BACHELOR THESIS

Digital currencies:
Analysis of Bitcoin demand

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Declaration of Authorship

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Prague, May 13, 2013

Martin Janota

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Signature
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Abstract

This thesis examines motives of demand for digital currency Bitcoin. We estimate transaction and speculative motives of Bitcoin users and their impact on the emerging digital currency. We analyze Bitcoin data and argue that external Bitcoin trading is mostly influenced by speculative motive. Speculative trade volume on average appreciates Bitcoin exchange rate. However internal Bitcoin transactions are driven mostly by transaction motive and are largely independent on Bitcoin trading. Speculative and non-speculative motivated users thus coexist in separate circuits, interacting mostly indirectly through exchange rate and acceptability of Bitcoin.

In the last part we argue that quantity theory of money is well applicable on transaction-based data, which Bitcoin provides, and use it to estimate money velocity and output index. We show that growth of Bitcoin accounts brings significant network effect and along with number of transactions largely explains growth of output index.

**JEL Classification**  
E41, E42, F31

**Keywords**  
motives of money demand, acceptability, digital currencies, Bitcoin, Quantity theory of money

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Abstrakt

Tato práce se zabývá motivy poptávky po digitální měně Bitcoin. Odhaduje význam transakčních a spekulativních motivů uživatelů a jejich vliv na vývoj vznikající digitální měny. Na základě zkoumání transakčních a obchodních dat tvrdíme, že obchodování s Bitcoinem je převážně ovlivňováno spekulativním motivem. Kurz Bitcoinu v průměru posíluje při mimořádných objemech obchodů. Transakce uvnitř systému jsou ale určovány transakčním motivem a jsou do značné míry nezávislé na obchodování s Bitcoinem. Spekulativní a ostatní motivy uživatelů Bitcoinu tedy koexistují v oddělených okruzích a ovlivňují se nepřímo skrze kurz a akceptabilitu měny.

V poslední části tvrdíme, že kvantitativní teorie peněz je dobře aplikovatelná na transakční data, která jsou v případě Bitcoinu k dispozici, a využíváme ji k výpočtu rychlosti obratu peněz a indexu produktu. Na datech ukazujeme, že růst počtu Bitcoinových účtů přináší síťové efekty a spolu s počtem transakcí dobře vysvětluje růst indexu produkce.

Klasifikace

E41, E42, F31

Klíčová slova

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### Acronyms

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<th>Description</th>
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<tr>
<td>DC</td>
<td>Digital currency</td>
</tr>
<tr>
<td>DCE</td>
<td>Digital currency exchange</td>
</tr>
<tr>
<td>PPP</td>
<td>Purchasing power parity</td>
</tr>
<tr>
<td>etv</td>
<td>Estimated transaction volume</td>
</tr>
<tr>
<td>BTC</td>
<td>Bitcoin</td>
</tr>
<tr>
<td>USD</td>
<td>US dollar</td>
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<tr>
<td>QTM</td>
<td>Quantity theory of money</td>
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Preliminary scope of work

This work will analyze digital currencies and the applicability of monetary theory. It will assess digital currency specifics and review theory which can be applied on digital currencies. Emergence of digital currencies will be examined from institutionalist perspective. In the empirical part I will analyze the basic functions of money and motivations of users on Bitcoin data and try to find similarities and differences with respect to national currencies. The major part of the thesis will consist of work with Bitcoin transaction data, which is uniquely available for Bitcoin and not for national currencies. The last part of the work will outline possible challenges, which digital money alternatives pose for monetary theory and policy.

References

Hayek, Friedrich: Denationalization of Money, 1974
1 Introduction

Money and currencies were always in the center of attention of economics. Historically, there has been multitude of currencies used in the same area, fulfilling different functions. In 20th century, when currency became a synonym for national currency and questions concerning multiple small currencies were subsided. Managing currency was technically difficult until internet allowed almost anyone to create some sort of electronic currency that would be stored and operated through computer network. Over past decade the costs associated with issuing and operating some digital tokens plunged. Creating and managing digital currency became feasible for a single person with computer and a bit of expertise. Digital money projects started appearing as the internet usage spread. But the practical use and hence the crucial acceptability were limited by the spread of internet usage and volume of e-commerce. In the current state when internet is easily accessible at all times; all goods and services are available in electronic stores; transportation costs are low; shipping from across the world is feasible and payment systems are fast and secure, the usage of alternative digital money is technically almost unlimited and the questions concerning multiple small currencies are relevant again.

Over the last decade digital currency emergence has increased exponentially. The economic importance of digital currencies has also boomed and non-negligible share of trade goes though digital currencies today.\(^1\) Digital currencies are a sandbox for monetary theory, they can simulate emergence of money, its spread, microeconomic motivations and even systemic properties that large national currencies cannot provide or only at very high cost.

In this thesis we examine one digital currency project of past years – Bitcoin. The currency has attracted attention thanks to its unique concept and extraordinary appreciation and it has raised questions about basic functions and legal definitions of money. The crucial doubts around Bitcoin revolve around whether the currency serves any real economic purpose, as national currencies do. In our thesis we analyze the use of the currency according to money demand motives (transaction vs. speculative) and try to determine which motive dominates or what is their relationship. Since

\(^1\) The European Banking Federation assessed the broad statistic including all e-money (wallets, currencies, credits, etc.) purchases in the EU in 2011 at 38 billion EUR. [1]
we cannot directly observe motives of currency users, we derive information from available trade and transaction data. The data availability is a unique feature of Bitcoin, unlike for national currencies. Thanks to public availability of Bitcoin transaction data, Bitcoin could be used study microfoundations of money and currency design.

The central line, which the thesis follows, are the motives of Bitcoin users. Secondarily, we follow the applicability of economic theory on free floating digital currencies and use of transaction data. Occasionally we take quick detour from the main topic and explain some side issues, if we deem it necessary for understanding our reasoning.

The thesis is structured as follows: Chapter 2 outlines basic terminology which we will use throughout the text. Chapter 3 explains the specifics of digital currencies, for the reader to understand our point of departure, when working with Bitcoin. Chapter 4 reviews relevant literature about currency emergence. Chapter 5 discusses theoretical concepts applicable to Bitcoin exchange rate. We introduce important assumption about Bitcoin price level in this chapter. Chapter 6 introduces Bitcoin, its mechanics, history and data. In this chapter we also test minor hypothesis about Bitcoin mining. Chapter 7 gets to the core of the thesis, which are motives of money demand for Bitcoin users. We discuss three motives (transaction, store of value, speculation) and then test their impact on exchange rate and trade volume. In Chapter 8 we use transaction data aggregates to estimated Bitcoin velocity and output index. Then we use the index to test growth of output index with respect to number of transactions and active accounts to support our claims from Chapter 7.
2 Terminology

There are nowadays dozens of alternative methods of transferring and storing over the world web. They vary greatly, from simple storage platforms or payment systems for national currencies to entirely independent private currencies.

There is no general consensus about what should be called „alternative currency“ and how should its subsets be called. Official definitions of money tend to be catch-all phrases, along the Directive 2009/110/EC of the European parliament and of the Council, paragraph (8):

“The definition of electronic money should cover electronic money whether it is held on a payment device in the electronic money holder’s possession or stored remotely at a server and managed by the electronic money holder through a specific account for electronic money. That definition should be wide enough to avoid hampering technological innovation and to cover not only all the electronic money products available today in the market but also those products which could be developed in the future.“

Legal definitions are not too helpful from economic perspective. In order for the text to be coherent, this paper will use the following terminology:

**National currency** is a currency issued by local monetary authorities, with the legal tender status (USD, Euro, etc.).

**Alternative currency** is a non-national currency. Issuers are usually private organizations or local authorities. Therefore the motives of issuer can vary from profit to supporting local community. Legally alternative currencies are often not recognized as money. Alternative currencies do not play significant role in the financial system and hence their macroeconomic importance is marginal. On the other hand, they can work very well as medium of exchange.

**Digital currency** (DC) can be used to describe a lot of things. Here the term is used for a currency which has no physical representation and is exchanged through computer networks. In this paper DCs are treated as subset of alternative currencies. Some digital currencies were created for a specific type of transactions, such as buying digital items on specific website. Some were designed as stand-alone currency, these are the focus of this paper.
This paper is about monetary theory and digital currencies, so we focus on digital currencies, which are independent on national currencies, with their value derived from demand for them. Most digital currencies are just representations of a national currency. These do not have the monetary properties of an independent currency and we will not concentrate on those.
3 Specifics of digital currencies

Digital currencies are very heterogeneous group, it is difficult to classify them according to simple criteria. There are however some similarities among them and similarities between them and national currencies, that may allow us to apply some monetary theory. For us, the most important similar features of DCs and national currencies from monetary perspective are:

1. Digital currencies not linked to national currencies have their own money supply.
2. DCs have exchange rates (price at which they are sold) and exchange rate regimes.
3. Digital currencies generate seignorage.
4. Function as medium of exchange, as store of value and as speculative instrument.

Some aspects are notably differently from national currencies. Most of the differences make applicability of economic theory more difficult (like unavailability of some statistical data), some may help (absence of physical money). Most notable differences are:

1. DCs have no specie, all transactions are processed through digital network.\(^2\)
2. DCs have payment systems separate from national currencies.
3. There is often little statistical data about purchased goods, services and prices. Many digital currencies have no tax evidence, the transactions are not recorded by national authorities and bureaus of statistics.
4. DCs are not used in the financial markets\(^3\), they usually have no associated interest rates, no loans are issued in DCs, financial assets are not traded in DCs. As a result the money flows of DCs will be small compared to national currencies.

\(^2\) There may be chips with stored units of a digital currency, but the transaction still has to be processed online.

\(^3\) The field is rapidly developing, but at the moment mostly legal issues prevent the use of private digital currencies in financial markets.
5. DCs are not macroeconomically important.

6. DCs are not legal tender. As a result, DCs are issued only if demanded. Issuers cannot force the usage of their currency.

7. DCs can be decentralized, with no central issuer and monetary authority.\(^4\)

\(^4\) So far this is only true for Bitcoin and its clones.
4 Currency Emergence

Economic theory is surprisingly shallow when it comes to explaining why a certain currency in certain area and time emerged. Reliable prediction is entirely out of reach. There are classical theories dealing with emergence of monetary from barter economy - search models, OLG models. We will use the basic ideas underlying those theories. As for the emergence of alternative currencies, the literature consensus is that it is suboptimal and irrational to have more currencies in one area [2] (literature overview in Schmitz 2001). Nevertheless, the theoretical rejection of multiple currencies may be lack of imagination, rather than real argument [3].

4.1 OLG perspective

Overlapping generations models work with long time periods and money serves as store of value. Since digital currencies serve primarily as medium of exchange and only to some extent as a store of value this model does not seem fully relevant (though [4] argues that those two motives are essentially the same). If there already is a currency, agents can smoothen their consumption and they have no incentive to use another currency, from the perspective of OLG model. In some cases where a DC also serves as store of value, the chief concern of an agent will be the value of the currency (exchange rate) and the probability of collapse.

As emphasized by OLG type models [5], there has to be high degree of certainty that fiat currency will be accepted in the future to make it acceptable today. First, digital currencies is a rapidly growing and changing area and the technologies may simply move forward. Second it is possible that competition among digital currencies will grow and better alternatives will emerge. Third, it is still in legal vacuum and regulation could take it down. For those and other reasons, potential users will use the currency cautiously and will not store sizable wealth in it.

From OLG perspective, using alternative currency with little acceptability and high future uncertainty, when there is safe national currency, is not too rational.
4.2 Search models

Kiyotaki and Wright formalized Search model application on money as a medium of exchange in [6] and [7]. Their model works with large group of non-cooperating utility-maximizing agents. Each agent wants to trade his good for another one. Here comes the obstacle, double coincidence of wants is necessary for an agent to by willing to trade his good for another one. This can be solved if many agents start accepting some good in all transactions. The more agents would accept the monetary good, the higher will its acceptability be, even more than proportionally, reflecting network effects. Acceptability is the core variable of the model. The solution of the model has three results: agents fully accepting money, agents being indifferent between money and barter and agents only trading through barter. However, in our case there is already fully monetized economy.

In [7] Kiyotaki and Wright add a module for two currencies in circulation. In this model, one equilibrium is such that one currency is always accepted and the second one is partially accepted. There is also an equilibrium where both currencies are universally accepted, despite different yields. The paper arguments with liquidity sometimes being valued more than yield and we also use this argument later on with respect to Bitcoin.

In [8], the Kiyotaki Wright model is modified for a situation of two countries and two competing currencies that can exchanged. [9] further tweaks the basic model, by introducing mixed strategies and dynamic equilibria. Nonetheless the basic idea of this class of models is still rather tautological – money will be used if it is accepted; and if agents think it will be accepted, they use it. We will now go back to the core idea of acceptability.

4.3 Acceptability

The notion of acceptability of a commodity as a medium of exchange was first coined in Menger’s 1892 article On the Origins of Money [10]. Although the article deals mostly with commodity money, the main ideas are relevant for any currency and it is at the roots of Kiyotaki-Wright’s model. In Menger’s interpretation people transform their produces into more liquid, more generally acceptable goods. Such goods usually have large and developed market, which makes them acceptable by many counterparties. As agents individually find that some commodity is more accepted than others, they will start converting more of their other goods into the more acceptable one. Acceptability is ever more relevant for electronic money, where physical
qualities (durability, transportability, divisibility) are not important anymore. However Menger did not explain the evolutionary dynamics of money. The transformation of commodity into money is gradual and we cannot say at the beginning if it will become universally acceptable or if other commodity will surpass it. Menger’s agents just adopt a currency if they think it will be accepted. They move towards a focal point – “a solution that people will tend to use in the absence of communication, because it seems natural, special or relevant to them” [11], a term later coined by Schelling [12]. This issue has been addressed by including agents with limited information and running simulations [13]. It makes convergence toward one currency more complex. But still, there is not much space for alternative currencies.

Menger lists spatial limits and time limits of acceptability of a commodity, among which are

1. Spatial distribution of demand
2. Development of arbitrage and speculation with the commodity
3. Interest paid for holding it
4. Persistence of demand in time

Out of those four criteria, Bitcoin fully passes only the first.

Menger talked only about commodities with intrinsic value, since agents without prior knowledge will only want to purchase something valuable by itself. Alternatively, money can be enforced by „influence of the sovereign power“. With digital currencies it is a bit different. They have little intrinsic value. They are created instantly, but not legally enforced. They do not circulate like goods, they just stand waiting to be demanded. The demand is crucial for the emergence of alternative currency, as there is no way to emit the money, other than selling it to people who show their interest in it.

Some digital currencies are designed to be exclusively used to trade a specific good or service. This links the currency to the exclusively traded goods and Menger’s acceptability of that good can be partly applied to the currency.

As we will see in our example, Bitcoin started with no acceptability and no certainty that it will survive, but after it became used to trade some goods it attracted more users and volume. From
theoretical view this is still rather puzzling. Acceptability explains the expansion of the currency, but it has no predictive power.

4.4 Functions of money

Every monetary textbook starts with reviewing the roles that money plays. Usually three main functions are mentioned: medium of exchange, store of value and unit of account. There are multitude of other possible functions, like: transfer of value, basis of credit system, standard of deferred payment and many others. All secondary functions are derived from the fact that money is used as a medium of exchange. We will call the motive behind medium of exchange use of currency transaction motive.

Digital currencies are specific in medium of exchange and sometimes store of value being the only functions they fulfill. In that sense it is much more pure money – its properties depend on microeconomic factors and motivations of its users, not on financial system issues which dominate national currencies. This makes theory based just on simple exchange (such as transaction costs models) applicable on digital currencies. Most digital currency transactions are relatively small, so called micro-transactions. Agents therefore do not expose any sizable portion of their wealth if they want DC just to conduct micro-transactions. Consequently agents have only limited concern for their alternative currency holdings losing value.

In contrast, if DC is purchased with store of value or speculative motive, then agents should be very sensitive to changes in value of the chosen DC.

---

5 Transaction with value below 10 USD.
5 Digital currency exchange rate

Bitcoin is a free floating currency with no limits on exchange rate. It can be easily bought or sold and has exchange rate just like any currency. In this chapter we review theoretical background which we later use with respect to Bitcoin exchange rate. But first we deal with one practical issue of digital currency conversion.

5.1 Digital currency exchanges

A necessary condition for the existence of a free floating digital currency is the ability to buy and sell it for other currencies, both digital and national. This is provided by specialized digital currency exchanges.

Digital currency exchanges (DCEs) are online exchange offices, which exchange national vs. digital currencies, DC vs. DC or DC vs. national currency. For conversions DCEs charge percentage fee or spread. DCEs also usually provide accounts in traded currencies. There is large number of these exchanges, almost no barrier to enter the industry and hence it is very competitive area. They differ in the range accepted currencies, fee structure and additional services.

The principal concern for a potential client is the security of their accounts with the DCE. There two main sources of risk to the accounts – hackers and authorities. While all DCEs boast their security, successful hacker attacks are not uncommon. Second source of risk is similar to the digital currencies themselves, the area is not fully regulated and DCEs can be shut down by authorities or at least severely limited by new regulation. Even if a DCE is only down for a few days, credibility is lost and the business may not survive. This is additional source of uncertainty connected to using digital currencies.
5.2 Exchange rates determination

There is broad economic theory dealing with exchange rates, but the applicability on digital currencies is limited. The problem is that most exchange rate theory derives exchange rates from national economic data or from financial markets. Digital currencies are small and their prices often reflect microeconomic motivations. Therefore the most useful theories are those based on very simple microeconomic concepts, here we list three groups:

- Purchasing power parity
- Interest rate parity (covered and uncovered, real and nominal)
- Asset approach

5.2.1 Purchasing power parity

Purchasing power parity based theory is the simplest and oldest way to discuss currency value. It is based on trade of goods, which is what DCs are for, and it is very simple so it could be applicable on a currency with very straightforward properties like Bitcoin.

Under the law of one price, one good should require the same purchasing power in two countries. When this holds for all goods, then we speak of absolute purchasing power parity and the nominal exchange rate is determined as the ratio of price levels in the two countries.\footnote{In the DC context, \textit{country} means the digital currency.}

\[ P_t = ER_t \times P_t^* \]

Where \( P_t \) and \( P_t^* \) are domestic and foreign price levels respectively, at time \( t \). \( ER_t \) is the exchange rate.

Real exchange rate in this case is equal to unity. The absolute theory has strong assumptions about transaction costs and trade barriers. In the case of digital currencies these assumptions actually seem less limiting than in the case of a national currency. This is because DCs are used parallel to national currency within one country, so there are no trade barriers.
More commonly used is the relative PPP. Relative PPP postulates that relative change in ER is proportional to the relative change of price levels in the two countries. If both countries experience the same price level changes, then the exchange rate should be constant over time.

\[
\frac{\Delta ER_t}{ER} = \frac{\Delta P_t}{P_t} - \frac{\Delta P_t^*}{P_t^*}
\]

How is this applicable on DCs? The PPP theory sounds compelling if we realize that digital currencies are primarily designed for goods markets. Nonetheless there are several issues.

First, under PPP exchange rate is determined endogenously, based on price levels. In reality many agents set their prices in digital currencies based on the current exchange rate and price in national currency. The exchange rate is determined first on exchanges, so the process of determination is reversed, prices are endogenous. Second, only some goods that are traded in national currencies are traded in DCs and vice versa. Third, price level data in DCs is not always available.

Still, we believe PPP is one of the best tools for Bitcoin analysis and we will use it in the later chapters.

5.2.2 Interest rate parity

Another approach makes the exchange rate dependent on interest rates, rather than price levels.

\[ i = i^* + \Delta er \]

Where \( i \) and \( i^* \) are interest rates in domestic and foreign country respectively, \( er \) is the log of exchange rate.

Interest rates depend on the price of assets, in digital currencies there are neither interest rates nor assets. Still we do not completely discard the idea. If a currency has zero interest rate, then foreign currency interest rate has to be matched by appreciation. Agents with speculative motive for purchasing and holding digital currency will expect the DC to appreciate to match interest rates of national currencies and to cover risk premium from investing into not so stable currency. This may be happening with Bitcoin as well.
5.2.3 Asset approach

In modern exchange rate determination theory there is accent on international capital flows. Money moves into currencies where assets with interesting risk-reward ratio are denominated. These money flows ultimately beat all trade related money flows in total volume. With digital currencies, the store of value or speculative motive is also present, however since there are no yielding assets denominated in DCs, all speculative profit expectations are based on appreciating exchange rate. From the view of portfolio theory (and interest parity mentioned before) the higher risk should be compensated by higher return. So the less acceptable and more volatile a DC is, the higher its expected appreciation must be to satisfy speculative motives. The implication for Bitcoin is that the currency itself is viewed as speculative asset, which may influence exchange rate more than transaction of store of value motives.

Next subchapter thematically falls into this chapter, but reader may find it more meaningful after reading the Bitcoin introduction first in Chapter 6.

5.3 Purchasing power parity and Bitcoin prices

"If internal prices were as flexible as exchange rates, it would make little economic difference whether adjustments were brought about by changes in exchange rates or equivalent changes in internal prices. But this condition is clearly not fulfilled..."

-Milton Friedman [37]

How flexible are the internal prices for Bitcoin?

As we argued above, PPP hypothesis should be applicable on floating digital currencies like Bitcoin very well, because there are no transaction costs or trade barriers. All Bitcoin traded goods come from regions with their own national currency, so there should be no difference, other than which currency is used to purchase them. And since Bitcoin exchange rates are determined by dollar demand (some of which is only speculative, with no relation to real transactions), it remains for the prices to adjust.
Assumption 5.1 (Law of one price) : Prices of Bitcoin traded goods are determined in national economies.

This is a very strong assumption. Though we have reasons to believe the law of one price holds for most prices, this relationship is not perfect in reality. Some Bitcoin traded goods are probably priced only within Bitcoin economy, there is no way of knowing the real figures. If law of one price holds for all Bitcoin traded goods (as we assume), then we can speak of absolute purchasing power parity.

Under absolute\(^7\) PPP, exchange rates are determined by ratio of domestic (Bitcoin) and foreign (for example US) price levels. In our case, the mechanism is reversed and Bitcoin prices are set based on exchange rate (which is not influenced by prices) :

\[ P_t = ER_t \times P_t^* \]

There are several reasons for this:

1. Vendors have dollar costs
2. People adjust their price calculations to the currency they use most (i.e. national currency)
3. Bitcoin exchange rate is too volatile for vendors to set fixed Bitcoin prices
4. Final accounts have to use legal tender, so vendors convert their Bitcoin revenue into national currency for accounting and tax purposes
5. Exchange rates are influenced by speculative demand for Bitcoin, but this demand does not serve to purchase any goods, i.e. affects prices only through exchange rate

There is one more problem in determining Bitcoin price level – we do not know the basket of goods, therefore we do not know which national price index to use to best correspond to price of Bitcoin goods. We can only reasonably assume that Bitcoin goods are final – i.e. not intermediary goods. Then final consumer prices are the most accurate index from the real economy we can get. We use monthly US consumer price index and monthly Bitcoin price average to obtain Bitcoin price level index, which we use in the last chapter.

\(^7\) Absolute PPP reflects the assumption that prices in Bitcoins are determined outside Bitcoin. Relative PPP would suppose that there is some internal Bitcoin price level.
6 Bitcoin

In this part we introduce an interesting digital currency project of past years. The way it was programmed determines many of its monetary properties, so it is necessary to discuss its mechanics.

First, we briefly explain where did Bitcoin come from, how it works and the historical development of Bitcoin price and volumes. Second, we explain our approach to data with its special issues. Third, we discuss Bitcoin mining and test a minor hypothesis.

The order of following Bitcoin chapters is thematic with several small detours, since the topic is not intuitive, we often consider it necessary to explain our motivation and reasoning before moving on.

6.1 Introduction

Bitcoin is a digital currency with a unique feat that it is neither issued nor operated by any central authority. Instead, running the currency is spread among all people using it.

For some groups the idea of monetary system with no central authority is compelling. Historically, commodity standard was closest to a decentralized monetary system. Making a fiat currency decentralized (not controllable by any single authority) has been technologically difficult. Bitcoin seems to have succeeded in offering a decentralized emission mechanism and payment system. All transactions are executed by the whole system. What makes it new? Even early versions of computer networks allowed transfer of some digital tokens. But it was not possible to keep track of transactions and prevent double spending of those tokens without a central controlling authority. The advance of internet technologies and cryptography as well as the size of computational performance connected to the internet opened new possibilities. A group of unrelated computers around the world can together make a monetary system, which confirms transactions and issues new currency, but does not depend on any single computer within the network – this is the distinctive feature of Bitcoin.
In 2008, a paper describing Bitcoin protocol appeared on the internet. [14] Bitcoin started working in 2009 with the first block of data. Its origins are veiled in myth, because the creators remain anonymous (present themselves under name Satoshi Nakamoto, which is a pseudonym). Bitcoins were designed as a medium of exchange in online environment. Upon the start, there was no market for Bitcoin (no shops accepted Bitcoin). Now Bitcoins are used to buy and sell all sorts of consumer goods and services from digital items to furniture\(^8\).

To get an idea of relative importance of Bitcoin, look at following Figure. In Figure 1 we see the market value of all issued Bitcoins in 2011 and 2012. The project started to pick up volume first in 2011, the market capitalization of Bitcoins issued has been in tens to hundreds of million USD since. These figures are small compared to national currencies.

\[\text{Figure 1: Market capitalization of Bitcoin supply}\]

\[\begin{array}{c}
\text{Source: Blockchain [39], author's processing}\\
\end{array}\]

\(^8\) See [15] for an extensive list of Bitcoin shops and purchasable goods.
6.2 Bitcoin mechanism

Bitcoins are units of the currency, they are stored in digital „wallets”. Digital wallet is software, which allows the user to store or send Bitcoins to other digital wallets. Every time a transaction is requested by some wallet (node in the technical terminology), it is submitted to all computers connected to the network and confirmed. Record of the transaction is then joined to the end of data chain which tracks all past transactions and prevents double spending. All computers connected to this network contribute to processing of transactions and building the chain. So the whole system is decentralized, as long as the network is not dominated by one entity with sufficiently strong computational performance to outcompete others and create alternative record of activity. This is theoretically possible, but unlikely as long as many computers are connected.9

As transactions are confirmed and pieces of the chain are computed by participating computers, the one which solves it fastest and correct will be rewarded by some small amount of Bitcoins. This is how the currency is emitted. The process is called mining. Reward for miners is a built-in seignorage. The purpose of this seignorage is to motivate people to dedicate computational performance to the network. The frequency of releasing new Bitcoins is programmed to be geometrically declining until 21 million Bitcoins are in circulation in 2140 (there were about 11 million Bitcoins in Q1 2013).10

We will not go into more technical details since this paper is about economics. For those interested in technical details, please see the original paper [14] or [17] and [18].

6.3 Historical development of Bitcoin

Bitcoin started as a currency with no explicit use in 2009. The first two years there were only hundreds of wallets (and their owners) actively using Bitcoin. In 2011 Bitcoin attracted media attention [19] and numbers of transactions started to grow. So did the acceptability by online shops (vendors) and price (exchange rate) of Bitcoins. Every new Bitcoin user had to buy Bitcoins from the currency owners, so the Bitcoin exchange rate development gives a picture of the currency.

9 The current distribution of computational performance can be found at [16].

10 One Bitcoin is devisible up to 8 decimal places, so the maximal number of units will be $21 \times 10^{14}$. 
The price of Bitcoin is determined by supply and demand on digital currency exchanges. There are no reliable financial derivatives involving Bitcoin so there is only spot price and no shorting (speculation on depreciation).  

**Figure 2 : BTC/USD exchange rate**

![BTC/USD exchange rate chart](image)

Source : Bitcoincharts [21]

As we can see in Figure 2, Bitcoin exchange rate has been very volatile so far. The currency has existed since 2009, but was used only by a group of enthusiasts. In May 2011 the price of Bitcoins shot up from a few cents to 30 USD within months. This boom ended in June 2011 after successful theft of large number of Bitcoins from one Bitcoin exchange, which questioned Bitcoin’s safety. In November 2011 price of Bitcoin touched bottom at 2.1 USD/Bitcoin. In 2012 the Bitcoin price and trade volume have been steadily rising. In 2013 Bitcoin exchange rate accelerated again, by then Bitcoin was recognized as volatile but appreciating currency by broader internet community.

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11 Strictly speaking, this is not true. There are private attempts to create financial markets instruments. But the liquidity of these is shallow, regulation and enforcibility of contract none.
6.4 Motivation to study Bitcoin

Bitcoin is the most interesting digital currency project of the past years. Economic theory is skeptical about fiat currency appearing out of the blue, but Bitcoin has been thriving since its introduction. Since all the transaction data is public we can collect and analyze it and with the help of economic theory determine which factors shaped the currency (and may possibly shape other similar digital currencies).

Some economic questions we will ask:

- What are the motives of Bitcoin users?
- What is the motivation of Bitcoin miners?
- How does Bitcoin spread, who accepts it, what is its main use?
- What goods or services can be bought with Bitcoins?
- How does exchange rate (value) against national currencies develop?
- Can we derive any economic data from monetary transaction statistics?

6.5 Bitcoin data

Bitcoin data is very specific. It is technical, rather economic. It has to be combined from multiple sources and it is very heteroscedastic. Therefore, using and interpreting the data is a tricky task, as many things are counterintuitive or contingent to the purpose with which one uses the data.

Out of the few academic papers dealing with Bitcoin (for example [22]), most suffer from wrong assumptions during data collection, which then sometimes yields extreme interpretation results. The tricky thing is that some assumptions are necessary to be able to aggregate and use the data at all. It is not unlikely that this paper suffers from such errors as well. We hope this thesis will help future researchers avoid our mistakes, when dealing with Bitcoin data.

In this chapter we describe specific issues of our datasets, which we later use to test hypotheses.
6.5.1 Data sources

Basically two separate sources of data about Bitcoin are available

1. Transaction data from within Bitcoin network

2. Trade data from Bitcoin exchanges

These two sources are theoretically independent. Trade data is pretty straightforward – there are *prices* and *trade volumes*. Transaction data is much more complex. We know how many Bitcoins were transferred between two wallets at a time, whether a fee was paid and how long it took before the transaction was verified. Bitcoin network also provides interesting aggregate data: *number of transactions* over time, *number of active accounts*, *transaction volume*, *hash rate* (computational performance of the whole network), *total fees paid* and mining data. In combination with trade data we can get market capitalization or ratio of transactions to trade.

Additional data is harvested by third party websites running Bitcoin wallets. Then there are specialized websites, which for example track unique IP addresses connected to Bitcoin and plot them on world map.

6.5.2 Data in time

While transaction data is available since the start of Bitcoin (3.1.2009), trading on exchanges began later, in summer 2010. During the first months, Bitcoin had very few users and the data had a random character. In 2011 Bitcoin volumes briefly skyrocketed, but after large Bitcoin theft, volumes were falling for the rest of year. Though there is pattern of more stable data in late 2011, there was still relatively high volatility. Starting in 2012 most observed variables were relatively stable. In early 2013 several Bitcoin characteristics followed exponential growth trend, due to technological changes in Bitcoin mining and speculation about financial possibilities of Bitcoin.
So when working with the time series, we sometimes split the sample (especially when it concerns trading data), because different samples display different levels of volatility.

### 6.5.3 Trade data

About 75% of Bitcoins are purchased for USD [20], also majority of shops accepting Bitcoin operate on US market [15]. We will simplify our calculations by using US price level and USD/BTC exchange rate.

For Bitcoin exchange rate we use data from the largest Bitcoin exchange, Mt.Gox\(^\text{12}\), which has about 75% market share and has been the biggest exchange from start. We will therefore use trade data from this exchange [38] as a representative of the whole market. The exchange rate is quoted in USD per 1 BTC. The exchange rate is often referred to as ”Bitcoin price”, not to be confused with “Bitcoin price level” used later parts of this thesis.

\(^{12}\) See [21] for list of all exchanges and volumes.
Trade volume data can be measured in BTC, but since Bitcoin users think in USD terms, rather than BTC terms and convert most prices of goods and services according to exchange rate, it often makes more sense to use trade volume in USD.

Bitcoin exchanges are open 24/7, so unlike other exchanges, trades occur continuously during the whole year. The exceptions are technical issues of the exchanges which so far have been in single digits.

6.5.4 Transaction data

This data is available either directly through the Bitcoin client or collected by many Bitcoin webs usually in combination with trade data. We use aggregate transaction data from [39].

There is one problem with reliability of transaction data - transfers. One person can own any number of Bitcoin wallets and this ownership is difficult to trace. Therefore anyone can launder money through a series of their owned accounts. Nonetheless, all transfers within the system are permanently stored in the data chain and all Bitcoins have unique identification, which can be tracked. Bitcoin thus offers pseudo-anonymity where everyone knows which money is moving through which accounts, but nobody knows who owns these accounts. The implication for transaction data aggregates is that it is biased upwards. There is no easy way to filter transfers out. In order to be able to work with the data, we have to make an assumption.

**Assumption 6.1 (Transfer proportionality in time)**: Ratio of transfers to real transactions is stable in time.

This assumption allows us to work freely with logarithms of transaction volume and number of transactions, because relative changes should be unbiased.

6.5.5 Seasonality

Since there is no serious accounting in Bitcoin, nor yearly state budget, the only reason to make yearly/quarterly/monthly Bitcoin data is comparability with national accounts. For example, there is little difference if we take data for say 1/1/2010-31/12/2010 or for 2/1/2010-30/12/2010, other than the 2 days. In national accounts there would effects of companies reporting earnings and taxes, governments passing budgets etc. Bitcoin data is evenly distributed in this respect.
6.5.6 Data biases and log form

We already mentioned the transfer issue. There are more technical issues that make Bitcoin data less reliable. This is especially true of transaction volume.

Technically everything is recorded as transaction. For example when I have 1 BTC and want to pay 0.9 BTC, Bitcoin network will send the whole 1 BTC and then send 0.1 BTC back as change. In this respect Bitcoin is like cash money. There are algorithms which separate change from the real transactions (into so called estimated transaction volume – etv, which we always use in this paper). To make it more complicated, some Bitcoin transactions occur within Bitcoin dark pools and are not recorded accurately. This biases the transaction volume downwards.

Another source of biases are duplicities which may arise for example when manipulating Bitcoins between wallets by wallet providers. Some transactions are bundled by companies who offer financial services to vendors which again messes transaction record.

In aggregate growth figures, the biases should be tolerable. Estimated transaction volume is a figure we use several times as a measure of nominal output within the Bitcoin system.

Overall there are many sources of biases, mostly upward, that make the absolute values of Bitcoin data inaccurate over small time frames. However the biases are often proportional and the relative values and changes of data series thus retain the information. Therefore in this paper we always work with series in logarithmic transformation (relative changes).

6.5.7 Estimation methods

As we explained in this chapter, the data is difficult to work with. Often the data cannot be interpreted as straightforwardly as other economic data. Therefore we decided to use the simplest possible methods to process the data, which are the most sensitive and accurate, but the easiest to interpret. Since the core data is transaction based, simple histogram is a good tool to support some arguments. For identifying significant correlations we use OLS with robust standard errors on logarithmic or log-differentiated data. The biggest problem we encountered was the correlation of many Bitcoin variables, which does not allow us to insert more than 2-3 uncorrelated variables into one equation.

Should Bitcoin data be used for economic research, it would deserve a thorough investigation by statisticians with technical background and setting general recommendations how to use it. This task is however beyond the scope of this thesis and beyond skill level of its author.
6.6 Bitcoin intrinsic value

According to Menger [10], goods valuable by themselves have better chance of becoming accepted currency. In this chapter we discuss the costs of producing Bitcoins and how it connects with the value of Bitcoins.

Since computational performance is needed to create and operate Bitcoin, it might seem that Bitcoin is backed by the performance. But since the performance is consumed and cannot be redeemed it is not comparable to, for example, commodity backing.

Mining costs and Bitcoin price

Bitcoins are released into circulation as a reward for finding the appropriate blocks of data that are then connected to the end of the whole record of transactions (block chain). The chance that a computer will receive the reward is proportional to the share of the whole computational performance (so for a single computer these are very low and it would take a long time to receive any reward). In practice Bitcoin miners join mining pools, where they share coins mined by the whole pool, so the individual revenue is more predictable. Some people made a business mining Bitcoins by purchasing high-performance GPUs or ASICs and running a so called "rig". Running such rig has its costs, fixed costs – purchasing the hardware, variable costs – electricity, internet connection and maintenance.

Second source of miner income are the fees that users offer to speed up processing of their transactions. This does not release new Bitcoins. Over time the number of new released Bitcoins is declining, while the total volume of transaction fees should grow. The miner profits will be moving towards larger share of fees.

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13 Graphics processing units(GPUs) were largely replaced by Application Specific Integrated Circuits(ASICs) in 2013.
We can see from Figures 4 and 5 that most income comes still from new coins, so the mining profit depends mostly on Bitcoin price. With low Bitcoin price, mining will no longer be profitable and miners will stop their rigs. We will test the relationship of Bitcoin mining and Bitcoin price on data.

**Hypothesis**

Bitcoin mining activity responds to Bitcoin price and electricity costs.
Figure 6: Hash rate and electricity

Source: Blockchain [39], US energy administration [40], author’s processing

Figure 7: Hash rate and BTC price

Source: Blockchain [39], author’s processing
Figures 6 and 7 suggest correlation between hash rate and BTC price and electricity price. We will approximate the mining activity with total performance of the network (hash rate) and run a regression explaining the average monthly hash rate with US residential electricity price and Bitcoin price (exchange rate).

**Data**

Data for 9/2010-12/2012 was used. One-month lag is included in explanatory variables because miners can respond only with some delay.14

**Model**

\[
\log(\text{monthly average hash rate}_t) = \alpha + \beta_1 \log(\text{average BTC price}_{t-1}) + \beta_2 \log(\text{electricity price}_{t-1}) + \epsilon_t
\]

**Results**

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Const</td>
<td>12.3295</td>
<td>5.98544</td>
<td>2.0599</td>
<td>0.04996 **</td>
</tr>
<tr>
<td>(l_{\text{avg_BTC_p_1}})</td>
<td>1.32211</td>
<td>0.0546591</td>
<td>24.1883</td>
<td>&lt;0.00001 ***</td>
</tr>
<tr>
<td>(l_{\text{residenti_1}})</td>
<td>-2.24678</td>
<td>2.43793</td>
<td>-0.9216</td>
<td>0.36555</td>
</tr>
</tbody>
</table>

R-squared 0.961312

Adjusted R-squared 0.958217

Bitcoin exchange rate is very strong in explaining the computational capacity (mining). Just exchange rate alone explains about 95% of variance. Miners perfectly expand their rigs and more miners join the network, if they expect profitable mining. Electricity price was insignificant, but this may be because the electricity prices for miners are different from the US aggregate index.

Bitcoin mining is a topic for itself and beyond the scope of this thesis. We only demonstrated the strong adaptability of Bitcoin environment to exchange rate. This finding supports our Assumption 5.1 of Law of one price in Chapter 5.3.

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14 A version without lag provides very similar results.
7 Bitcoin user motives

We are now getting to the topic of this thesis, which are motives with which people purchase, hold and use Bitcoin. In this chapter we go through transaction and store of value motives and then ponder on speculation. We will try to establish whether Bitcoin demand is motivated by real transaction purposes or not. We will use trade and transaction data, which is the only available Bitcoin statistic, unlike for national currencies. Towards the end of the chapter we test two related hypothesis connected to speculation and discuss connection to acceptability.

7.1 Motivation

Most Bitcoin transactions are tiny fractions of one Bitcoin to a few Bitcoins large. In histogram of transaction size in Figure 8, we see vast majority of transactions within Bitcoin network were between 0.001 and 50 BTC, only a small share of transactions was larger in 2012.

Figure 8: Histogram: Number of transactions by wallet

Source: Dorit and Shamir [22], author’s processing
Although we do not have any direct data about where this money is going, we can reasonably assume most are purchases of goods and services, since their dollar value is rather small.\textsuperscript{15}

**Figure 9 : Average transaction size (USD)**

However the average transaction size is way higher, in ten-hundreds of USD. This is caused by occasional transactions valued in thousands of USD. These are hardly purchases of goods, since goods of such value are rarely even sold for Bitcoin. Some share of Bitcoin transactions is for other purposes than small trade. As we will argue in this chapter, some of the largest transactions may be connected with speculation, illegal activities or capital flight.

### 7.2 Bitcoin as a medium of exchange (transaction motive)

If people use Bitcoins for buying goods, there must be some benefit in using Bitcoin over other currencies. For Bitcoin the most obvious are :

- Lower transaction costs
- Tax reasons
- Anonymity
- Specific goods only traded for Bitcoins

\textsuperscript{15} In 2012 Bitcoin price was between 5 and 10 USD.
7.2.1 Transaction costs

Bitcoin has its own payment system, performance of which depends on computational performance in the whole network (number of computers running Bitcoin client). Placing a transaction order in the network is free. Every transaction must be validated and confirmed by the network. This takes some time.

Users may offer a small sum to the network to speed up the confirmation time. The network will prioritize transactions with fee and the transaction should be confirmed faster. People usually offer fee for smaller denominated transactions (see Figure 20 in Appendix). Most likely explanation it that smaller transactions are purchases of goods in stores, where prompt execution is required by the buyer, while larger ones are transfers where a few minutes are not so important.

Bitcoin is in general competitive in transaction fees compared to national currency payment systems.16

**Figure 10 : Average transaction fee**

![Average transaction fee](image)

Source : Blockchain [39], author's processing

16 The transaction fees for card payments vary greatly, depending account type, providing institution, currency, size of transaction and local regulation, but they averaged around 3% in the USA and 0.6% in Europe in 2012. The average fee for Paypal is about 3%. To that we have to add currency conversions, usually a few more %.

17 Transaction fee is measured as miners revenue from fee/total transaction volume.
As we can in Figure 10, the average transactions fee has gradually declined to 1-2% in 2013, which low compared to commercial alternatives. See [3, p.2] for general list of competitive advantages of digital currencies with references.

7.2.2 Taxes

With digital currencies it is often hard to track what goods are purchased and who bought/sold them, because transactions are recorded in payment system separate from national currencies. In this environment tax authorities have poor tools to monitor tax payments. Many goods are thus sold without tax (mostly small goods, i.e. not large business transactions). This makes some small transactions between individuals much cheaper. Obviously such activity is illegal and bears some risk. This risk is more acceptable if the transaction cannot be easily tracked to people conducting the trade.

7.2.3 Anonymity

As we mentioned earlier, all transactions are permanently recorded. While everyone can theoretically follow all Bitcoin transactions, it would require more effort to track down the people behind the accounts. Reid and Harrigan [23] performed a detailed analysis of Bitcoin anonymity with following conclusions:

“Using an appropriate network representation, it is possible to associate many public-keys with each other, and with external identifying information. With appropriate tools, the activity of known users can be observed in detail. This can be performed using a passive analysis only. Active analyses, where an interested party can potentially deploy 'marked' Bitcoins and collaborate with other users can discover even more information. We also believe that large centralized services such as the exchanges and wallet services are capable of identifying and tracking considerable portions of user activity.”

Digital currency exchanges are the place where anonymity of some digital currencies ceases to exist, because the untraceable account in some DC is connected to some other account during the conversion and DCEs validate the identity of their customers. So if anyone really wanted to decipher the identity of, say Bitcoin users, they could do so with data from DCEs.

Bitcoins are dominantly traded on Mt.Gox DCE. In the past the site has been target of hacker attacks and during the first major attack in June 2011 it resulted in theft of large number of Bitcoins from clients‘ accounts. This incident deprived Bitcoin demand for several following months. Another incident in April 2013 initiated burst of price bubble. This demonstrates the
weaknesses of the currency. Although it is in theory self-sustaining and independent on outside world, in reality exchange rates are influenced by one dominant exchange and if one wants to trade Bitcoins through the exchange, the anonymity is gone.

So using Bitcoin probably would not help large criminal activities escape directed law enforcement efforts. Nonetheless, a cautious user can still achieve higher level of anonymity than with other currencies. For this reason Bitcoin is a currency of choice for small illicit trade and people not willing to share their personal data in each online transaction.

7.2.4 Unique Bitcoin goods

Demand for good only offered for Bitcoin has to go through Bitcoin, that is simple. But since we have no data about any specific goods purchased uniquely with Bitcoins we do not know how important this factor is, if at all.

Case: Silk Road

In February 2011 a digital black marketplace called Silk Road appeared. Silk Road can only be accessed via Tor network (it mixes all data traffic of computers using Tor, making individual computer untraceable). The only method of payment accepted on Silk Road is Bitcoin. This high level of anonymity is required because Silk Road offers prescribed pharmaceuticals, illegal substances, forged documents and gun parts, among others. A few months after the launch of Silk Road one article [19] brought it to public attention, suddenly Bitcoin transactions and price started rising. We have no proof that this volume was driven by narcotics, but the time concurrence is remarkable. Silk Road is probably the only “e-store” where anyone can get drugs. This creates a unique demand for Bitcoin. A paper analyzing Silk Road in 2012 [24] estimated the share of Silk Road transactions to all Bitcoin transactions at 4.5%-9% at the time.

The connection to large scale drug trade also spurred both law enforcement and enthusiasts to find and track large Bitcoin holdings. As leaked FBI report suggests [25], investigators were rather unsuccessful in tracking Bitcoins to criminals and even less sure about what to do with Bitcoin network, which is a nightmare for any intelligence agency. Some enthusiasts were more successful at finding large amounts of Bitcoin, but these coins soon flew to other accounts without any hint who owned them.

7.2.5 Digital currencies from the merchant perspective

How did acceptability of Bitcoin develop? The vital thing for a new digital currency today is whether merchants accept it. Digital currencies are somewhat closer to shopping in online stores or buying digital items, than in physical stores. Today, many retail items and services (books, clothing, electronics, games, music, software, digital items, financial services, travelling, food,
petrol) can be purchased with Bitcoins. But stores accepting Bitcoins are mostly small, so Bitcoins are used in small volume relative to national currencies.

We already mentioned some potential benefit from using Bitcoins, now let us list some drawbacks from the perspective of retailer:

- Their costs are in other currencies and they cannot hedge themselves against exchange rate risk
- Bitcoin exchange rate is too volatile, prices have to be constantly adjusted
- Alternative currencies including Bitcoin have no legal status, which makes it difficult to get Bitcoins into their accounting. For large stores, where Bitcoin sales would make only negligible part, accepting Bitcoin may bring more administrative costs than profit. Also, Bitcoin transfers are irreversible, which is against the policies of many stores.

One of most obvious drawbacks of Bitcoins (and other free floating currency projects) is volatility of purchasing power of the coin and volatility of nominal exchange rate. Digital currencies are relatively small and a few million dollars, which is nothing in normal forex market, may greatly impact the exchange rates of free floating digital currencies. In case of Bitcoin there is not even a central authority which could manage the currency supply and defend the currency stability. Any threat of legal intervention, security breach on large Bitcoin exchange or jump in acceptability of Bitcoin will bestir Bitcoin, because all value stands on current expectations.

### 7.3 Bitcoin as store of value

The use of Bitcoin as a store of value is rather theoretical. Though Bitcoin allows value to be transferred in time, it is too unstable and unpredictable compared to national currencies. In addition to that, Bitcoin holdings will not generate any interest. We can say that under normal conditions Bitcoin is an inferior store of value. However in absence of better alternatives, over the medium term Bitcoin does offer the basic feature required from a store of value –

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18 See [15] for a complete list.

19 Notably Ebay, which would otherwise make a big market for Bitcoin.
redeemability at a future date. The value at a future date, however is much less predictable then a store of value would require.

The special status of Bitcoin – legally it is not currency, but in many aspects it can be used as a currency, makes Bitcoin an option to transfer money cross-border, despite legal barriers. Normal capital controls do not apply to Bitcoin, since it has its own transfer system. Bitcoin thus may serve as vehicle through which money escapes capital controls. Bitcoin is too small to facilitate transfer of large sums, but it can easily transfer individual’s wealth up to millions of USD.

This property has been possibly used in at least two cases:

**Case : The Euro-crisis**

On March 24 2013, Cyprus imposed restrictions on how much money can people withdraw from banks or take outside the country and all transactions above 25 thousand Euro were subject to central bank’s approval. Around the time Bitcoin was very strongly appreciating, Bitcoin community speculated about connection between Bitcoin-EUR exchange rate and capital controls in Cyprus. [26] Though if there was a connection it could be people from other Euro-paying countries (Spain, Italy) buying Bitcoins in fear of capital controls in their countries. Either way, there is no data to confirm this connection.

**Case : Argentina**

The official running annual inflation rate in March 2013 in Argentina was 10.6%, unofficial estimates were more than double. Argentina has been scrutinized by IMF for inaccuracy of its economic reporting. Argentinian citizens were concerned for the value of their savings. The convertibility of peso into other currencies has been limited since Argentinian crisis in 1990s. Argentina has been setting barriers to capital outflow and currency convertibility in 2013. On the black market the value of peso was much lower than the official exchange rate. At the same time one Bitcoin exchange reported trade volumes in Argentina more than doubling. [27] There are also large retailers accepting Bitcoins in Argentina. It is possible that under high inflation and capital controls, Bitcoin is viewed as a safer alternative store of value. Also, with capital controls it is easier to purchase Bitcoin for domestic peso and then sell Bitcoin for USD elsewhere. Similarly to previous case, we cannot prove any direct causality, but the coincidence is remarkable.
7.4 Bitcoin financial services

There are websites offering various financial services in Bitcoin, from simple wallets across loans, payment systems for vendors to options, futures and hedge funds. The reasons have not been considering these too seriously so far were very low volumes and no regulation. At the time being the volume traded of Bitcoin financial instruments is so low that it is illiquid. Also the analytical infrastructure common for national currencies financial markets is missing. Though this may change in the near future, news about companies that applied for banking license in Bitcoin business [28] or that are planning to start trading Bitcoins on Wall Street [29] are appearing with increasing pace.

What will not change so easily is the legal status of Bitcoin agreements. Since Bitcoin is not considered a currency in most countries, most financial legislation is not applicable. Giving a loan to someone in Bitcoin is thus a very risky business. Bitcoin can be legally sanctioned as goods which makes basis for some legal arrangements, but it lacks the easy enforceability of standardized financial contracts. What direction will the forming legislation considering digital currencies take may largely determine future of DCs.

7.5 Bitcoin speculation

Speculation is the selling (or buying) of merchandise with a view to rebuy (or resell) at a later data, where the motive of such an action is the anticipation of a change of current price and not an advantage resulting from their use or their transformation or transfer from one market to another.

-Nicholas Kaldor [30]

We believe that significant share of Bitcoins was purchased with the intention of holding appretiating asset, not using it as a medium of exchange. This is signaled by the volume of Bitcoins just lying in wallets and not being used [21] for transactions. The fluctuations of Bitcoin

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20 For a detailed list of financial products and services sold in Bitcoin see [15].

21 [22] estimated this to be as high as ¾ of whole Bitcoin supply.
exchange rate cannot be explained by changes in transaction motive alone. Some share of Bitcoin demand is not driven by transaction or store of value motive, but some other motives, which we will call speculative.

How can we measure the level of speculation with Bitcoin? The situation is easier than with national currencies because people can only speculate on appreciation. Therefore strong appreciation with high trade volumes should indicate speculative demand. We support this intuition by data.

7.5.1 Volume effect on price

We will test whether trade volume (forex) is influenced by number of transactions within Bitcoin network and by number users, proxied by number of active accounts.

**Hypothesis**

Trade volume is not correlated with number of transactions. Trade volume is not correlated with number of users.

**Reasoning and evidence**

Only small goods and services are traded for Bitcoin so non-speculative demand does not cause rapid appreciation and higher trade volume.

Data from exchanges support this. Small Bitcoin purchases (smaller than 10000 USD) account for more than 97% of trades. But these 97% of transactions account for only 38% of total trade volume. Figure 11 illustrates this. Transactions are relatively evenly distributed, with median just below 100 USD. Trade volumes have median around 10000 USD. While most transactions are below 100 USD, most trade volume is created by transactions around 10000 USD large. Over time the two have been diverging further apart (see Appendix Figures 24-27).

Large transactions always create larger share of total volume, but this disparity between number of transactions and their volume is so big, that the likely explanation are different motives behind number of transactions (most people purchase Bitcoins as medium of exchange) and trade volume (most capital is speculative).

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22 In this paragraph we use the term transaction in reference to purely trade transactions, not to be confused with transaction vs. trade distinction throughout the rest of the paper.
Figure 11: Distribution of number of trade orders and volume by transaction size

We will also test this on trade-transaction data.

Model

We regress logarithmic differences (relative returns) of USD trade volume on number of transactions and number of active accounts\(^{23}\) within Bitcoin network. The growth of number of active accounts is also a proxy for growth of number of users.

\[
d_{\log}(\text{USD trade volume}_t) = \alpha + \beta_1 d_{\log}(\text{no. of transactions}_t) + \beta_2 d_{\log}(\text{no. of active accounts}_t) + \epsilon_t
\]

Data

Trading data is available since 8/2010, so we use whole currently available dataset: 8/2010-3/2013.

Results

Model 2

\(^{23}\) Account=Address=Wallet
Growth of transactions does not significantly contribute to growth of trade volume. As expected, most trade volume has little to do with transactions. However, growth of active accounts significantly contributes to trade volume. Testing for linear restriction could not reject the coefficient for growth of number of addresses (and users) equal to one. That could mean that trade volume grows proportionally with number of users.

So trade volume increases with number of users, but not with number of transactions. However the coefficient of determination is very low, so the variation in trade volume is largely unexplained.

Let us conclude by stating that Bitcoin trade and hence exchange rate is driven mostly by demand not destined for transactions. It remains to prove whether high trade volume associates with appreciation (as we expect) or depreciation (as it is sometimes modeled for stock\textsuperscript{24}).

**Hypothesis**

Bitcoin appreciates on unusual trade volume.

**Model**

Again, logarithmic differences will be used in this model. Using trade volume in USD seems more suitable than in BTC, since Bitcoin demand “thinks” in USD terms, rather than BTC terms.

---

\textsuperscript{24} For example [31] or [32]. While there is prevalent evidence about notable price changes happening on large trade volumes in stock markets, there is no consensus about the direction of the change.
If we used BTC trade volume, it would be directly influenced by price (endogeneity), because dollar demand is converted into Bitcoin trade volume through Bitcoin price.

As a control variable we add estimated transaction volume-etv a measure of Bitcoin nominal output.

\[ d_{log}(BTC \ price_t) = \alpha + \beta_1 d_{log}(estimated \ transaction \ volume_t) + \beta_2 d_{log}(USD \ trade \ volume_t) + \epsilon_t \]

**Data**

Trading data is available since 8/2010, but the first year-and-half of trading is very volatile, with lower trade volumes. Therefore, in addition to the whole period regression, we also perform the regression on two spit samples: 8/2010-12/2011 and 1/2012-3/2013. This split is based on volatility of price and level of trade volume, both have settled after 2011 (though rising again in March 2013). See Figure 12.

**Figure 12: Bitcoin price percentage return**

Source: Mt.Gox [38], author’s processing
Results

Model 3: Whole dataset

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>const</td>
<td>0.00709992</td>
<td>0.00261692</td>
<td>2.7131</td>
<td>0.00679 ***</td>
</tr>
<tr>
<td>d_l_etv</td>
<td>-0.000330382</td>
<td>0.00515466</td>
<td>-0.0641</td>
<td>0.94891</td>
</tr>
<tr>
<td>d_l_USD_trade</td>
<td>0.036211</td>
<td>0.00543243</td>
<td>6.6657</td>
<td>&lt;0.00001 ***</td>
</tr>
</tbody>
</table>

R-squared 0.131226 Adjusted R-squared 0.129397

Model 4: Data for 8/2010-12/2011

<table>
<thead>
<tr>
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<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
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<td>const</td>
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<td>0.10193</td>
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<tr>
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<td>0.00263144</td>
<td>0.00608929</td>
<td>0.0432</td>
<td>0.96555</td>
</tr>
<tr>
<td>d_l_USD_trade</td>
<td>0.0423682</td>
<td>0.00726459</td>
<td>5.8321</td>
<td>&lt;0.00001 ***</td>
</tr>
</tbody>
</table>

R-squared 0.143798 Adjusted R-squared 0.140359

Model 5: Data for 1/2012-3/2013

<table>
<thead>
<tr>
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<th>Coefficient</th>
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<th>p-value</th>
</tr>
</thead>
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</tr>
<tr>
<td>d_l_USD_trade</td>
<td>0.0185927</td>
<td>0.00303305</td>
<td>6.1300</td>
<td>&lt;0.00001 ***</td>
</tr>
</tbody>
</table>

R-squared 0.122207 Adjusted R-squared 0.118289

In all three cases growth of trade volume had a significant positive impact on growth of BTC price. In the second period, the coefficient value got smaller (0.0185) compared to 0.0424 in the early period. Our hypothesis of stronger Bitcoin appreciation with higher trade volume is confirmed. Though, the coefficient of determination is not too high for a strong conclusion.
7.5.2 Transaction vs. trade ratio

One measure of Bitcoin speculation could be the ratio of Bitcoin transaction volume within the network to Bitcoins traded on exchanges for other currencies. When the ratio is low, Bitcoin forex trade is relatively high compared to transactions and vice versa. The absolute value of transaction vs. trade ratio is not entirely reliable measure of speculative purchases, because many shops convert received Bitcoins instantly into national currency, so this ratio is affected on both sides, instead of only on transaction side.

This ratio is sometimes cited as an index of speculation with Bitcoin. There is good intuition behind this use. Since, as we found out trade volume is not explained by transaction motives, it is likely heavily influenced by large-scale speculation. Transactions within Bitcoin network are relatively small (Figure 9), compared to external trade volumes (Appendix Figure 22). Though, the absolute value of the ratio has limited interpretation. Nonetheless, deviations of the ratio in time may signal relative increase or decrease in speculative demand. The long term development of this ratio will tell us whether Bitcoins are increasingly circulating within the network (transaction motive) or just on the exchanges(speculation).
In Figure 13 we see the ratio and logarithmic changes in Bitcoin price almost mirroring each other. Decline in the ratio accompanied relative growth of Bitcoin price. This again is consistent with the initial statement that in case of new currency and in absence of short financial instruments, all speculative attention leads to appreciation. Still, the series is too short to make long-term conclusions about the stability of the ratio.

1.1.1.1 Transaction or trade domination

On average the ratio has not been as volatile as it theoretically could be, if transactions and trade were independent, determined by different motives. Their relative changes are somehow moderated, so the ratio does not shoot from zero to infinity. One of the two motives adjusts to the other or both mutually adjust to each other. But what is the causality? The logic that we follow in price level determination – that all is exogenous – would make us lean toward trade domination and transaction volume adjusting to it. On the other hand it sounds weird that real transactions adjust to forex trade. Most likely is a combination of both in some proportion.
7.5.3 General acceptability

Increase in trade volume increases the price, market capitalization and forex liquidity of Bitcoin in turn attract attention of media and vendors, who may consider accepting Bitcoins. Increase in transaction volume attracts more users and vendors through the acceptability of Bitcoin – the possibility to sell it for goods and services. An increase in either trade or transaction volume thus contributes to acceptability of Bitcoin.

Even better, there are cross effects between trade and transaction volume. Speculators (demonstrated in trade volume) appreciate higher transaction volume, because the medium of exchange use of currency gives them more certainty, that their investment will not vanish overnight. Common users appreciate the improved liquidity and acceptability that speculative capital brings. There is only one problem – Bitcoin price and price level is set by speculators, but common users have to bear it. Regardless, Bitcoin user will accept this arrangement, as long as their Bitcoin holdings are appreciating, which has been on average true so far.
8 Bitcoin from the perspective of quantity theory of money

In this chapter we are going to estimate index of real output in the Bitcoin ‘economy’ and use it to test hypotheses about size of transactions and network effects.

We will use two theoretical concepts, the quantity theory of money and purchasing power parity and an assumption about Bitcoin price level determination.

First we explain the theoretical background and necessary assumptions. While using the QTM, we calculate Bitcoin money velocity. Since Bitcoin data is all about transactions, we can calculate velocity directly from transaction data and it might be another useful tool for understanding digital currency like Bitcoin. Then we estimate the real transactions index. We will regress it on number of active accounts and number of transactions. This should tell us more about motives with which new accounts appear.

8.1 Quantity equation

While sophisticated monetary theory of the 20th century meets obstacles when it should be applied to digital currencies, the simple concepts are valid. In a monetary setting that is driven by simple algorithms and monetary parameters are determined by technology, we can use the quantity theory of money.

For our application the best suited is the old Fisher version [33], which uses transaction volume. In newer versions transaction volume was replaced by more easily measurable output, but in our case the opposite is true, transactions are easier to follow. So we have the following form:

\[ M \times V = P \times T \]

Now we will explain how do known variables from Bitcoin data fit into this equation.

---

25Bitcoin is used to buy goods and services created in national economies. So technically it does not have any separate ‘economy’. We use the term in reference to Bitcoin nominal output (transaction volume).
Money supply \((M)\) – is coded in the currency, money supply grows at a predetermined exponentially decreasing rate.

Transaction volume or nominal output \((P*T)\) – is a more problematic measure. Since one person can own multiple Bitcoin accounts and we only have data for transfers between accounts, it is possible that one person is just laundering money between accounts and no real trade occurs. The crude transaction volume is biased. In response to this a metric called "Bitcoin-days destroyed" was created. This metric counts the number of days a Bitcoin was unused. When coins are transferred, the number of coins times number of days unused gives a measure of transaction volume. This metric is more accurate from technical point of view, but it does not make economic sense. Hence, we will use the simple transaction volume, as it is still a better alternative.

![Figure 14: Transaction volume (BTC)](image)

Source: Blockchain [39], author’s processing

Transaction volume data (known variable), is our measure of nominal output, equal to \(M \times V\). We will denote it \(X\).

\[
M \times V = X = P \times T
\]

Number of transactions \((T)\) – this figure is easily available.
Figure 15: Number of transactions

Source: Blockchain [39], author’s processing

Velocity

We obtain the transaction velocity using formula:

\[ V = \frac{X}{M} \]

For comparison purpose, we calculate quarterly velocity.
In Figure 16 we see the quarterly velocity of Bitcoin slowly rising with one outlier in winter 2011/12 caused by spike in transaction volume. The value around 2 is comparable to money velocity of USD monetary aggregates [34], in 2012 these were: M1 – 6.5, M2 – 1.5.

The series is too short to make any strong conclusions. Still, it is relatively stable compared to all other variables. Velocity plays a very important role in our setting. Since Bitcoin money supply is following a fixed trend, all variation (at a point in time) in the right hand side of the equation is absorbed by velocity, for example:

\[ M_t \times V_t \uparrow = P_t \times T_t \uparrow \]
\[ M_t \times V_t \downarrow = P_t \downarrow \times T_t \]

Over time, growth of transaction volume in excess of Bitcoin supply growth should be reflected by increase of velocity and vice versa:

\[ M \uparrow \times V \uparrow = X \uparrow \uparrow \]

This may be the reason behind growing velocity.
There is also theoretical explanation behind the growth of velocity. If we follow Hicks’ interpretation of Keynes [36], money demand is modeled as real balances, based on interest rate and income:

\[
\frac{M}{P} = L(i, Y)
\]

Now that we have price level \( P \), we can compute index of real money balances.

**Figure 17 : Index of real money balances**

[Graph showing index of real money balances]

Source : Blockchain [39], FRED [35], author’s processing

If we combine real balances with the quantity equation in output form:

\[
M \ast V = P \ast Y
\]

and express velocity, we arrive at:

\[
V = \frac{Y}{L(i, Y)}
\]
In this form, velocity would grow with growth of $Y$ if $\frac{dl}{dy} < 1$, that is if the sensitivity of demand for money to output is less than one. Interest rates are negligible for Bitcoin, as we explained earlier.

### 8.2 Output estimate

We know the nominal output, exchange rate, US price level and price determination mechanism. We can plug the PPP into QMT and get:

$$ M \ast V = ER \ast P^{*} \ast T $$

We already know all the variables besides $T$ so we can express it. We will acquire dollar transaction index in constant prices, we will call it *real transactions index*.

**Figure 18 : Real transactions index, monthly**

Source : Blockchain [39], FRED [35], author’s processing
The relative development of the index over time is more meaningful than the absolute value. This estimate is very crude, the index is overreacting, because of the law of one price assumption. In reality prices of some goods and services likely do not respond to prices in USD, but to other currencies. Some goods adjust their Bitcoin prices with some delay and some goods are not affected by exchange rates at all. Thus, the index is imperfect, but still should capture major changes in flow of real transactions.

Real growth of Bitcoin

We will try to explain growth of real transactions index with growth of number of active Bitcoin accounts, this is an approximation of growth of new users\textsuperscript{26}, and with number of transactions. If the growth of transaction volumes has some real fundament, driven by transaction motive, then real transactions should be explained by number of active accounts and number of transactions.

\textsuperscript{26} One person can control multiple accounts so the approximation is biased upwards.
Models
We will run two regressions separately, because monthly growth of number of transactions and number of addresses are correlated and cannot be both present in one regression due to collinearity issues. We will use variables in logs, as we are interested in relative changes. Linear time trend is included to control its effect.

\[
\log(\text{real transaction index}_t) = \alpha + \beta_1 \log(\text{number of transactions}_t) + \beta_2 t + \varepsilon_t
\]

\[
\log(\text{real transaction index}_t) = \alpha + \beta_1 \log(\text{number of addresses}_t) + \beta_2 t + \varepsilon_t
\]

Data
We will use the whole available dataset, monthly data for 8/2010-3/2013. The index was calculated above.

Results

<table>
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<tr>
<th>Model 6</th>
<th>Coefficient</th>
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<tr>
<td>R-squared</td>
<td>0.835935</td>
<td></td>
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<tr>
<td>Adjusted R-squared</td>
<td></td>
<td></td>
<td></td>
<td>0.824216</td>
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</tbody>
</table>

Restriction : b[L_monthly_no_t] = 1
Test statistic: Robust F(1, 28) = 4.08658, with p-value = 0.0528769

The number of transactions is significant in explaining real transactions. This means nominal number of transactions is closely related to real transactions. Coefficient size was 1.76, which would mean that real size of transactions is getting bigger, if real transactions index responded more than proportionally to growth of number of transactions. However as test of linear restriction revealed, the coefficient is not significantly larger than 1 (at 5% confidence level), though by very small margin. We cannot say that real size of transactions is getting bigger. This may mean that Bitcoin is still used for trading only small goods.
We see that number of active accounts is strongly significant and explains about 92% of variance in the data. Also the size of the coefficient is significantly greater than 1. This result suggests that growth of number of active accounts (a proxy for growth of number of users) contributes more than proportionally to real transactions, 1% increase in number of accounts gives 1.7% increase in real transactions index.

This finding is in accordance with the intuition behind search models (Kyotaki-Wright). Higher number of users in the network increases the chances of finding a suitable counterparty (desired goods) through increase in general acceptability of the currency.

The conclusion from this chapter is that, internally, Bitcoin behaves like a medium of exchange, transaction index can be explained by number of transactions and number of users. This contrasts with external Bitcoin relations (trade) examined in previous Chapter, where we established that Bitcoin trading is influenced mostly by speculation. The speculative and non-speculative motives can coexist in separate circuits, as long as the currency is appreciating and internally flexible.
9 Other coins

The cryptographic method used in Bitcoin is not unique. It can be used to make clones. And since it bears no costs, anyone can make some alternative crypto-coins and indeed dozens have been inspired by Bitcoin (examples: Namecoin, Litecoin, RuCoin, Lifecoin, PPCoin, Terracoin). This has an indirect implication for Bitcoin inflation – Bitcoin supply is limited, but the number of alternative xy-coins is unlimited.

From monetary viewpoint, these alternatives should not compete with the original Bitcoin since they are smaller currencies with the same qualities and less acceptability, but the same argument could be used against Bitcoin vs. national currency in the first place. Nevertheless, the success of Bitcoin started a new class of crypto-currencies and it is very likely that we will be seeing more of them in the future. This might pose a challenge for monetary policy, statistical bureaus, tax authorities and law enforcement, because they have little control over these currencies.
10 Conclusion

This thesis analyzed digital currency Bitcoin. We examined transaction and speculative motives of Bitcoin users and their impact on the emerging digital currency. We reviewed selected theory with the aim to find applicable concepts that would help us understand evolution and exchange rate of Bitcoin. Some of Bitcoin properties can be understood through Menger's concept of acceptability of money and Search models built on this concept.

After introducing Bitcoin and its main features, we estimated hypothesis about Bitcoin speculation affecting trade volumes and exchange rate. We argued that external Bitcoin trading is mostly influenced by speculative motive. Trade volume on average appreciates Bitcoin exchange rate, because Bitcoin only allows speculation on appreciation. However internal Bitcoin transactions are driven mostly by transaction motive and are largely independent on Bitcoin trading. Traders and currency users thus coexist in separate circuits, interacting mostly indirectly through exchange rate and acceptability of Bitcoin.

Assuming law of one price as determinant of prices in Bitcoin economy allows us to compute velocity of money and output index through the quantity theory of money. We argue that velocity is a very useful indicator of trend in real output growth for transaction-based digital currencies. Real output index responds more than proportionally to growth of number of active accounts, in accordance with Search models and network effects. The index also grows with number of transactions, though we could not prove that transactions are getting larger. This finding supports supposition of Bitcoin use as medium of exchange, instead of only as speculative instrument.

While working with Bitcoin data we confronted a number of obstacles, most of which stem from how the currency was programmed. While Bitcoin provides great volumes of unique data, the data is subject to many technical biases and interpretation is often complicated. Still, we believe that Bitcoin is a useful sandbox for monetary economics and has potential for much more future research. We hope this thesis contributed to digital currencies research, which we believe have received less attention than they deserve.
References


[38] Mt.Gox [online]. [accessed 2013-05-12]. Available at: https://mtgox.com/


Appendix A

- Figure 20: Bitcoin transaction confirmation time
- Figures 21-22: Histograms of trade transactions
- Figures 23-26: Time evolution of trade volume distribution
- Figures 27-30: Infographic of Bitcoin price determination
- Models 1-7: Regression results
Bitcoin transaction confirmation time

Sample from 13/3/2013

Source : Bitcoinstats.org
Histogram of trade transactions (Bitcoin purchases)

Source: Mt.Gox [38], author’s processing

**Figure 21: Histogram: Number of trade transactions**

![Histogram of trade transactions](image)

**Figure 22: Histogram: USD trade volumes**

![Histogram of USD trade volumes](image)
Number of trade transactions and their volume by transaction size in time

Source: Mt.Gox [38], author’s processing

Figure 23: Trade volume distribution 2010 H2

Figure 24: Trade volume distribution 2011
Figure 25: Trade volume distribution 2012

Figure 26: Trade volume distribution 2013 Q1
Infographics

Source: author’s creation

Figure 27: Chart: Closed Bitcoin economy

Figure 28: Chart: Bitcoin economy with new users coming
Figure 29: Chart: Bitcoin economy with new goods/shops

Figure 30: Chart: Bitcoin economy with inflow of speculative capital
Regression results

Chapter 6.6.1

**Model 1**: OLS, using observations 2010:09-2012:12 (T = 28)
Dependent variable: l_monthly_avg
Heteroskedasticity-robust standard errors, variant HC0

<table>
<thead>
<tr>
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<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
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<tbody>
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<td>0.36555</td>
</tr>
</tbody>
</table>

Mean dependent var 7.908613  S.D. dependent var 2.457980
Sum squared resid 6.310914  S.E. of regression 0.502431
R-squared 0.961312  Adjusted R-squared 0.958217
F(2, 25) 340.7200  P-value(F) 7.26e-19
Log-likelihood -18.87134  Akaike criterion 43.74269
Schwarz criterion 47.73930  Hannan-Quinn 44.96449
Rho 0.516186  Durbin-Watson 0.945778
Chapter 7.5.1

Model 2: OLS, using observations 2010/08/18-2013/03/31 (T = 953)
Missing or incomplete observations dropped: 4
Dependent variable: d_l_USD_trade
Heteroskedasticity-robust standard errors, variant HC0

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
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Mean dependent var 0.008093  S.D. dependent var 0.868577
Sum squared resid 702.0433  S.E. of regression 0.859647
R-squared 0.022515  Adjusted R-squared 0.020457
F(2, 950) 5.681989  P-value(F) 0.003524
Log-likelihood -1206.621  Akaike criterion 2419.241
Schwarz criterion 2433.820  Hannan-Quinn 2424.795

Restriction:
b[d_l_no_addres] = 1

Test statistic: Robust F(1, 949) = 0.0184167, with p-value = 0.892081

Restricted estimates:

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Standard error of the regression = 0.857514
**Model 3**: OLS, using observations 2010/08/17-2013/03/31 (T = 953)
- Missing or incomplete observations dropped: 5
- Dependent variable: d_l_price
- Heteroskedasticity-robust standard errors, variant HC0

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
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<td>0.00261692</td>
<td>2.7131</td>
<td>0.00679 ***</td>
</tr>
<tr>
<td>d_l_etv</td>
<td>-0.000330382</td>
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<td>-0.0641</td>
<td>0.94891</td>
</tr>
<tr>
<td>d_l_USD_trade</td>
<td>0.036211</td>
<td>0.00543243</td>
<td>6.6657</td>
<td>&lt;0.00001 ***</td>
</tr>
</tbody>
</table>

Mean dependent var: 0.007393  
S.D. dependent var: 0.086718
Sum squared resid: 6.219621  
S.E. of regression: 0.080913
R-squared: 0.131226  
Adjusted R-squared: 0.129397
F(2, 950): 22.27555  
P-value(F): 3.51e-10
Log-likelihood: 1045.455  
Akaike criterion: -2084.910
Schwarz criterion: -2070.331  
Hannan-Quinn: -2079.356
**Model 4**: OLS, using observations 2010/08/18-2011/12/31 (T = 501)
Dependent variable: d_l_price
Heteroskedasticity-robust standard errors, variant HC0

<table>
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<th>p-value</th>
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<td>d_l_etv</td>
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<td>0.0423682</td>
<td>0.00726459</td>
<td>5.8321</td>
</tr>
</tbody>
</table>

Mean dependent var 0.008331 S.D. dependent var 0.114733
Sum squared resid 5.635342 S.E. of regression 0.106376
R-squared 0.143798 Adjusted R-squared 0.140359
F(2, 498) 17.01541 P-value(F) 7.11e-08
Log-likelihood 413.2426 Akaike criterion -820.4852
Schwarz criterion -807.8354 Hannan-Quinn -815.5219
rho -0.138425 Durbin-Watson 2.274919

**Model 5**: OLS, using observations 2012/01/01-2013/03/31 (T = 451)
Missing or incomplete observations dropped: 5
Dependent variable: d_l_price
Heteroskedasticity-robust standard errors, variant HC0

<table>
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<th>Coefficient</th>
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<tr>
<td>const</td>
<td>0.00621846</td>
<td>0.00157434</td>
<td>3.9499</td>
</tr>
<tr>
<td>d_l_etv</td>
<td>0.00255089</td>
<td>0.00475341</td>
<td>0.5366</td>
</tr>
<tr>
<td>d_l_USD_trade</td>
<td>0.0185927</td>
<td>0.00303305</td>
<td>6.1300</td>
</tr>
</tbody>
</table>

Mean dependent var 0.006278 S.D. dependent var 0.035753
Sum squared resid 0.504915 S.E. of regression 0.033571
R-squared 0.122070 Adjusted R-squared 0.118289
F(2, 448) 23.57720 P-value(F) 1.84e-10
Log-likelihood 892.2933 Akaike criterion -1778.587
Schwarz criterion -1766.252 Hannan-Quinn -1773.726
### Chapter 8.2.1

**Model 6:** OLS, using observations 2010:08-2013:02 (T = 31)
Dependent variable: l_real_tra
Heteroskedasticity-robust standard errors, variant HC0

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>const</td>
<td>-9.23785</td>
<td>2.7153</td>
<td>-3.4021</td>
<td>0.00203 ***</td>
</tr>
<tr>
<td>l_monthly_no_t</td>
<td>1.76347</td>
<td>0.37767</td>
<td>4.6693</td>
<td>0.00007 ***</td>
</tr>
<tr>
<td>time</td>
<td>-0.0393192</td>
<td>0.0596557</td>
<td>-0.6591</td>
<td>0.51521</td>
</tr>
</tbody>
</table>

Mean dependent var 10.89371
S.D. dependent var 2.461265
Sum squared resid 29.81631
S.E. of regression 1.031924
R-squared 0.835935
Adjusted R-squared 0.824216
F(2, 28) 83.66483
P-value(F) 1.55e-12
Log-likelihood -43.38365
Akaike criterion 92.76731
Schwarz criterion 97.06927
Hannan-Quinn 94.16964
rho 0.563239
Durbin-Watson 0.745590

Restriction: 
\[ b[l\text{\_monthly\_no\_t}] = 1 \]

Test statistic: Robust F(1, 28) = 4.08658, with p-value = 0.0528769

Restricted estimates:

<table>
<thead>
<tr>
<th></th>
<th>coefficient</th>
<th>std. error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>const</td>
<td>-3.98244</td>
<td>0.786037</td>
<td>-5.066</td>
<td>2.11e-05 ***</td>
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<tr>
<td>l_monthly_no_t</td>
<td>1.00000</td>
<td>0.000000</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>time</td>
<td>0.0765687</td>
<td>0.0217590</td>
<td>3.519</td>
<td>0.0015 ***</td>
</tr>
</tbody>
</table>

Standard error of the regression = 1.08359
**Model 7**: OLS, using observations 2010:08-2013:02 (T = 31)
Dependent variable: \( l_{\text{real-tra}} \)

Heteroskedasticity-robust standard errors, variant HC0

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>const</td>
<td>-4.1312</td>
<td>1.01749</td>
<td>-4.0602</td>
<td>0.00036 ***</td>
</tr>
<tr>
<td>( l_{\text{monthly_no_a}} )</td>
<td>1.73979</td>
<td>0.183758</td>
<td>9.4679</td>
<td>&lt;0.00001 ***</td>
</tr>
<tr>
<td>time</td>
<td>-0.0194008</td>
<td>0.0240743</td>
<td>-0.8059</td>
<td>0.42711</td>
</tr>
</tbody>
</table>

Mean dependent var 10.89371 S.D. dependent var 2.461265
Sum squared resid 13.53769 S.E. of regression 0.695334
R-squared 0.925509 Adjusted R-squared 0.920188
F(2, 28) 181.6674 P-value(F) 9.22e-17
Log-likelihood -31.14520 Akaike criterion 68.29040
Schwarz criterion 72.59236 Hannan-Quinn 69.69274
rho 0.426389 Durbin-Watson 0.989991

Restriction:  
\( b[l_{\text{monthly_no_a}}] = 1 \)

Test statistic: Robust F(1, 28) = 16.208, with p-value = 0.000391979

Restricted estimates:

<table>
<thead>
<tr>
<th></th>
<th>coefficient</th>
<th>std. error</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>const</td>
<td>-1.14092</td>
<td>0.610876</td>
<td>-1.868</td>
<td>0.0719  *</td>
</tr>
<tr>
<td>( l_{\text{monthly_no_a}} )</td>
<td>1.00000</td>
<td>0.000000</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>time</td>
<td>0.0859517</td>
<td>0.0169102</td>
<td>5.083</td>
<td>2.01e-05 ***</td>
</tr>
</tbody>
</table>

Standard error of the regression = 0.84212
Appendix B

There is a DVD enclosed to this thesis which contains empirical data.

- Folder 1: Transaction aggregates from Blockchain [39]
- Folder 2: Trade transaction data from Mt.Gox [38]