receptive market in China, where by late 2013 the country's largest exchange was circulating almost a third of estimated global volume. However, in mid-December 2013, the Chinese authorities banned financial institutions from engaging in business with bitcoin-related companies. Later in 2014, the PBoC released a notice announcing it is considering preventing bitcoin exchanges from holding corporate bank accounts, which would eliminate the last channel for trading the cryptocurrency. Both the 2013 and 2014 announcements have dealt considerable blows to bitcoin prices and trading volumes.

Among the strongest believers in the money-like properties of bitcoin are apparently the Russian authorities, which have ruled that cyber currencies are in fact money substitutes and therefore illegal as only the rouble can be accepted as official tender (Einhorn, 2014).

This chapter served as a brief review of existing academic literature on the question of cryptocurrencies as money, as well as an overview of important policy stances on this matter. Previous research seems to agree that cryptocurrencies such as bitcoin have degrees of moneyness, but cannot yet be considered currency. Whether cryptocurrencies pass the scarcity test seems to be taken as an assumption and not analyzed in any way, as cryptocoins are compared both to fiat money and commodity money, which derive their scarcity from two very different sources, government control over supply and natural limits, respectively.

3. Money scarcity and currency competition

There are some general characteristics of objects/tokens/artifacts that grant these the possibility of functioning as money in modern economies: durability, ease of transportation, divisibility, high difficulty or near impossibility of being reproduced. The key characteristic I will analyze in relation to bitcoin and cryptocurrency is scarcity: for something to be money, it must not be easy to reproduce, it needs to be scarce, but not too scarce. To demonstrate the importance of scarcity we could hold a mental experiment where chestnuts (Canadian Foundation for Economic Education, 1994) were real-world money. Chestnuts are relatively scarce now in nature, but their production and thus the money supply could be greatly expanded by anyone with a patch of land – very soon the value of the currency would greatly fall, up to a point that transportation would become a serious issue even for the simplest transactions. Images of Weimar Republic consumers transporting money by the sacks to make day to day purchases are evocative in this sense.

Scarcity in the context of money supply will always be a property of an economic good: although mud pies, soups with flies in them or worthless computers might also be scarce, these are not economic goods. Money, digital or not, is an economic good because it can be exchanged freely for other economic goods and its possession might be the subject of conflict. Also, scarcity is not only restricted to tangibility, the ability to perceive the object/token with our senses or to manipulate it physically; as argued, radio airwaves are intangible, yet scarce economic goods (Tucker and Kinsella, 2010).

For centuries commodity money was the solution human economies across the globe found to meet the scarcity condition. Gold and other precious metals have had success as money because they were difficult to mine and their supply is limited in nature. Locally, the supply of precious metal would have suffered shocks, such as with the flood of post-Columbian silver into 16th century Spain, but globally the production of metal would have always been limited and predictable over longer cycles. Today, government fiat money, although without any intrinsic value, mimics the scarcity criteria through central banks' monopoly on controlling the money supply: base money creation is only possible with central monetary authorities, counterfeiting is illegal and most central banks around the world have as their raison d'être the maintenance of currency value. Of course, the scarcity property of fiat currency can be broken through or despite actions of monetary authorities: the most common causes of currency extinction (with the average lifespan of fiat currency sitting at 27 years) are hyperinflation, monetary reform, war and independence (Walker, 2014).

Bitcoin and cryptocurrencies are neither commodity nor fiat money, but have scarcity literally by design. The production of bitcoin occurs through a process called mining, whereas users dedicate computing power to solve complex problems and confirm network transactions, thus being awarded digital coins in return. The complexity of mining is designed to increase as more and more coins are being released onto the market, requiring more and more powerful machines to harvest until ultimately the final limit of 21 million units is reached. Of extreme interest is whether the 21 million is a hard limit, or whether developers might be able to make changes to this in the future. It is worth mentioning that in order for this manipulation to be legitimized, the users running previous versions of the software would have to accept these updates, a situation which might not occur (Murdock, 2014). At the same time, the cap might be credibly enforced in the future through market discipline. Despite the fact that most alternative coins were designed by adopting bitcoin's stance on a limited supply, there are a few notable exceptions: dogecoin's developers left the currency uncapped and peercoin maintains an annual inflation rate of 1%. But in what concerns market leaders bitcoin and litecoin, scarcity is built into their initial design as their supply is inelastic and ultimately caped.

Therefore, scarcity for these cryptocurrencies does not pose and issue if we isolate them from each others. But what if we were to consider their combined supplies as one? If all cryptocurrencies were the same, i.e. there would be strong similarity/ near identity between them up to the point that they were interchangeable/ almost perfectly fungible, then theoretically the supply of one could be continuously expanded through the supply of others. There are today hundreds of cryptocoins in existence, with no technological barrier to the emergence of others.[3] Similarity would violate the scarcity property of any individual coin up to the point that we might pose the question of whether cryptocurrencies in general, such and easily replicable type of money, would posses scarcity at all. In the case of perfect fungibility of cryptocoins, this digital would-be money cannot achieve money status at all.

From a theoretical standpoint, similarity or fungibility would not be challenged by small, slight differences: for cryptocoins to not be interchangeable, they would have to display significant, major differences. Therefore the magnitude of differences, not simply their existence, matters. As an analogy, we might consider the case of gold: of course, gold comes in various purities depending on the amount of alloy it contains, but we can hardly make a case for various alloys being a different type of money; minor differences do not matter for money to be interchangeable with each other.

3.1. Fungibility/ interchangeability between cryptocurrency

Bearing the distinction between major and minor differences in mind, I next ask the question whether bitcoin and litecoin are fundamentally different. Coming back to the main research question, fundamental difference would clear away all doubt hanging over the scarcity

[3] A (comprehensive?) list of cryptocurrencies in existence can be found at https://www.cryptocoincharts.info/v2/coins/info

property, but slight differences would not. Although the philosophy of litecoin and bitcoin as cryptocurrencies with inelastic supplies is the same, the two differ slightly in technical properties (Litecoin.info, 2014).

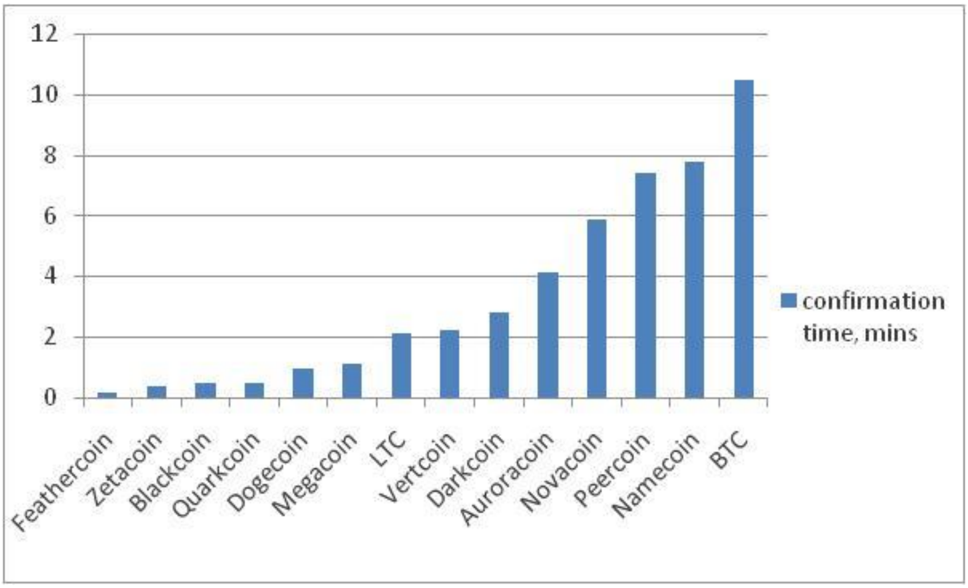
One important difference is the hash functions the two use for proof of work: while bitcoin uses the SHA256 function, litecoin is based on scrypt. The later is considered less susceptible to mining by powerful ASIC machines and thus enables virtually anyone with an internet connection to mine with their personal computer GPUs and even CPUs, considerably bringing down the market entry costs for litecoin mining, which should translate into a more dispersed mining market.

In addition to this, the difficulty of litecoin mining adjusts so that a block is generated every 2.5 minutes on average, instead of the 10 minutes average of Bitcoin. This translates into faster transaction times, which should be an advantage for buyers and merchants, however this acceleration is done at the expense of less conservative, possibly weaker security guarantees. It is important to note that bitcoin has the longest transaction confirmation time of all major cryptocurrencies, and although Litecoin confirmation takes 4 times less on average, there are altcoins with far better performance, as we can see in Graph 3. For example, Dogecoin confirmation takes little under a minute, while Feathercoin only requires 16 seconds.[4]

It is also important to mention that bitcoin and litecoin function on distinct technical infrastructures, i.e. they use separate "clients" and electronic wallets. There is no possibility of storing bitcoins on a litecoin wallet and viceversa.

[4] Cryptocurrency statistics can be found at http://bitinfocharts.com.

Graph 3: Average transaction confirmation times, selected cryptocurrencies



Source: author; data from http://bitinfocharts.com/

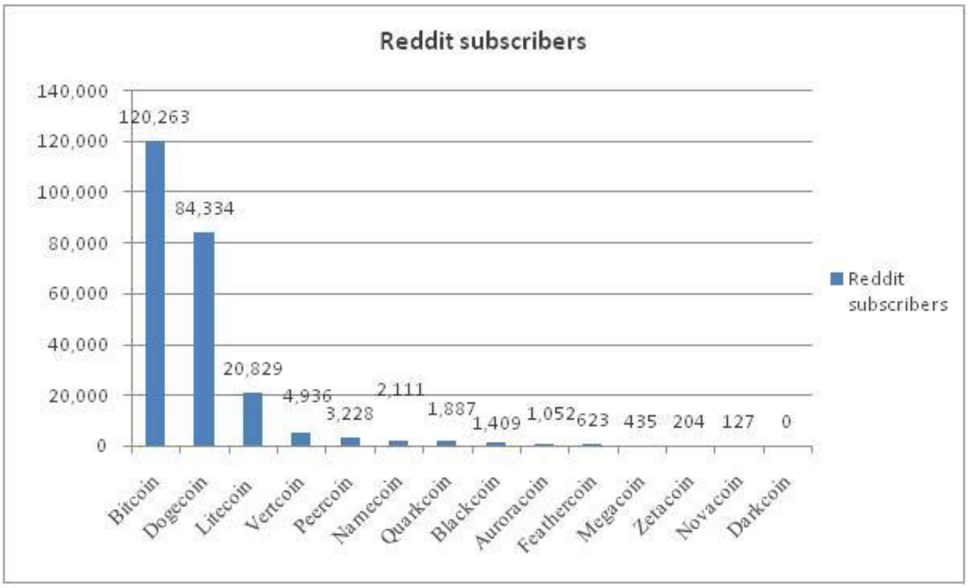
In spite of these technical differences, bitcoin and litecoin are basically indistinguishable if we compare them to other forms of money, such as commodity money or fiat currency. They are both digital coins that rely on encryption for security, pseudonimity and the avoidance of double-spending, on mining for transaction confirmation and monetary supply, and are both decentralized peer-to-peer networks. As far as final usage as money is concerned, the difference between them is arguably zero, i.e. they are fundamentally the same artifact. Of course, they are different at the moment in terms of liquidity, velocity, etc., but these are equilibrium difference, realized outcomes that do not belong to fundamentals.

It is, however, quite possible that this theoretical fungibility may translate, depending on market perceptions, into empirical observations of either complementarity (i.e. same money) or substitutability (i.e. different money) between the two coins. We can entertain two competing explanations as to why the market would perceive the two as either complements or substitutes. Theoretically speaking, it is quite possible that market perceptions go in either direction.

1. Bitcoin and litecoin are complements, i.e. they are perceived by the market as the same type of money or as goods that consumers/investors wish to hold simultaneously. It is not unheard of that people wish to hold two types of money that are perceived as similar. Gold and silver is a notable example of complements: they both serve the purpose of storing value when inflation is expected to rise and while both are commodity monies, gold is more marketable when it comes to large transactions, while silver is the most marketable for small transactions. However, scarcity would be an issue for cryptocurrencies that investors want to hold together because of the problem of an infinite total supply, whereas it can never be an issue for precious metals, where natural barriers will always limit the total supply.
2. Bitcoin and litecoin are substitutes, i.e. they are perceived as different and competing. Despite the fact that their technological differences are negligible and they share great interchangeability from a user perspective, investors or consumers may want to hold one or another depending on their expectation about future use, diffusion, and liquidity.

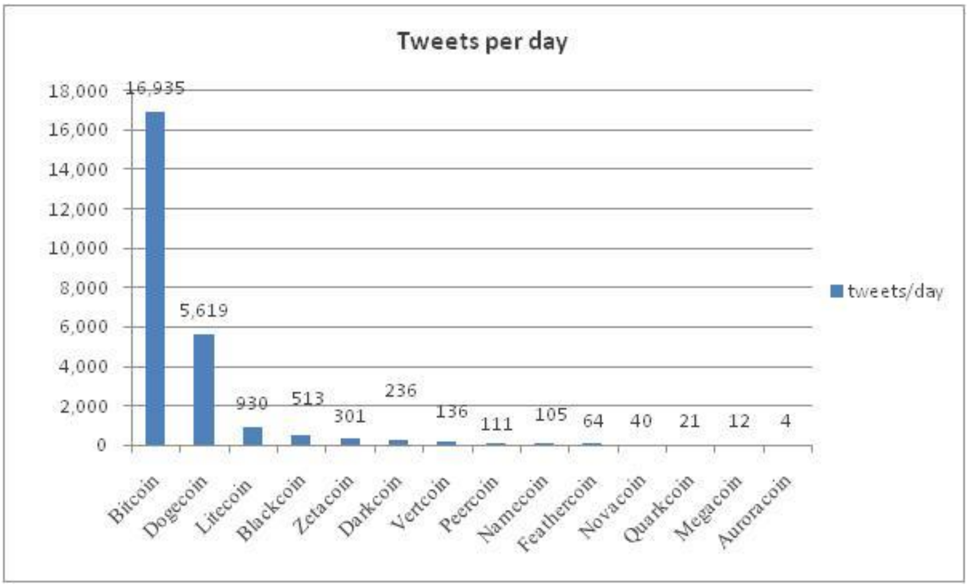
An empirical analysis would be welcome towards clarifying which of these views prevails at the moment in the market. I make an argument for the necessity of an empirical analysis of price behavior and co-movements because given technical or monetary fundamentals such as transaction speed and elasticity of supply ultimately have to pass the test of markets. How investors, consumers or merchants trading cryptocurrencies perceive the coins also depends on their popularity as displayed by news headlines and the size of their networks, on their marketing strategies and advertising efforts. Strong bitcoin contenders such as litecoin may not necessarily have comparable networks, as we can see form Graphs 4 and 5 below.

Graph 4: Number of Reddit subscribers, selected cryptocurrencies



Source: author; data from http://bitinfocharts.com/

Graph 5: Number of daily tweets, selected cryptocurrencies



Source: author; data from http://bitinfocharts.com/

Therefore, although they might be fundamentally similar, the verdict on scarcity may ultimately be provided by market perceptions on whether the two coins are complements, i.e. the same type of money for which an empirical analysis would identify strong, positive price correlations, or substitutes, i.e. alternative types of money for which prices move in opposite directions.

3.2. Currency competition

Cryptocurrency scarcity is strongly linked to the concept of competing currencies. If bitcoin technology is easy to replicate and infinite altcoins that bear no significant differences with the original can be generated instantly through basic computer programming, and these coins could be used interchangeably with bitcoin, than it might be possible that their supply would actually add to that of the original, thus effectively erasing any scarcity embedded into bitcoin's design. Competition in the market of cryptocurrency could only exist if bitcoin alternatives have distinguishable features, market themselves as such and are perceived as being different by users/investors/consumers. But in the absence of true competition, the scarcity of cryptocurrency as new potential monies might indeed be questionable. Some regard the current process of cryptocurrency proliferation as an intermediate phase, with an equilibrium to be reached through the existence of several robust currencies in the long run, that would include cryptocurrencies competing among themselves and with fiat currencies (Selgin said in a recent article cited Simonite, 2013).

Although not in reference to digital money, currency competition was already an ideal explored by thinkers such as F. Hayek some decades ago. Hayek envisioned a world where money would be "good" (1999) by virtue of being denationalized, having ceased to be a state monopoly and its production left to the competitive private sector. Introducing competition between privately issued currencies and eliminating government monopoly over the money supply was Hayek's solution to inflation and, in his view, the swings in the business cycle that followed the phenomenon. In his view, competition would be the ultimate force pushing for the stability of good money, which would drive out the poorly managed money in market sentiments (1999, p.154).

Despite the fact that bitcoin supporters and enthusiast draw near the Austrian School of Economics and Hayek's concept of good money, the linkage between the concept and cryptocurrency has fallen under heavy criticism from, among others, the U.S. Federal Reserve. In a letter dedicated to discussing the advantages and disadvantages of bitcoin, the Chicago Fed argues that the linkage is “misguided”, as bitcoin has proved to be completely unlike Hayek envisioned, as its supply is automated and not disciplined by market forces (Velde, 2013, p.4). However, I would argue that currency competition as envisioned by Hayek closely resembles the cryptocurrency market of today: the status-quo of today is that bitcoin is competed by a myriad of digital coins with each striving to assert its trustworthiness and expand its network of users; ultimately, the security and reliability of their computer codes and the credibility in the impossibility of manipulating the money supply will sift the good digital coins from the bad. Network effects and first mover advantages may even be less important on cryptocurrency markets, as users and miners can simply and rapidly move to another currency if a developer implements unpopular changes. Bitcoin and digital coins may yet have the potential of displaying the type of competition Hayek imagined.

3.3. Conflicting views on cryptocurrency scarcity

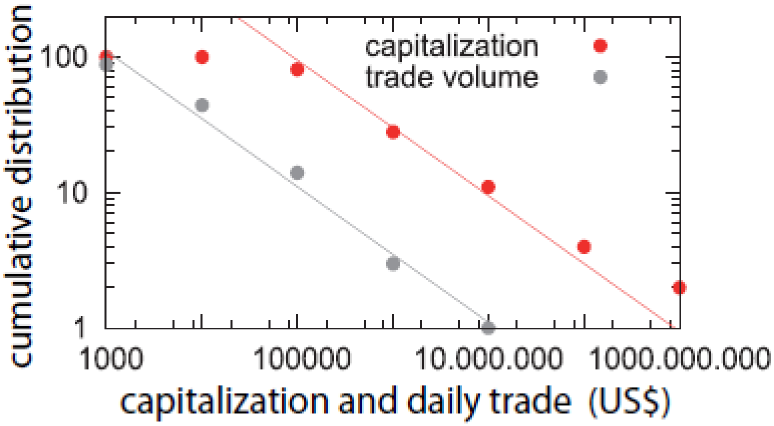
To my knowledge, the literature exploring the scarcity property of cryptocurrency is indeed very scarce. Non-academic literature such as briefs, blogs or news articles give various verdicts towards the interchangeability between cryptocoins. In a brief on this topic, Dejardins Economic Studies (2013) argue that the bitcoin model does not necessarily ensure scarcity: even if the supply is programmed, the high degree of substitutability of the coins and their proliferation would mean that the total combined supply could row indefinitely. However, these arguments do not benefit from any sort of analysis or hypothesis testing.

Blogs such as *Economic Thought*, edited by Jonathan M.F. Catalán (2013) argue, on the other hand, that different cryptocoins are imperfect substitutes to each other; there being some degree of brand discrimination between them, investors will often prefer one over another.

This would shatter any fears over the potential inflationary tendency of proliferating cryptocurrencies. But, yet again, these types of appraisals are lacking in analytical bite.

The only piece of literature on cryptocurrency scarcity with academic credentials is a paper by Bornholdt and Sneppen (2014) which suggest analyzing the value of any cryptocurrency from a popularity standpoint, where value depends on communication and communication depends on popularity. As can be seen in Graph 6 below, the authors depart from the observation that in terms of capitalization and trading volume distribution, bitcoin does not distinguish itself as special, but rather its dominance is only explained by its historical first mover advantage, making it susceptible to replacement by any of its competitors.

Graph 6: Capitalization and daily trade, main cryptocurrencies



Source: Bornholdt and Sneppen (2014), p.1

The authors conclude that bitcoin is not at all special, but simply the current dominant currency, a situation that might change in the future. This implies that value in the cryptocurrency market is determined by popularity rather than any fundamentals, with all cryptocoins being fundamentally equivalent, thus all amplifying the aggregate supply and creating a non-scarce good.

4. Description of data and methodology

In order to determine whether bitcoin and litecoin are perceived as substitutes or not by the market, I conduct an empirical analysis using daily closing price and trade volumes data from major exchanges Bitstamp and BTC-e. The time series comprises little over 600 daily observations spanning over almost 2 years, from litecoin launch in August 2012 until March 2014. Gold and silver data represent prices and volumes for COMEX future contracts, downloaded from the metadatabase Quandl.com, for the same two year period.

Although there are over 300 crypto currencies that have been coded ever since bitcoin made its debut, and we have already seen that some of them have received considerable attention that translates into high market capitalization, my analysis solely focuses on the first two largest coins. The choice of focusing solely on bitcoin and litecoin is based on both objective and more pragmatic criteria:

1. Quantitative information and statistics are rather difficult to compile for most altcoins; bitcoin and litecoin, as market leaders, are fortunate exceptions and data availability is a main criteria for restricting my research to these two alternative cryptocurrencies. Available data for bitcoin and litecoin offer the longest time series and largest set of variables.
2. Bitcoin and litecoin are the largest and oldest cryptocoins out there; they have withstood the test of markets longer than any other
3. Their trading volume matters for the real economy

I calculate correlations on a monthly and weekly frequency to investigate price co-movement and its dynamics; alternating signs for correlations are rationalized through a bubble/non-bubble framework, whereas I test whether the sign and magnitude of correlations depend on price and volume swings.

For correlation calculations I use the common Pearson coefficient:

$$\rho_{X,Y} = \mathrm{corr}(X,Y) = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y},$$

Complementarity and substitutability for the entire sample and for 4 separate subsamples is formally analyzed through the calculation of direct price elasticities and of cross-price elasticities of volume.

Elasticities are defined as the sensitivity to the changes in one coin's price of:

1) Price changes in the other, which I define as direct price elasticity.

This is defined as

$$E_{pBTC,\, pLTC} = \frac{\%\ change\ in\ litecoin\ price}{\%\ change\ in\ bitcoin\ price}$$

2) Volume changes in the other, which I define as cross price elasticity of volume.

This is defined as

$$E_{BTC,\, LTC} = \frac{\%\ change\ in\ the\ traded\ volume\ of\ litecoin}{\%\ change\ of\ bitcoin\ price}$$

calculated as:

$$E_{A,B} = \frac{\partial Q_A}{\partial P_B}\frac{P_B}{Q_A}$$

5. Empirical analysis

The empirical analysis aims to determine whether the two cryptocurrencies are perceived by the market as complements (corresponding to interchangeability as a theoretical concept, whereby two coins are the same type of money) or substitutes (corresponding to different types of money, that are not perfectly fungible). The entirety of the analysis is carried in terms of correlations and elasticities. In terms of elasticities, direct price elasticity (the sensitivity of one coin's price to movements in the price of the other) is positive for complements and negative for substitutes, and similarly cross-price elasticity (the sensitivity of one's volume to movements in the price of the other) is positive for complements and negative for substitutes. Price correlations are calculated for the entire analyzed periods, but also on a weekly basis to track the evolution of price co-movements, then attempt to explain this evolution based on various factors. Obviously, positive correlation, i.e. prices move in the same direction, indicates complementarity and viceversa.

	Complements/ Perceived as Interchangeable	Substitutes/ Perceived as different
Direct price elasticity	+	-
Cross price elasticity of volume	+	-

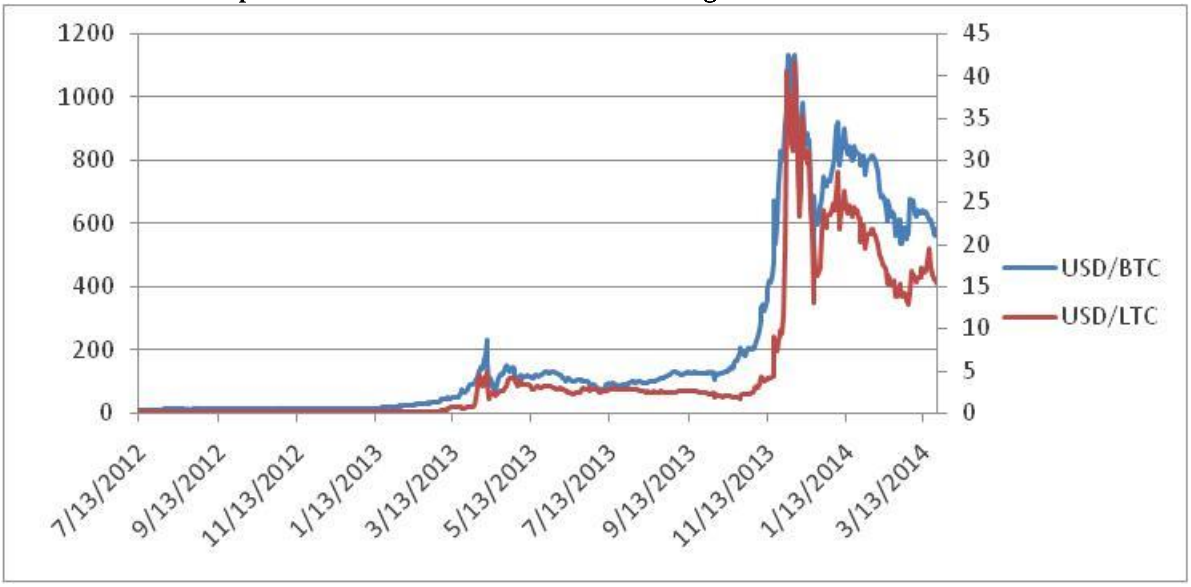
Because the analysis deals with time series, unit root tests[5] are conducted to check for non-stationarity. Where this is an issue, first differences result in stationary series, without exception. LM serial correlation tests are also conducted to check for autocorrelation in the residuals. Results for the tests can be found in the Appendix.

[5] Both KPSS and ADF test are conducted. In the cases where their results conflict at the borderline, KPSS is chosen as more robust.

5.1. BTC – LTC relationship for the entire period

At a first glance, BTC and LTC prices move closely together (see Graph 7); correlation is positive and very high (0.97) for the entire period of coexistence on global exchanges, August 2012 to March 2014, comprising little over 600 daily observations.

Graph 7: Evolution of historical USD exchange rates of BTC and LTC



Source: author; data from Bitstamp and BTC-e

Direct price elasticities that measure one coin's price sensitivity to changes in the price of the other can be estimated by regressing logged prices. Price elasticities are positive and statistically significant, but we cannot trust price time series to be stationary. Indeed, the ADF test (see Appendix) indicates that BTC has a unit root, prompting the use of first differences in the estimation. Contemporaneous price sensitivities calculated with first differences are statistically significant at 1% and positive, which suggests that for the period as a whole, an extra increase in the price of bitcoin brought on an increase in litecoin prices of a comparable magnitude. However, the reverse elasticity, while also positive and significant, is far less in magnitude, suggesting that LTC is more sensitive to BTC price movements than viceversa. No real significant lag structure can be identified, which leads to the conclusion that contemporaneous price movements are most relevant, while previous days do not count.

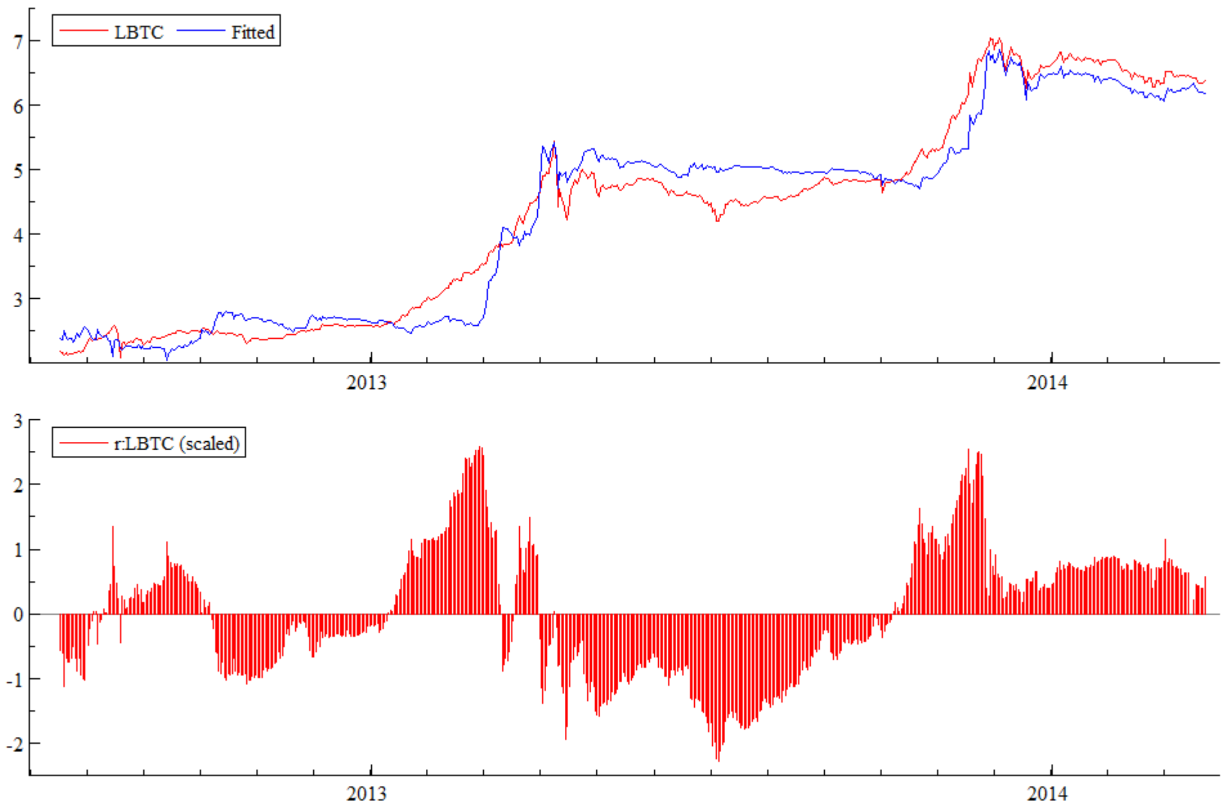
Table 2: Regression outputs for BTC, LTC daily prices, with lag structures

VARIABLES	**(1)** **ln BTC**	**(2)** **Δ ln LTC**	**(3)** **Δ ln BTC**
ln LTC	0.66*** [0.006]		
Δ ln BTC		0.908*** [0.09]	
Δ ln BTC(-1)		0.1 [0.08]	
Δ ln BTC(-2)		-0.004 [0.06]	
Δ ln BTC(-3)		0.017 [0.05]	
Δ ln BTC(-4)		0.004 [0.08]	
Δ ln BTC(-5)		0.12* [0.06]	
Δ ln LTC			0.35*** [0.06]
Δ ln LTC(-1)			-0.06 [0.038]
Δ ln LTC(-2)			-0.0005 [0.035]
Δ ln LTC(-3)			-0.027 [0.035]
Δ ln LTC(-4)			0.046 [0.037]
Δ ln LTC(-5)			0.046* [0.028]
Constant	4.38*** [0.01]	0.001 [0.003]	0.003 [0.002]
Observations	615	614	599
Adjusted R-squared	0.95	0.32	0.34

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

A short analysis of regression errors clearly indicates that there are periods of constant over and underestimation. Therefore, we can gain further insight by breaking up the analysis into subsamples. This test also suggest that we might uncover a far more complex relationship between the two price movements by computing more frequent correlations, at monthly and weekly level.

Graph 8: Estimation errors for direct price elasticities (Log LTC on Log BTC)



Source: author; data from Bitstamp and BTC-e

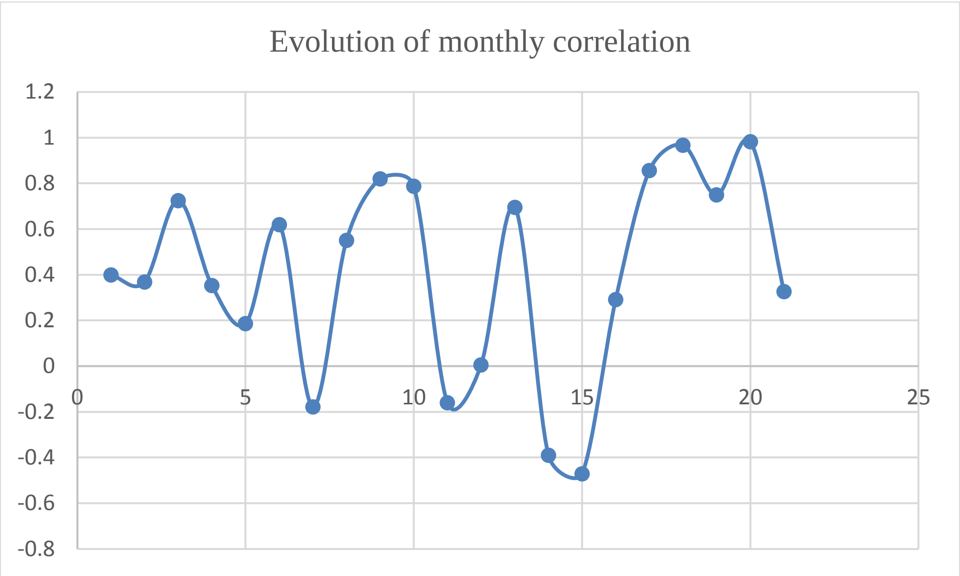
5.2. BTC – LTC relationship, weekly/monthly breakdown

In this part of the analysis, I proceed with splitting up the sample into 4 periods following two very broad criteria: 1) the subsamples are first determined based on whether the elasticities are over or underestimated as per the standard error test; 2) the subsamples try to capture "bubble" periods, times of great swings in cryptocurrency prices followed by near implosion. The selection of subsamples is rather arbitrary, but allows for detailed snapshots of price movements around critical market events. Subsamples are defined as follows:

1) Week 45 to week 80 since bitcoin launch: day 309 to day 554
2) Week 81 to week 100: days 555 to 694
3) Week 101 to week 112: days 695 to 778
4) Week 113 to end of sample: days 779 to 928

Correlations are then calculated with monthly and weekly frequency. I start by analyzing correlation on a monthly frequency, to first try and determine whether the price relationship is different at this level of detail compared to the general picture described above.

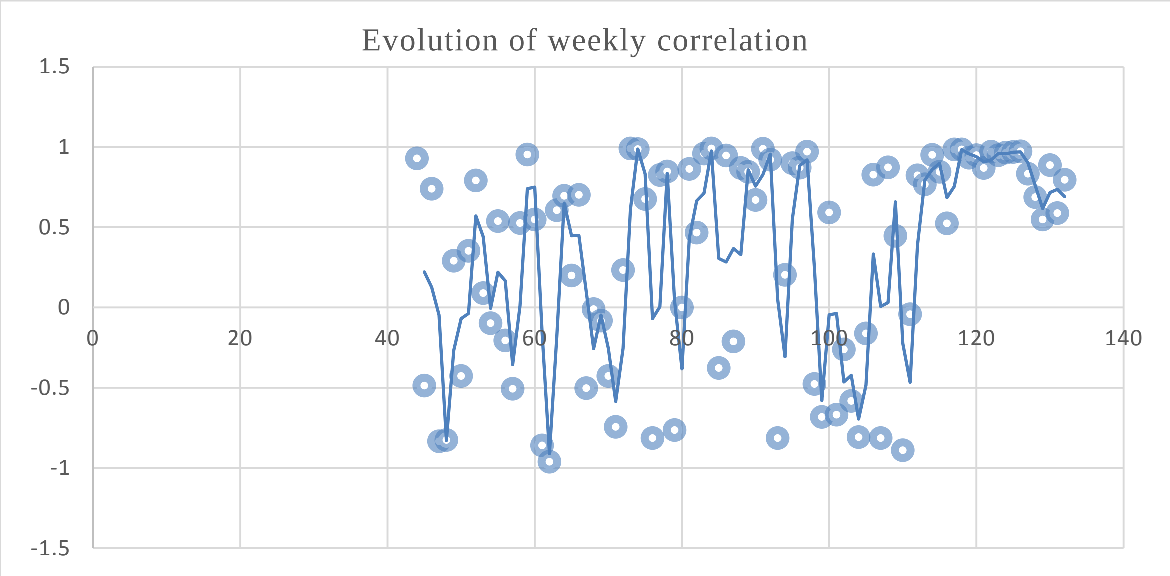
Graph 9 : Evolution of monthly price correlation



Source: author; data from Bitstamp and BTC-e

Monthly correlation analysis allows us to capture the existence of periods of negative correlation, despite the fact that this detail level confirms the general picture on the overall. As can be inferred from Graph.., most of the analyzed period switches from months of high to low positive correlation. Months 14 and 15 are the only ones in succession of negative correlation. Months 8-10 and 17-20 are continuous periods of very high positive correlation.

Graph 10: Evolution of weekly price correlation

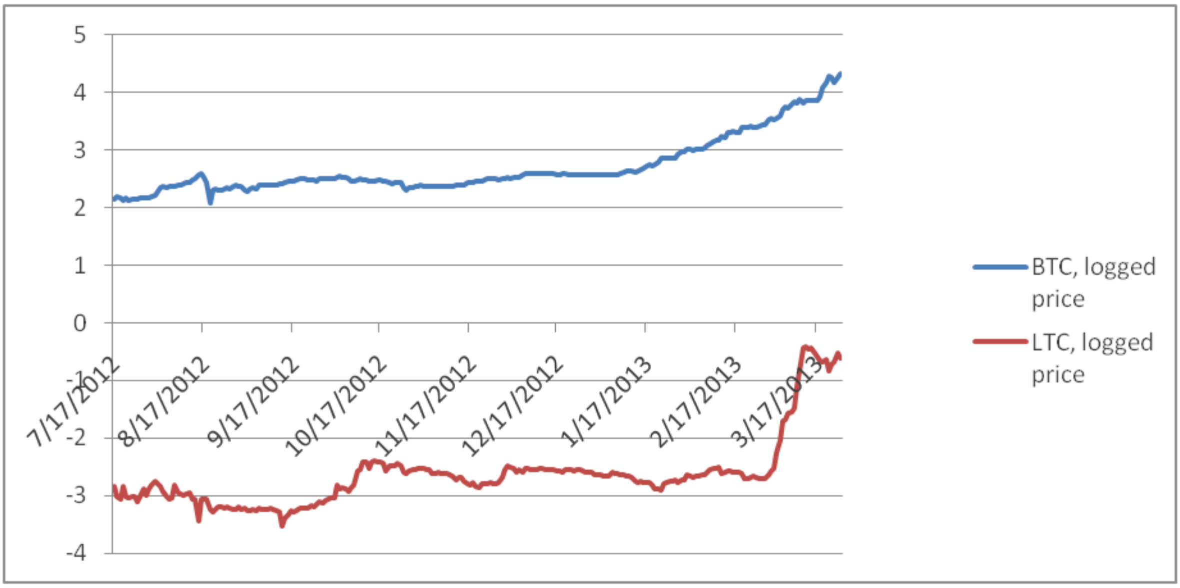


Source: author; data from Bitstamp and BTC-e

Analyzing price relationships at a weekly level uncovers a far more complex picture. Correlation seems to jump from positive to negative on almost a weekly basis, which leads us to believe that no real conclusion of complementarity or substitutability can be drawn for the entire period as a whole and that the initial finding of strong positive correlation was misleading. Positive correlations periods seem to be more frequent and more intense, but by no means is the price co-movement locked in this direction.

1. Shifts from negative to positive correlation are more frequent in the initial phase (w45 to w80 of BTC launch, September 2012 to March 2013). Swings in the initial period may be due to uncertainty over LTC and its status towards the more mature BTC. The snapshot below clearly indicates more volatility in the price of litecoin. LTC grows faster in Oct 2012 and Mar 2013, but at the same time has sharper drops in Nov and Dec 2012. From an investment perspective, more volatility translates into more risk, and also more return. If investors perceive the two cryptocurrencies as alternative, risk-based, investments, this would explain periods of negative correlation when LTC brings significantly higher returns than BTC.

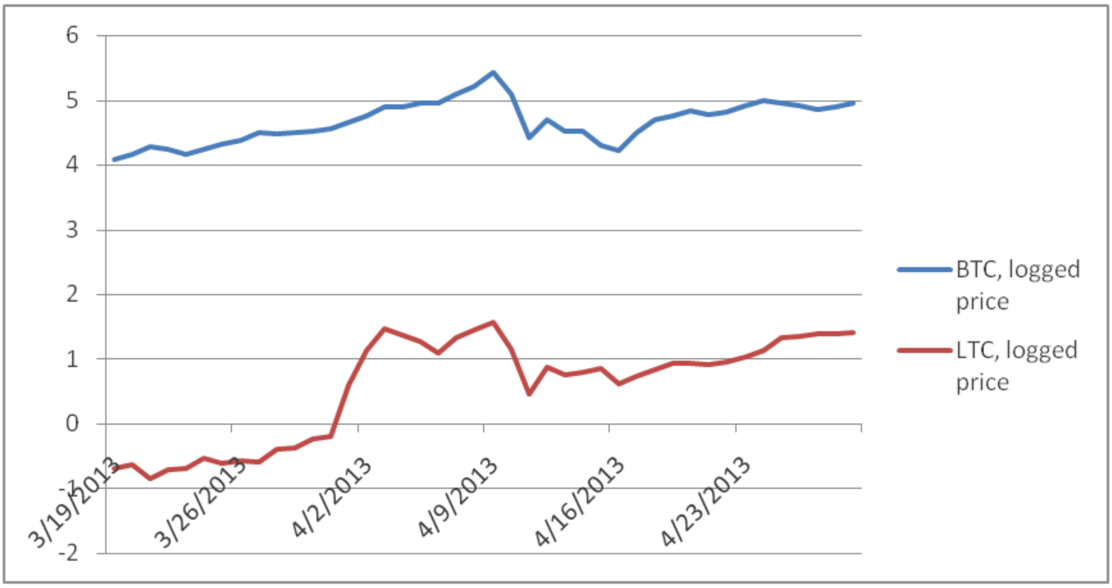
Graph 11: Logged BTC and LTC price evolution, first subperiod



Source: author; data from Bitstamp and BTC-e

2. After the initial period follows a shorter second phase of almost unbroken high positive correlation (w81 to w100, April to August 2013). This period is crucial as it marks the first BTC bubble in April 2013, when the price followed a path through 47$ - 229$ - 68$ in under a month due to negative news relating to a DDOS attack and a Mt.Gox scaling issue. The analysis shows that shortly before, during and after a major BTC bubble, the two coins' prices are highly, positively correlated, which suggests they are both riding a wave of common optimism surrounding cryptocurrency. When there is significant good news for Bitcoin, the shock will affect both, and viceversa for bad news. The graph below is a snapshot of the April 2013 bubble.

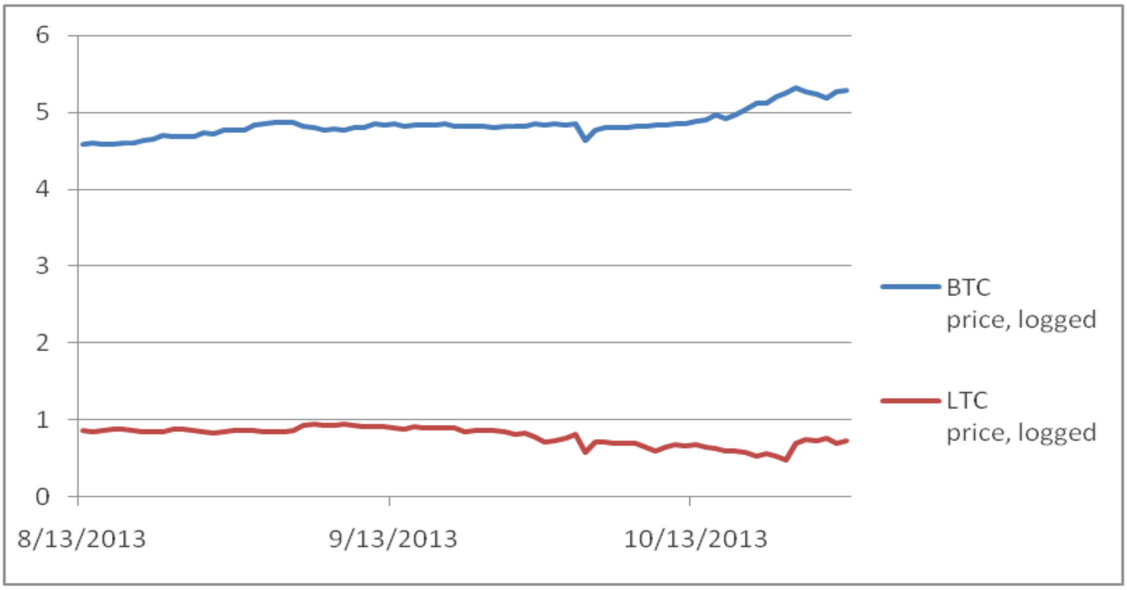
Graph 12: Logged BTC and LTC price evolution, second subperiod



Source: author; data from Bitstamp and BTC-e

3. Next follows a short third phase of low negative correlation (w101 to w112, August to October 2013). This is a period of relative stability for BTC prices, with no significant news shocks. We can observe both the divergence in prices (slow growth in BTC, decline in LTC) and their relative stability in the snapshot below. By overlapping the current and previous snapshots, we might pose the question whether correlations are "bubble" dependent.

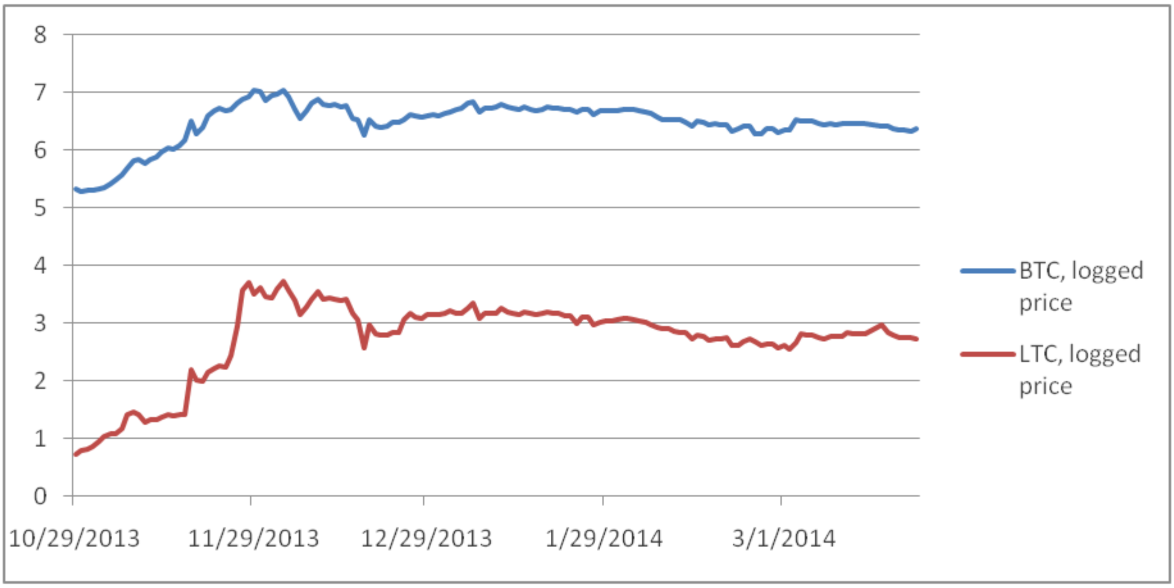
Graph 13: Logged BTC and LTC price evolution, third subperiod



Source: author; data from Bitstamp and BTC-e

4. The fourth phase (November 2013 - March 2014) is an uninterrupted series of high positive correlation when we witness the largest boom and bust (December 2013) for both currencies and a subsequent period of seemingly adverse events that impacted them in the same manner (the PBofChina crackdown, the Mt. Gox collapse in February 2014, the debate over regulatory and fiscal status in the US, etc.). It is worth mentioning that LTC's bubble is far more spectacular (higher jump, sharper drop).The persistent, high positive correlation is evident in the snapshot below.

Graph 14: Logged BTC and LTC price evolution, fourth subperiod



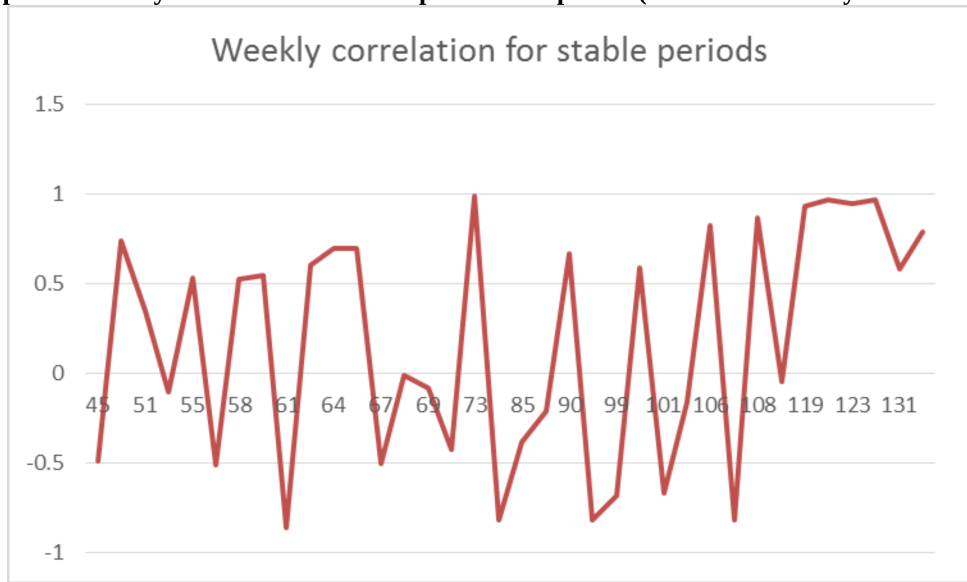
Source: author; data from Bitstamp and BTC-e

A possible explanation for the apparent time-dependency of weekly correlations is that during booms, investors and users buy and place confidence in both, whereas during normal times, they buy the one perceived to have a better return to risk ratio.

5.3. Defining an arbitrary "stable" period

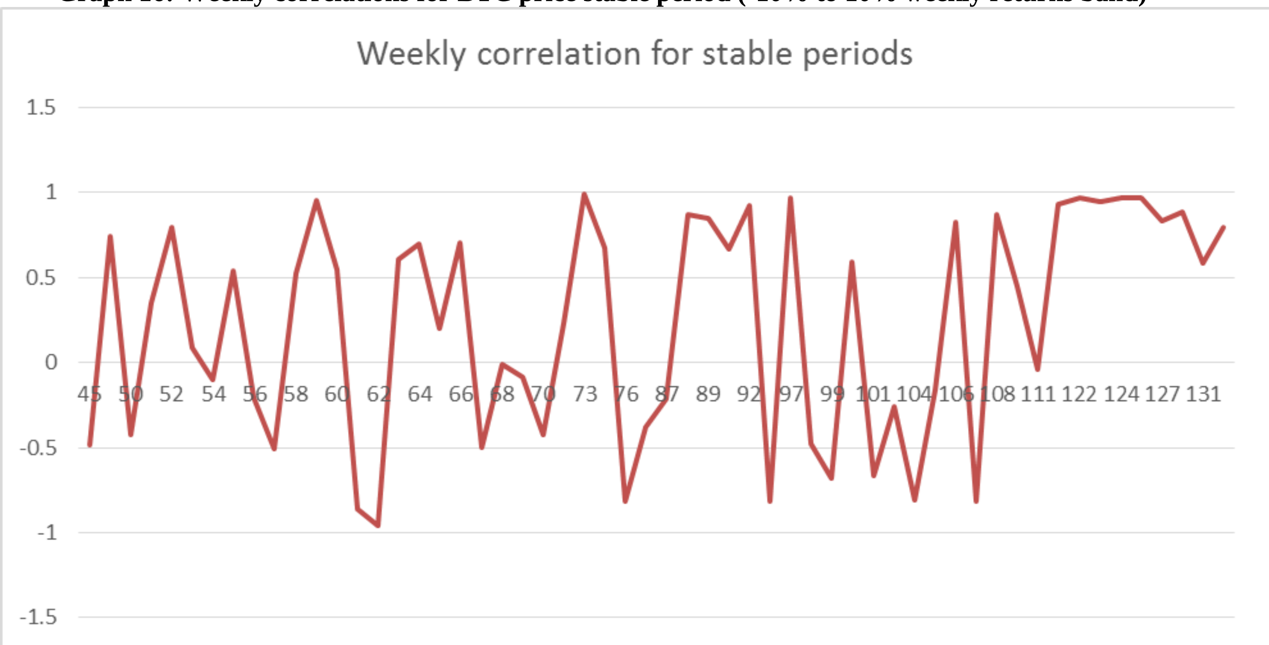
Below are graphed the correlations for weeks where returns are "reasonable" by cryptocurrency standards, i.e. within a -5% to 5% interval or, alternatively a -10% to 10% range.

Graph 15: Weekly correlations for BTC price stable period (-5% to 5% weekly returns band)



Source: author; data from Bitstamp and BTC-e

Graph 16: Weekly correlations for BTC price stable period (-10% to 10% weekly returns band)



Source: author; data from Bitstamp and BTC-e

If we eliminate bubble periods, weeks with negative correlation are just as frequent as with positive co-movements and average correlation for these samples are not higher than 0.17 (for the 5% band) and 0.23 (for the 10% band) compared to an average correlation for the entire analysis of 0.33. This would confirm the bubble hypothesis and suggest that the strong positive correlation for the period as a whole is driven to a large extent by strong correlation during “bubble” subsamples.

However, weekly averages don't really capture bubbles that build up over several weeks. Therefore I will focus on eliminating the periods that resemble a boom-bust in the price evolution graph (dramatic price spikes and drops). I test the "bubble" hypothesis by defining an arbitrary "stable" period and checking whether price elasticities and correlations are different in these times of relative tranquility. My definition of this "stable" period is rather arbitrary, but can offer valuable insight to the analysis. The period range eliminated based on a rough boom-bust approach is as follows: w80 to w87, days 554 to 609 and w103 to w 132, days 720 to 924.

Table 3: Regression outputs for "stable" subsample, changes in prices and in volumes

VARIABLES	**(1)** **Δ ln LTC**	**(2)** **Δ ln BTC**	**(3)** **Δ ln LTCvol**	**(4)** **Δ ln BTCvol**
Δ ln BTC	0.36*** [0.13]			
Δ ln BTC(-1)	0.22** [0.1]			
Δ ln BTC(-2)	0.1 [0.09]			
Δ ln BTC(-3)	0.006 [0.09]			
Δ ln BTC(-4)	0.12 [0.09]			
Δ ln BTC(-5)	0.15 [0.11]			
Δ ln LTC		0.097** [0.04]		
Δ ln LTC(-1)		0.011 [0.03]		
Δ ln LTC(-2)		-0.058 [0.04]		
Δ ln LTC(-3)		-0.04 [0.06]		
Δ ln LTC(-4)		0.11 [0.07]		
Δ ln LTC(-5)		-0.04 [0.04]		
Δ ln BTC			-2.06* [1.13]	
Δ ln LTC				-1.17* [0.61]
Δ ln LTC(-1)				1.61** [0.66]
Δ ln LTC(-2)				-0.34 [0.60]
Δ ln LTC(-3)				-0.31 [0.61]
Δ ln LTC(-4)				-0.82

				[0.55]
Δ ln LTC(-5)				-0.07
				[0.52]
Constant	0.002	0.004**	0.003	0.016
	[0.003]	[0.002]	[0.05]	[0.04]
Observations	356	346	356	346
Adjusted R-squared	0.04	0.086	0.003	0.02

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Overall, this test uncovers two significant findings, which both confirm the "bubble" hypothesis:

1. Direct price elasticities are still positive, but are considerably lower than the whole sample estimations.
2. Volumes to price elasticities are negative. As we will see later, they are also higher (in absolute value) than for the entire period, which suggests greater volume to price sensitivity for non-bubble sample).

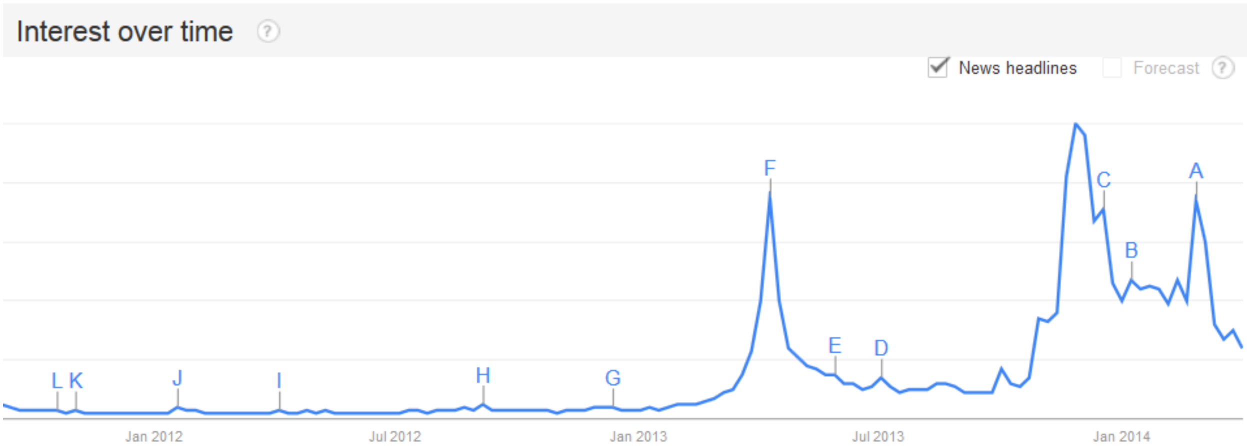
A possible explanation for the fact that correlation differs based on whether the two coins are experiencing bubbles or stable periods could be the fact that during times of great "hype" around cryptocurrencies, i.e. when they compete together against other asset classes more so than against each other, their overall "income" effect is larger than their "substitution" effect. A possible clue into this "bubble" puzzle is a paper by Brière (2013) that uncovers that bitcoin correlations with other asset types (commodities, hedge funds, real estate) is extremely low, which make cryptocurrencies a great portfolio diversification tool.

5.4. Google trends: Relationship between interest and price correlations

The "bubble" hypothesis, i.e. whether correlations behave differently in times of dramatic price movements, can also be tested by checking the relationship between weekly correlations and market interest in cryptocurrencies as exhibited by Google searches. The basic logic is that interest grows during times of dramatic price moves, thus if correlations are significantly associated with Google trends data then price movements are probably bubble-dependant.

A simple snapshot confirms an initial assumption that news affects BTC prices and that price response is rapid.[6] A paper by Kristoufek (2013) already established a positive relationship between bitcoin price and search queries on both Google trends and Wikipedia, as we can see in the graphs below.

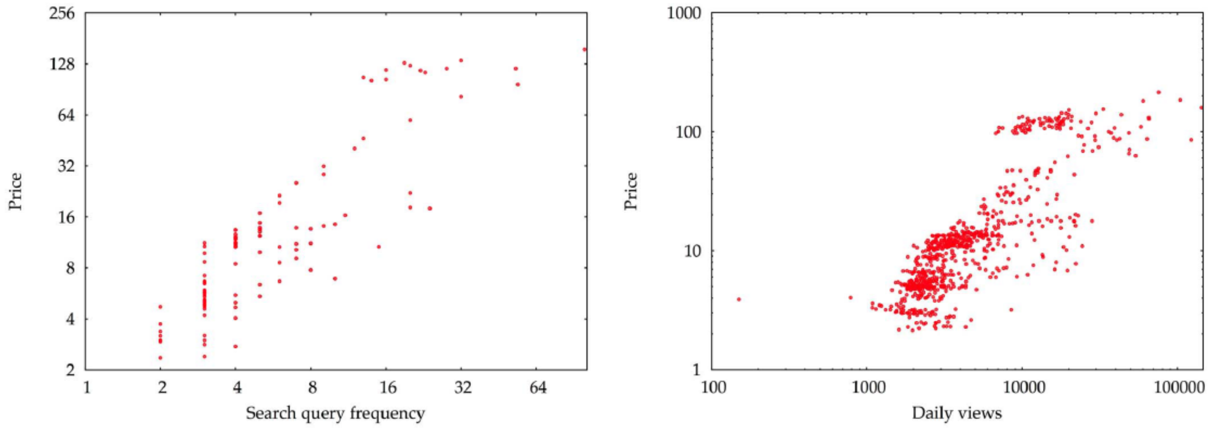
Graph 17: Interest displayed by Google searches and news headlines



Source: Google trends

[6] Key to news headlines. Source: Google trends.
L: The Guardian: Bitcoin value crashes below cost of production as broader use stutters
K: Computerworld: DevilRobber Trojan hijacks Macs for Bitcoin mining, steals data, spreads via pirated software
K: Wall Street Journal: 'The Good Wife' Season 3, Episode 13, 'Bitcoin for Dummies': TV Recap
I: The Baltimore Sun: Bitcoin, the financial traders' anarchic new toy
H: Register: Bitcoin exchange shuts after heist
G: The Guardian: Tech Weekly Podcast: digital currency Bitcoin gets Europe banking approval
F: News.com.au: Hacker currency Bitcoin crashes
E: The Age: Bitcoin... how it pays its way
D: Market Watch: Winklevoss twins file with SEC to create bitcoin trust
C: iAfrica.com: Bitcoin crashes on China measures
B: The Economic Times: Bitcoin impact: Laxmicoin seeks regulatory clarity for launch
A: Deutsche Welle: Bitcoin exchange Mt. Gox goes offline

Graph 18: Scatterplot of BTC price and search frequency/daily views on Google and Wikipedia



Source: Kristoufek (2013), p.3

A formal analysis indicates that the relationship between interest in the two cryptocurrencies is positively associated with their price correlations, i.e. an increase in correlation is associated with rising interest in BTC and LTC. Magnitudes for both BTC and LTC interest-correlation relationships are comparable.

Table 4: Regression outputs for weekly correlations on interest by google searches

VARIABLES	**(1) Weekly correlation**	**(2) Weekly correlation**
BTC interest	0.011***	
	[0.001]	
LTC interest		0.012***
		[0.002]
Constant	0.16*	0.23***
	0.08	[0.07]
Observations	88	88
Adjusted R-squared	0.18	0.16

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Interest as measured by Google searches is positively linked to price correlations. For both BTC and LTC, an increase in searches is associated with an increase in their price correlation. Of course, this would explain their strong positive correlation during peak bubble time, when spectacular price movements draws in stronger interest on the web.

5.5. Relation between change in weekly price averages and weekly correlation

Whereas previously the association between weekly correlations and price movements was rather qualitatively assessed by taking snapshots of different subsamples, a formalization of this relationship can be arrived at by regressing weekly price averages for both BTC and LTC on the weekly correlations.

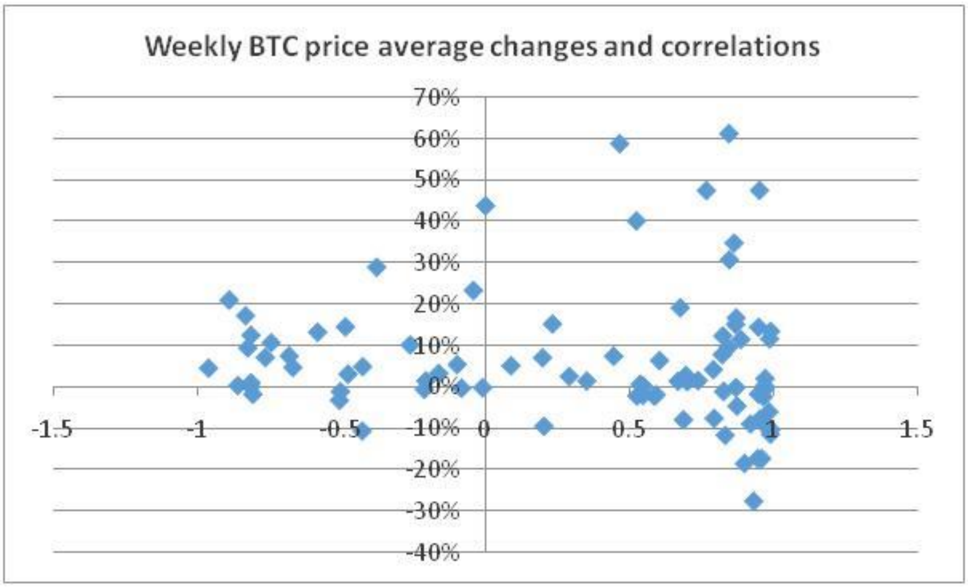
Table 5: Regression outputs for weekly correlation and weekly price averages

VARIABLES	(1) Weekly correlation	(2) Weekly correlation	(3) Weekly correlation	(4) Weekly correlation
Weekly price average BTC	0.0009***			
	[0.0001]			
ln weekly price average BTC		0.16***		
		[0.03]		
Weekly price average LTC			0.03***	
			[0.005]	
ln weekly price average LTC				0.1***
				[0.02]
Constant	0.12	-0.38**	0.16**	0.34***
	[0.08]	[0.17]	[0.08]	[0.06]
Observations	89	89	89	89
Adjusted R-squared	0.17	0.14	0.15	0.12

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Results are statistically significant, indicating a positive relationship between price movement and correlation between the currencies. This signifies that when there is a shock that drives BTC prices up, correlation will strengthen, possibly indicating an overall effect of good news for all cryptocurrencies. When BTC prices are going down, correlation is also decreasing according to our results, meaning that LTC tends to separate itself and indeed act as a substitute/ alternative. Another way of interpreting the results would be: if there is a rise in average prices of BTC or LTC for consecutive weeks, their correlations increase, but their co-movement starts to decrease if this streak is broken. This image is reflected in the graph below, where we can see that the highest price increases for BTC (over 20%) have driven strong positive correlation between the currencies, possibly explained as LTC bandwagonning on bitcoins success. The same applies for negative price shocks.

Graph 19: Scatterplot of changes in weekly BTC price average and weekly correlation



Source: author; data from Bitstamp and BTC-e

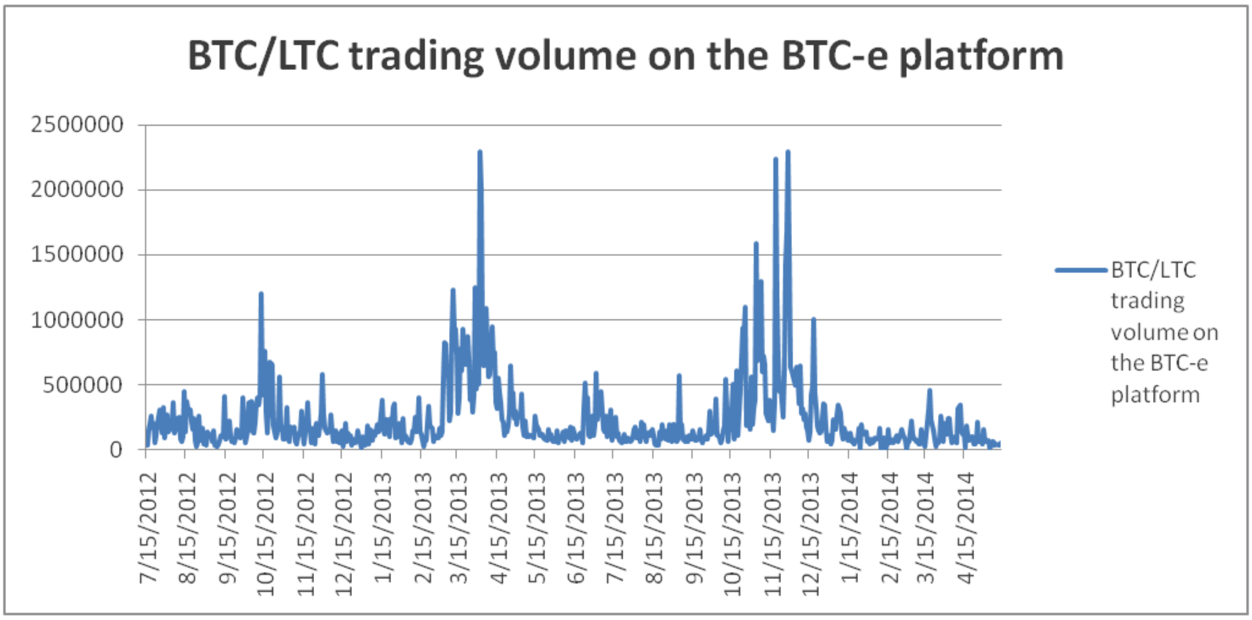
The higher R^2 and coefficient on the log specification of BTC price averages indicates that shocks to bitcoin are more important in influencing the currency correlation than changes in LTC prices; this is to be expected, as Bitcoin has a higher market capitalization and is the more established cryptocurrency.

A summary of weeks with highest price changes or highest correlations (Annex) can provide further information on the sensitivity of correlations to price shocks. The periods of high BTC price increases or decreases are mostly times of high positive correlation, which suggests that the two cryptocoins “stick together” during very good (for example the bubble of week 110-116) or very bad times. The periods of strongest negative correlation are usually times of good BTC performance and LTC drops, which suggests scenarios of people divesting away from LTC and back into BTC.

5.6. Volume analysis

The following graph, showing the direct trading volume for the BTC/LTC pair on the BTC-e exchange, reveals a mechanism through which high positive correlations appear to be associated with bubble periods. The highest activity for the BTC/LTC pair is during the periods March-April 2013 and November 2013, corresponding to major bubbles. If direct trading is so intense during these periods, it would explain why correlation is so strong, positive.

Graph 20: BTC/ LTC pair trading volume on the BTC-e exchange



Source: author; data from Bitstamp and BTC-e

When generalized, this rule does not seem to hold, as we can see in the regression table below. On average, for the period as a whole, higher pair volumes translate into decreasing correlation. It is possible that the causality flows in the opposite direction in this case, with higher trade to exchange one coin for the other as a reaction to diverging price behavior.

Table 6: Regression outputs for weekly correlation and BTC/LTC volume average and changes in volume average

VARIABLES	(1) Weekly correlation	(2) Weekly correlation	(3) Weekly correlation	(4) Weekly correlation
Pair volume average	-6.74E-07*			

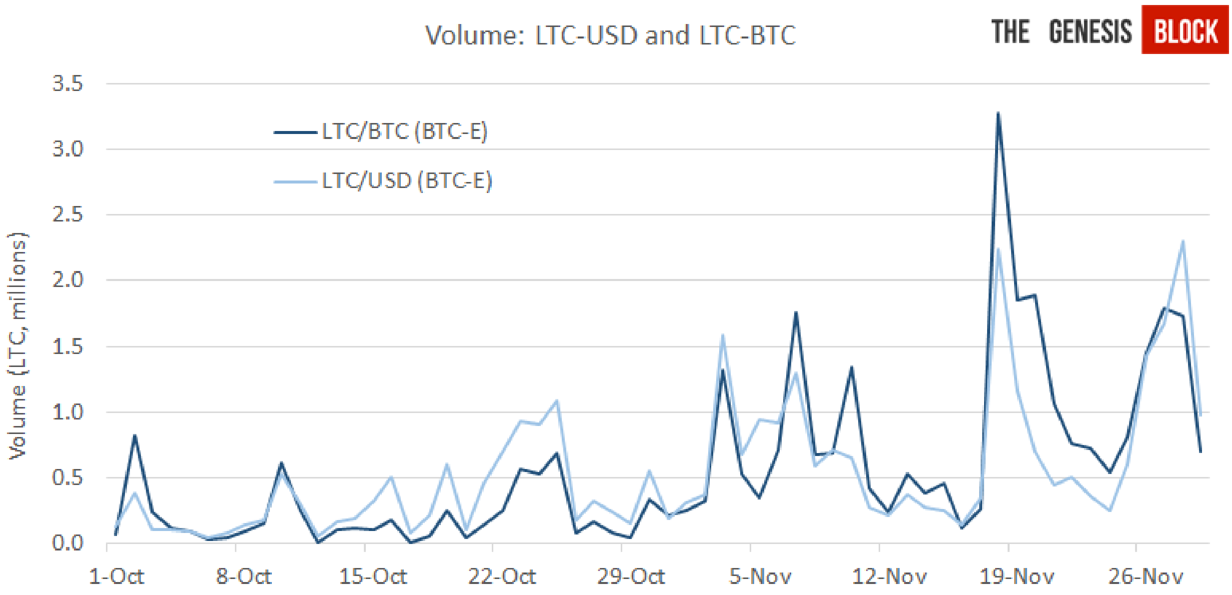
	[3.38E-07]			
Pair volume average(-1)	6.59E-07			
	[4.10E-07]			
Pair volume average(-2)	6.11E-07*			
	[3.48E-07]			
Pair volume average(-3)	4.52E-07			
	[4.03E-07]			
Pair volume average(-4)	-1.66E-07			
	[5.48E-07]			
Pair volume average(-5)	5.07E-08			
	[4.69E-07]			
Δ ln pair volume average		-0.49***		
		[0.14]		
Δ ln pair volume average(-1)		-0.23		
		[0.15]		
Δ ln pair volume average(-2)		0.09		
		[0.16]		
Δ ln pair volume average(-3)		0.22		
		[0.15]		
Δ ln pair volume average(-4)		0.14		
		[0.15]		
Δ ln pair volume average(-5)		-0.16		
		[0.15]		
Volume dummy			0.6***	
			[0.13]	
Interest dummy				0.23*
				[0.13]
Constant	0.06	0.29***	-0.074	0.24**
	[0.13]	[0.07]	[0.1]	[0.1]
Observations	72	70	89	88
Adjusted R-squared	0.08	0.1	0.18	0.02

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Another interesting test in the direction of determining whether correlation is indeed bubble/non-bubble dependant is to create dummy variable for periods of low trading volume and low internet interest in the cryptocurrencies. I define as non-bubble periods the 1/3 of weeks with low volume and low Google searches, using litecoin as a reference. By regressing weekly correlation on these dummies, I find that correlation for periods of low volume is slightly negative but statistically not different than zero, while periods of low interest have a positive, statistically average correlation of 0.24. While these results do not confirm that the currencies' prices move in opposite directions during "low" periods, it does suggest that price behavior is substantially different from "high" periods.

Even discussed outside the context of bubble periods, direct pair trading volume is an important determinant of price. On BTC-e, which is the leading litecoin exchange by volume, the BTC/LTC currency pair is traded with as much or more volume as litecoin-dollar, as we can see in the following graph.

Graph 21: Evolution of volumes for the LTC/USD and LTC/BTC trading pairs, BTC-e exchange



Source: The Genesis Block, 2013, http://tradeblock.com/research/bitcoin-litecoin-ratio-returns-historic-norm-peercoin-climbs-200/, accessed June 4, 2014

5.6.1. Relationship between correlations and average trading volume (weekly)

The regression table below offers yet another clue regarding the behavior of price correlation for the two cryptocurrencies. For both BTC and LTC, there is a positive relationship between correlation and traded volume, i.e., the more the coins are traded individually, the more their correlation increases. This can be interpreted as a stronger co-movement of prices in peak bubble times and a weakening of correlation during normal times.

Table 7: Regression outputs for weekly correlation and weekly volume average

VARIABLES	(1) Weekly correlation	(2) Weekly correlation
ln weekly volume average BTC	0.23***	
	[0.06]	
ln weekly volume average LTC		0.25***
		[0.04]
Constant	-1.75***	-2.5***
	[0.58]	[0.48]
Observations	89	89
Adjusted R-squared	0.1	0.2

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

5.6.2. Cross-price elasticities (price-volume)

Cross-price elasticities, the sensitivity of trade volume for one currency to movements in the price of the other is a potent test for identifying complementarity/ substitutability. Results show that an increase in BTC price is associated with a decrease in LTC traded volume, contemporaneously, with the coefficient significant at the 10% confidence level. The reverse also applies, although with less intensity. This would signify that they are substitutes: when the price of one goes up, people buy more of that currency and less of the other, thus volumes for the latter decrease.

Table 8: Regression outputs for changes in LTC, BTC volume and changes in price

VARIABLES	(1) Δ ln LTC volume	(2) Δ ln BTC volume	(3) Δ ln LTC volume	(4) Δ ln BTC volume
Δ ln BTC	-1.31*			
	[0.7]			
Δ ln LTC		-0.61*		
		[0.33]		
Δ ln BTC			-1.23*	
			[0.72]	
Δ ln BTC(-1)			0.55	
			[0.47]	
Δ ln BTC(-2)			0.38	
			[0.47]	
Δ ln BTC(-3)			0.24	
			[0.51]	
Δ ln BTC(-4)			0.39	

			[0.51]	
Δ ln BTC(-5)			-0.48	
			[0.48]	
Δ ln LTC				-0.77**
				[0.35]
Δ ln LTC(-1)				0.91***
				[0.27]
Δ ln LTC(-2)				-0.23
				[0.28]
Δ ln LTC(-3)				-0.01
				[0.28]
Δ ln LTC(-4)				-0.24
				[0.27]
Δ ln LTC(-5)				-0.16
				[0.25]
Constant	-0.002	0.006	-0.01	0.006
	[0.05]	[0.03]	[0.05]	[0.03]
Observations	614	614	614	599
Adjusted R-squared	0.003	0.005	-0.002	0.02

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

There are no significant relationships identified between previous days BTC price movements and current LTC traded volume. However, interestingly, the volume traded of BTC is significantly (at a high degree) and positively related to previous day LTC price movements: following an increase in LTC price in the previous day, there will be higher BTC trade currently. Although this association is harder to interpret, it may also suggest substitutability if considered together with the contemporaneous relationship. More specifically, in a scenario where LTC prices in the previous day went up and BTC volumes went down as the first estimation suggests, the downward price reaction of BTC would draw investors to buy the next day, thus driving BTC volumes up again.

5.6.3. Volume analysis for subsamples

Following the breakdown into subsamples already suggested previously in the analysis, I investigate the period specific reaction of trade volumes for one currency in percent returns for the other, contemporarily and as lagged reactions.

Percent return = $\%(Price_t - Price_{t-1} / Price_{t-1})$

All in all, the findings at subsample level mirror the general result for the entire sample, confirming the substitute hypothesis.

1. Period 1. w45 to w80, days 309 to 554

For the first subsample, there is a significant relationship between previous day LTC returns and current BTC trading, and it is positive, as for the period as a whole. There is no significant BTC return to LTC volume relationship.

2. Period 2. w81 to w100, days 555 to 694

In the second subsample we uncover a significant, negative contemporaneous relationship between BTC returns and LTC volumes and a significant positive relationship for previous day returns and current volume, both results mirroring the findings for the entire period.

Table 9: Regression outputs for changes in volume and % daily returns, for the four subperiods

VARIABLES	**(1) Δ ln LTC volume**	**(2) Δ ln BTC volume**	**(3) Δ ln LTC volume**	**(4) Δ ln BTC volume**	**(5) Δ ln LTC volume**	**(6) Δ ln BTC volume**	**(7) Δ ln LTC volume**	**(8) Δ ln BTC volume**
% return BTC	-0.58		-1.53***		-2.02		-1.008	
	[1.57]		[0.55]		[4.59]		[1.87]	
% return BTC (-1)	0.34		1.1*		3.47		-0.55	
	[1.7]		[0.64]		[2.98]		[1.84]	
% return BTC (-2)	0.35		-0.69		0.39		1.29	
	[1.7]		[0.68]		[2.97]		[1.8]	
% return BTC (-3)	-0.77		0.77		-0.33		-0.03	
	[1.8]		[0.63]		[2.35]		[1.8]	
% return BTC (-4)	2.77		0.03		5.83**		-1.05	
	[2.03]		[0.51]		[2.3]		[1.83]	
% return BTC (-5)	-3.06*		-0.27		-1.25		0.71	
	[1.66]		[0.65]		[2.93]		[1.86]	
% return LTC		-0.5		-0.11		-4.75***		-1.008
		[0.57]		[0.57]		[0.07]		[1.87]
% return LTC (-1)		1.43**		0.37		2.13		-0.55
		[0.6]		[0.37]		[1.76]		[0.79]
% return LTC (-2)		-0.41		-0.15		-2.09		1.29
		[0.6]		[0.46]		[1.42]		[1.006]
% return LTC (-3)		-0.33		0.013		-0.14		-0.03
		[0.59]		[0.51]		[1.94]		[1.01]
% return LTC (-4)		-0.86		0.23		-1.33		-1.05*
		[0.56]		[0.38]		[2.17]		[0.6]
% return LTC (-5)		-0.26		-0.37		-1.11		0.71
		[0.51]		[0.37]		[1.99]		[0.8]

Constant	-0.006	0.02	-0.008	0.0003	-0.05	-0.005	-0.014	-0.01
	[0.08]	[0.05]	[0.06]	[0.06]	[0.14]	[0.07]	[0.15]	[0.17]
Observations	244	237	140	140	84	84	143	143
Adjusted R-squared	-0.001	0.01	0.02	-0.03	-0.02	0.1	-0.03	-0.03

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

3. Period 3. w101 to w112, days 695 to 778

For the third subsample there is no significant relationship for current or previous day BTC returns and LTC trading volume, but there is significant negative contemporaneous association between LTC returns to BTC volume, which once more confirms overall findings.

4. Period 4. w113 to end, days 779 to 928

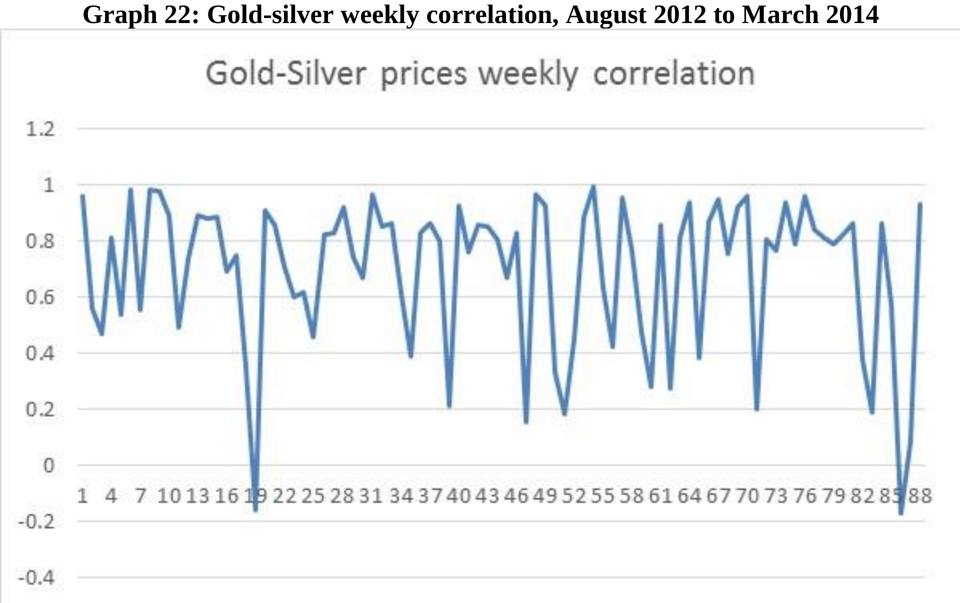
For the last period, there is no significant relationship between returns to volume in either direction, neither contemporaneously, nor for one day lags.

5.7. Another piece of the puzzle: the gold-silver comparison put to the test

Litecoin is commonly referred to, notably by its founders among others, as the silver to bitcoin's gold. It is therefore worth analyzing whether, for the very same period as above, the bitcoin-litecoin pair behaves similarly to gold-silver in terms of price correlations and elasticities. If our test confirms the validity of a parallel between the two pairs, this would indeed translate into potential substitutability between the two digital coins as the market would perceive them as different types of money, as are gold and silver perceived by investors.

Because of safe haven demand and inflationary concerns, gold and silver have traded historically at high positive correlations. As can be seen from the graph below, gold-silver weekly price correlations also vary considerably (switch from week to week), but they very rarely are negative.

Graph 22: Gold-silver weekly correlation, August 2012 to March 2014



Source: author; data from Quandl.com

This situation is different from our bitcoin-litecoin case, where negative correlations, although less frequent then positive co-movements, can indeed occur. This difference might be explained through the fact that gold and silver are regarded as substitutes to fiat currency, whereas digital money cannot yet claim that status. This would translate into stronger divestment away from fiat currency in times of uncertainty.

Table 10: Regression outputs for changes in silver/gold prices and volumes to changes in prices

VARIABLES	(1) **Δ ln silver price**	(2) **Δ ln gold price**	(3) **Δ ln silver volume**	(4) **Δ ln gold volume**
Δ ln gold price	1.03***		-2.88	
	[0.07]		[5.44]	
Δ ln gold price(-1)	0.32***		8.83**	
	[0.06]		[3.81]	
Δ ln gold price (-2)	0.05		9.8*	
	[0.05]		[5.6]	
Δ ln gold price (-3)	0.01		0.1	
	[0.05]		[4.01]	
Δ ln gold price (-4)	0.03		-9.41*	
	[0.04]		[5.03]	
Δ ln gold price (-5)	-0.002		10.81*	
	[0.05]		[6.41]	
Δ ln silver price		0.39***		-4.6
		[0.03]		[4.42]
Δ ln silver price(-1)		0.02		2.65
		[0.02]		[3.03]
Δ ln silver price (-2)		-0.03*		5.5*
		[0.02]		[3.34]
Δ ln silver price (-3)		-0.02		-3.4
		[0.02]		[2.44]
Δ ln silver price (-4)		0.014		0.35
		[0.02]		[3.26]
Δ ln silver price (-5)		0.01		-5.28
		[0.02]		[3.7]
Constant	-0.0001	-0.0001	-0.016	0.003
	[0.0005]	[0.0003]	[0.06]	[0.06]
Observations	583	601	539	581
Adjusted R-squared	0.44	0.41	0.015	0.008

White standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Looking at elasticities estimates, results show some similarity between the two pairs, bitcoin-litecoin and gold-silver. Direct price elasticities are positive and, interestingly enough, the estimates are very close for the two pairs, a 1% to 1% sensitivity of silver to gold prices and about 0.4% sensitivity of gold to silver prices. However, when looking at cross-price elasticities of volume, we notice no significant contemporaneous sensitivity in either direction for the gold-silver pair, but significant lag structures for silver volume sensitivity to changes in gold prices. This is different from the bitcoin-litecoin pair, where we uncovered no significant lag structure. This is possibly a consequence of gold-silver being a more mature, established pair, where their relationship has already crystallized by centuries of market interaction.

6. Conclusions and Policy implications

6.1. Conclusions

My analysis leads me to conclude that we cannot reject the possibility that bitcoin and litecoin are perceived by the market as different types of monies. Evidence is rather mixed and time dependant.

At a first glance, BTC and LTC prices move closely together; correlation is positive and very high for the analyzed period as a whole. Analyzing price relationships at a weekly level uncovers a far more complex picture. Correlation seems to jump from positive to negative on almost a weekly basis, which leads us to believe that no real conclusion of complementarity or substitutability can be drawn for the entire period as a whole and that the initial finding of strong positive correlation was misleading.

When breaking down the analysis into subperiods, I notice that the overall relationship is mainly driven by bubble events, when the cryptocoins price correlation becomes very strong. This "bubble" hypothesis, i.e. whether correlations behave differently in times of dramatic price movements, is then confirmed by checking the relationship between weekly correlations and market interest in cryptocurrencies as exhibited by Google searches, as well as between correlations and average weekly trading volumes for both currencies. During peak bubble times, when interest and trading volumes rise, price co-movement also seems to strengthen. I interpret this in the following way: during times of great "hype" around cryptocurrencies, i.e. when they compete together against other asset classes more so than against each other, their overall "income" effect is larger than their "substitution" effect and both their prices go up riding a wave of cryptocurrency enthusiasm. In normal times correlation can even turn negative, as with periods when LTC brings much higher returns or when people divest away from it and back to BTC. The ultimate test for complementarity/ substitutability, the cross price elasticities of volume, suggests that the two cryptocurrencies are rather substitutes to each other, as the market perceives them as being different types of money.

Finally, despite their fundamental similarity, the market perception surrounding the two cryptocurrencies is rather mixed, with evidence that cannot completely rule out substitutability. The implication of this finding is that the supply scarcity of any individual coin is not placed under question by the potentially infinite aggregate supply of all cryptocurrencies. Cryptocurrencies can posses scarcity, and, other properties left aside, can be regarded as money.

It is possible that, at this early stage, when the cryptocurrency market is growing as a whole, the relationship between the two has not yet crystallized. As the market evolves, volatility decreases and bubbles subside, it is not excluded that we may find stronger evidence in favor of substitutability.

6.2. Policy implications

The mixed conclusion regarding market perception, the arguments in favor of cryptocurrency scarcity and the impossibility of ruling out substitutability triggers a number of policy implications, primarily concerning central banks and financial services regulators.

1) ***Regulators can expect that liquidity will increase at a slow pace and price swings will become less violent as adoption of cryptocurrencies in general increases.***

   The fact that two dominant cryptocurrencies show signs of substitutability might give rise to the concern that competing coins are eating into each other's liquidity, giving rise to a coordination issue. It is not, however, necessary that regulators solve this coordination issue forcefully by endorsing one coin over others, but rather it is desirable that liquidity, albeit split, improves by way of the market maturing. No endorsement and divided liquidity is preferable to a scenario where arbitrary endorsing might lead to the collapse of the entire market and hamper future innovation.

2) ***Regulators should not focus exclusively on the media phenomenon bitcoin, but rather target a group of at least 5 dominant cryptocurrencies in their analyses and research.***

This analysis has shown that market perception around bitcoin and litecoin is rather mixed, with evidence for both complementarity and substitutability and the potential that in the future competition between (at least) two cryptocoins might become more pronounced.

3) ***Cryptocurrencies cannot be ruled out as money based on the fear that their aggregate supply could be expanded to infinity.***

The analysis brought me to conclude that inasmuch market perception over substitutability and effective competition between the two coins is concerned, scarcity of cryptocurrency in general does not seem to be under doubt. At the moment, the market does not perceive the total supply of cryptocurrency as affecting the individual supplies of any given coin. Thus, any official rulings or verdicts on cryptocurrency failing to fit the description of money/ potential money for lack of scarcity are not warranted.

4) ***Regulators can play a part in limiting the intensity and frequency of bubbles in the cryptocurrency market.***

As we have seen in the empirical analysis, price correlations appear to be time dependant and bubble driven, and speculation and uncertainty over regulator stance regarding cryptocurrencies are an important factor for bubble-like tendencies. Should regulators wish to diminish dramatic price swings, central banks and financial supervisors should communicate more effectively their position towards cryptocurrency and also signal checkpoints or thresholds for which the adoption or traded volume of cryptocoins might start posing a risk to price stability or financial stability and prompt more decisive regulator action.

Appendix

A.1. Unit root test for BTC price.

Null Hypothesis: BTC has a unit root
Exogenous: None
Lag Length: 20 (Automatic - based on SIC, maxlag=20)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.552229	0.4779
Test critical values:	1% level	-2.567817	
	5% level	-1.941214	
	10% level	-1.616437	

*MacKinnon (1996) one-sided p-values.

A.2. LM test for serial correlation in the residuals for interest as exhibited by Google searches (Google trends data).

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.490621	Prob. F(5,81)	0.2020
Obs*R-squared	7.414924	Prob. Chi-Square(5)	0.1916

Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 05/19/14 Time: 11:01
Sample: 1 88
Included observations: 88
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000170	0.075452	0.002255	0.9982
BTC_INTEREST	-1.25E-05	0.002450	-0.005118	0.9959
RESID(-1)	0.111907	0.108221	1.034062	0.3042
RESID(-2)	-0.128401	0.109163	-1.176228	0.2429
RESID(-3)	0.017898	0.109963	0.162762	0.8711
RESID(-4)	-0.006834	0.109868	-0.062205	0.9506
RESID(-5)	0.242187	0.109240	2.217026	0.0294

R-squared	0.084261	Mean dependent var	-1.02E-16
Adjusted R-squared	0.016428	S.D. dependent var	0.534282
S.E. of regression	0.529875	Akaike info criterion	1.643854
Sum squared resid	22.74221	Schwarz criterion	1.840915
Log likelihood	-65.32957	Hannan-Quinn criter.	1.723245
F-statistic	1.242184	Durbin-Watson stat	2.008452
Prob(F-statistic)	0.293712		

A.3. Unit root tests for interest.

Null Hypothesis: BTC_INTEREST has a unit root
Exogenous: None
Lag Length: 0 (Automatic - based on SIC, maxlag=11)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.536082	0.1163
Test critical values:	1% level	-2.591813	
	5% level	-1.944574	
	10% level	-1.614315	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(BTC_INTEREST)
Method: Least Squares
Date: 05/19/14 Time: 11:14
Sample (adjusted): 2 88
Included observations: 87 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
BTC_INTEREST(-1)	-0.057443	0.037396	-1.536082	0.1282

R-squared	0.026075	Mean dependent var	0.275862
Adjusted R-squared	0.026075	S.D. dependent var	10.91371
S.E. of regression	10.77048	Akaike info criterion	7.602923
Sum squared resid	9976.285	Schwarz criterion	7.631267
Log likelihood	-329.7272	Hannan-Quinn criter.	7.614337
Durbin-Watson stat	1.811296		

Null Hypothesis: BTC_INTEREST is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 6 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.093243
Asymptotic critical values*:	1% level	0.216000
	5% level	0.146000
	10% level	0.119000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	287.1908
HAC corrected variance (Bartlett kernel)	1117.438

KPSS Test Equation
Dependent Variable: BTC_INTEREST
Method: Least Squares
Date: 05/19/14 Time: 11:26
Sample (adjusted): 1 88
Included observations: 88 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.478805	3.623891	-1.787804	0.0773
@TREND(1)	0.618374	0.071940	8.595656	0.0000

R-squared	0.462114	Mean dependent var	20.42045
Adjusted R-squared	0.455860	S.D. dependent var	23.23925
S.E. of regression	17.14263	Akaike info criterion	8.543479
Sum squared resid	25272.79	Schwarz criterion	8.599782
Log likelihood	-373.9131	Hannan-Quinn criter.	8.566162
F-statistic	73.88530	Durbin-Watson stat	0.405716
Prob(F-statistic)	0.000000		

A.4. Unit root test for weekly price correlation.

Null Hypothesis: WEEKLY_CORR_2 is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.099956
Asymptotic critical values*:	1% level	0.216000
	5% level	0.146000
	10% level	0.119000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.323988
HAC corrected variance (Bartlett kernel)	0.449909

* For both interest and weekly correlation, ADF and KPSS give conflicting results, both at the borderline of 10% confidence level. The decision was to accept KPSS as more robust and claim stationarity.

A.5. Serial correlation test for weekly correlation regressed on weekly volume averages.

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.265192	Prob. F(5,82)	0.2869
Obs*R-squared	6.374236	Prob. Chi-Square(5)	0.2715

A.6. Unit root test for weekly volume averages.

Null Hypothesis: WEEKLY_VOLUME_AVERAGE_BT is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 5 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.075172
Asymptotic critical values*:	1% level	0.216000
	5% level	0.146000
	10% level	0.119000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

A.7. Summary of weeks with highest price changes or highest correlations

Periods of high BTC price increases

Week ending on	Week	Weekly corr	Weekly price average BTC	Weekly price average LTC	Change in Wk price average BTC	Change in Wk price average LTC
3/11/2013	78	0.846425195	44.00714286	0.253418286	31%	199%
3/25/2013	80	-0.000173759	67.85285714	0.511979	44%	-16%
4/1/2013	81	0.862712678	91.51285714	0.844072429	35%	65%
4/8/2013	82	0.465887013	145.45	3.733994286	59%	342%
4/29/2013	85	-0.377679869	138.9828571	3.690142857	29%	56%
10/21/2013	110	-0.889624645	155.6957143	1.78719	21%	-7%
10/28/2013	111	-0.042120081	192.0514286	2.011817143	23%	13%
11/11/2013	113	0.766779385	305.6128571	3.727751429	48%	51%
11/18/2013	114	0.950937357	451.19	4.731414286	48%	27%
11/25/2013	115	0.845227766	728.1557143	9.021648571	61%	91%
12/2/2013	116	0.5234339	1021.034286	32.71292857	40%	263%

Periods of high BTC price decreases

Week ending on	Week	Weekly corr	Weekly price average BTC	Weekly price average LTC	Change in Wk price average BTC	Change in Wk price average LTC
8/27/2012	50	-0.428045443	10.31285714	0.039924857	-11%	-5%
4/15/2013	83	0.958785618	120.15	2.690297143	-17%	-28%
4/22/2013	84	0.990216424	107.74	2.362837143	-10%	-12%
5/6/2013	86	0.945415448	114.7742857	3.523045714	-17%	-5%
6/10/2013	91	0.988983836	112.0328571	2.648132857	-11%	-7%
7/1/2013	94	0.202685794	92.27428571	2.693981429	-10%	6%
7/8/2013	95	0.898903474	75.14857143	2.550595714	-19%	-5%
12/9/2013	117	0.984155999	915.1414286	32.03998571	-10%	-2%
12/23/2013	119	0.931431704	621.5814286	17.26712857	-28%	-43%
2/17/2014	127	0.831718759	644.3842857	16.05107143	-12%	-16%

Periods of strong negative correlation

Week ending on	Week	Weekly corr	Weekly price average BTC	Weekly price average LTC	Change in Wk price average BTC	Change in Wk price average LTC
8/6/2012	47	-0.833251309	10.28857143	0.052899833	17%	2%
8/13/2012	48	-0.825510849	11.26	0.051768571	9%	-2%
10/15/2012	57	-0.506772847	11.93142857	0.084335429	-3%	48%
11/12/2012	61	-0.859539275	10.80714286	0.071152857	0%	-7%
11/19/2012	62	-0.961276348	11.29714286	0.063037571	5%	-11%

12/24/2012	67	-0.50356882	13.23571429	0.076536429	-1%	-2%
1/21/2013	71	-0.744107628	15.29428571	0.059946857	11%	-12%
2/25/2013	76	-0.814121869	29.93428571	0.068197571	12%	-9%
3/18/2013	79	-0.76486844	47.14428571	0.606848571	7%	139%
6/24/2013	93	-0.815123025	102.0042857	2.543694286	0%	13%
8/5/2013	99	-0.681710877	96.72285714	2.644928571	8%	-2%
8/19/2013	101	-0.668804455	99.36142857	2.385672857	5%	-2%
9/2/2013	103	-0.582857	123.9757143	2.373827143	13%	0%
9/9/2013	104	-0.807575593	121.73	2.535248571	-2%	7%
9/30/2013	107	-0.814226356	125.5285714	2.202515714	1%	-8%
10/21/2013	110	-0.889624645	155.6957143	1.78719	21%	-7%

Periods of strong positive correlation

Week ending on	Week	Weekly corr	Weekly price average BTC	Weekly price average LTC	Change in Wk price average BTC	Change in Wk price average LTC
10/29/2012	59	0.952843525	10.75714286	0.078253	-8%	-7%
2/4/2013	73	0.989770038	20.00285714	0.068055286	13%	10%
2/11/2013	74	0.986270188	22.32857143	0.076233143	12%	12%
4/15/2013	83	0.958785618	120.15	2.690297143	-17%	-28%
4/22/2013	84	0.990216424	107.74	2.362837143	-10%	-12%
5/6/2013	86	0.945415448	114.7742857	3.523045714	-17%	-5%
6/10/2013	91	0.988983836	112.0328571	2.648132857	-11%	-7%
6/17/2013	92	0.919819579	101.96	2.249055714	-9%	-15%
7/22/2013	97	0.969328731	87.26857143	2.72395	-1%	5%
11/18/2013	114	0.950937357	451.19	4.731414286	48%	27%
12/9/2013	117	0.984155999	915.1414286	32.03998571	-10%	-2%
12/16/2013	118	0.983946595	859.8928571	30.18441429	-6%	-6%
12/23/2013	119	0.931431704	621.5814286	17.26712857	-28%	-43%
12/30/2013	120	0.947993461	711.37	21.96511429	14%	27%
1/13/2014	122	0.970530536	835.6371429	23.99651429	2%	-4%
1/20/2014	123	0.947950786	820.9742857	23.91527143	-2%	0%
1/27/2014	124	0.964689848	801.37	22.04348571	-2%	-8%
2/3/2014	125	0.968396276	803.1314286	21.19977143	0%	-4%
2/10/2014	126	0.971361932	729.9985714	19.16321429	-9%	-10%

Glossary and abbreviations

Altcoins	*alternatives to bitcoin*
BIS	*Bank for International Settlements*
Blockhain	*transaction database shared by all nodes participating in a system based on the cryptocoin protocol; common ledger*
BTC	*bitcoin; in the empirical analysis, the price of bitcoin*
Cryptocurrency or cryptocoin	*digital money built on encryption protocols and decentralized, peer-to-peer networks*
EBA	*European Banking Authority*
ECB	*European Central Bank*
Fed	*U.S. Federal Reserve System*
IRS	*Internal Revenue Service*
LTC	*litecoin; in the empirical analysis, the price of litecoin*
PBoC	*People's Bank of China*
Pseudonimity	*property of the cryptocurrency ledger, by which transactions are recorded not by using real names, but by using coded addresses or "keys". Different from anonymity, the property of cash money*
SHA-256 and Scrypt	*the two most common algorithm systems used by cryptocurrency miners in order to authenticate blocks of transaction data*

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