

# **The Law of One Price on Bitcoin**

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## Abstract

The purpose of this study is to identify whether the Law of One Price theory holds across bitcoin exchanges in different countries given the uniquely defining characteristics of bitcoin. This was explored using Johansen's Cointegration to extract the economic relationship between the time series sampled. It was demonstrated in the results that the Law does not always hold, however this was dependent on which bitcoin exchange is being used. Prices across the same bitcoin exchanges were likely to hold because of similar transaction costs and the ease of trading. For the time series where the Law of One price did not hold, the explanatory factors could include the bitcoin market illiquidity and purposeful disequilibrium.

Bitcoin is a fairly new concept and has been press-worthy in the finance, economic and technological spheres. In South Africa, awareness of the digital currency is low, as is an understanding of its features and the impact on the economy as well as society as a whole. This study therefore aims to explore bitcoin in a finance context, in terms of the Law of One Price, while briefly gaining an understanding of the digital currency itself.

Keywords: Bitcoin, Law of One Price theory, arbitrage, equilibrium

## CHAPTER I: Introduction

### 1.1 Introductory paragraph

The theory of Law of One Price has been tested on many commodities around the world including wheat, wool, rice, milk, corn, timber and motor vehicles (Katrakilidis, 2008). This simple theory is also a highly logical one which states that regardless of where one is in the world, an identical good should cost an individual the same amount of money once expressed in a common currency. The most significant difference between those tests and a test involving bitcoin would be the unregulated digital nature of the cryptocurrency. This makes the testing of the Law intriguing as it is unknown whether the unique characteristics of bitcoin will aid or hinder the applicability of the Law of One Price theory.

While bitcoin is only one of many cryptocurrencies that is in existence it is the most prevalent cryptocurrency. Although implemented years ago, it has only recently seen an immense rise in popularity as “bitcoin has enjoyed wider adoption than any other previous crypto-currency” (Moore & Christin, 2013, p. 1). The history of cryptographic currencies dates back to the 1980’s when the idea of untraceable payments was founded according to Bonneau, Clark, Miller, Narayanan, Kroll and Felten (2016). This was further developed when the concept of publicly viewable trades was put forward in the 1990’s (Bonneau, et al., 2016). These concepts form the backbone of cryptographic currencies, other examples of which, are Litecoin, Ripple, Dogecoin and Ethereum (Coinmarketcap, 2016). There are currently 701 cryptocurrencies in existence with bitcoin having a market capitalisation of over R9 billion with the

nearest competitor only having just over one tenth of the market capitalisation (Coinmarketcap, 2016).

Bitcoin has captured the attention of individuals and financial institutions alike, such as South Africa's Standard Bank who considered testing a Bitcoin trading platform internally (Vermeulen, 2014). Accountancy SA, a prominent magazine in the industry, has stated that "this virtual currency is undeniably having a real-world impact" (Kun, 2014). It has also captured the attention of governments causing it to be banned in some form in Russia, China, India and Germany which represent some of the world's biggest economies (Chokun, 2014). It has however been touted as the future of money as people become more comfortable with, and accepting of, technological advancements made in recent years.

The theory of Law of One Price is considered to be fundamental to international trade and monetary policies around the world (Officer, 1986). According to Taylor (2000) the Law of One Price theory shows that the world is an integrated economy, where goods of the same quality should be priced the same. If pricing mechanisms were not representative of an integrated economy this would allow arbitrage opportunities across countries to take place according to Taylor (2000) and Sorkin (2012). That is, if the tariffs, taxes, transport and other costs were factored into the process, the converted cost would be the same for a good in South Africa (SA) as compared to the same good in the United States (US). The costs to be factored into the process are not limited to these as any cost necessary to move the good between the United States and South Africa in this instance would be relevant. If the US converted price including the relevant costs was greater than the SA price, this

would cause arbitrageurs to exploit the transaction in search of profits. Arbitrage would cause the cheaper SA good to be moved to the US, where the excess supply in the market should decrease the US price and the excess demand in SA will increase the price till the point where the Law of One Price should be restored. This theory relies on the fact that consumers should want to maximise their utility, they should pay a market related price for goods which is indicative of perfect competition and complete market integration (Lee, 2004). Therefore if the Law of One Price did not hold this would indicate that the world market is not fully integrated. This lack of integration could be due to a lack of information, additional costs, barriers of trade and other factors that influence cross-border trade (Sorkin, 2012). If the relationship between markets across the world are not fully connected or interlinked this could also be due to the new and uncertain circumstances surrounding the digital currency.

The digital nature of bitcoin means that there is not a physical asset or good that needs to be transported across countries. This means that there is no room for damage of the good due to inappropriate storage or a chance of the good being lost or stolen. The unregulated nature of bitcoin makes taxation an irrelevant cost as tax authorities around the world have not created appropriate tax laws or these laws are in the infancy stage. Tariffs therefore also become irrelevant to the process however the relevant costs would include currency exchange costs and bitcoin exchange costs.

The important role that the Law of One Price theory plays however has been difficult to prove. Some of the contentiousness comes from the methodology used to prove this theory, which will be described in the literature review in Chapter 2.4. Although

the focus of this paper is on testing the validity of the economic and finance theories of the Law of One Price and arbitrage, an understanding of bitcoin needs to be achieved due to the unique nature of the cryptocurrency and its impact on the aforementioned theory. In this age of rapid technological advancement an innovative yet highly controversial currency has arisen. “Bitcoin is a decentralized electronic currency, introduced by (the pseudonymous) Satoshi Nakamoto (Nakamoto, 2008) in 2008 and deployed on 3 January 2009.” (Meiklejohn, Pomarole, Jordan, Levchenko, McCoy, Voelker and Savage, 2013, p. 2) Its popularity is evidenced by its inclusion in the Oxford Dictionary (2014): “Bitcoin is a type of digital currency in which encryption techniques are used to regulate the generation of units of currency and verify the transfer of funds, operating independently of a central bank.” By definition bitcoin is a digital currency; however it is questionable whether it currently functions as one or whether it functions better as an investment asset.

While there have been many investigations into the nature and technology behind bitcoin there have not been many further probes into bitcoin in a finance context as indicated in Chapter I (Dong & Dong, 2014). Chapter II of this study will discuss the mechanics of a dummy bitcoin arbitrage transaction along with the aids to and hindrances of the Law of One Price and the associated process of arbitrage. Chapter III of this study will describe the methodology for the empirical tests performed, Chapter IV of this study will describe the results while Chapter V of this study will discuss and conclude on the research question asked.

## **1.2 Research Problem**



The price of a bitcoin is determined by the basic economic forces of supply and demand. For example, if one looks at the price of bitcoins in United States Dollars (USD), a customer should have an expectation of what the South African Rand (ZAR) equivalent will cost on one of the South African exchanges. The expectation should be that the ZAR price of one bitcoin should equate the USD price of one bitcoin translated at the spot exchange rate. This could be seen as a valid expectation as a result of the Law of One Price theory.

Bitcoins are however traded across different exchanges in different countries at different prices. With multiple exchanges within the same country, it has been found that bitcoins trade for different prices across each of these exchanges. Market inefficiencies will always exist, however these should quickly be eliminated by the mechanism known as arbitrage. This could result in opportunities for exploitation of the digital currency, with a possibility to create money-making opportunities. The money-making aspect is however not the only significant information that can be extracted from the existence of arbitrage. This is because if price differences exist and these differences are arbitrated away to restore price equilibrium, the Law of One Price theory will hold. The fact that the Law of One Price theory does not hold could also provide further information about user's perceptions of bitcoin, as well as some insight into how bitcoin is traded and the general bitcoin market characteristics.

### **1.3 Purpose**

The purpose of this study is to identify whether the Law of One Price theory holds for bitcoin exchanges in South Africa and some of its major trading partners being the European Union, Great Britain and the United States. This will be done by gaining an

understanding of whether there is a long-term economic relationship between the prices of one bitcoin between a South African, European, Great British and American bitcoin exchange. The relationship between these prices could be expected because of the completely identical nature and lack of barriers of trade which should promote the applicability of the Law of One Price theory. If it is found that there is no relationship between the prices across the bitcoin exchanges in these countries, this could result in the arbitrageur using the price mismatches in the market to make profits which would drive prices back to equilibrium. The Law of One price theory will be tested quantitatively using the statistical method of cointegration which returns information about how time series relate to each other in the long-run and therefore determines whether the Law of One Price theory holds across the bitcoin exchanges tested. This econometric test will provide information about the efficiency and integration of the different bitcoin exchanges across countries.

#### **1.4 Significance of the study**

South African exchanges have not been included in the limited testing on the conformity to the Law of One Price theory for bitcoin exchanges. Exploring this price equilibrium and factors of market efficiency will contribute to the growing volume of research about the noteworthy digital currency in the area of finance. The lack of price equilibrium could imply that bitcoin displays market inefficiencies across countries. This could be due to the bitcoin market possibly not pricing the available relevant information into the market prices. Whether arbitrage is capitalised on, and therefore the Law of One Price theory holds, provides useful information about users' perceptions of bitcoin. Capitalising on arbitrage opportunities could indicate that users think of bitcoin as a currency with a short-term view profit making view of the

asset. If the Law of One Price theory does not hold this could provide more information about the liquidity, transaction times and price volatility of bitcoin. This is because a highly liquid market, with fast transaction times and low price volatility should aid in the conformity to the Law of One Price theory holding. The inhibiting factors of the making Law of One Price theory hold could be very interesting. This could include that bitcoin market inefficiencies are due to purposefully inefficient behaviour on behalf of users. An example of this behaviour could be due to exchange control regulations which could motivate individuals or businesses to not restore equilibrium if they have more pressing reasons for using bitcoin. Illegal motives including money laundering could also result in customers not being concerned with being ensuring that the law of One Price holds. Bank transaction costs are also reportedly higher than bitcoin transaction costs which provides a more urgent motivation for bitcoin being used as a replacement for banking services especially for the unbanked population.

## **1.5 Research Question**

1. Does the Law of One Price theory hold for bitcoins on bitcoin exchanges in South Africa, the United States, Great Britain and Europe?

## **CHAPTER II: Background**

### **2.1.1 Mechanics of Bitcoin**

Bitcoin has a fairly complex and technologically intensive background which can be obtained from two sources.

The secondary source is a bitcoin exchange, of which there are hundreds around the world, where willing buyers and willing sellers come together to trade already mined bitcoins. The original source creates bitcoins through 'mining' where according to Goodspeed (2014) "these so-called miners use computers to solve highly complicated mathematical algorithms for specific blocks."

This is "a way to initially distribute coins into circulation, since there is no central authority to issue them" (Nakamoto, 2008, p. 4). These blocks then get added to a chain that is visible in the 'Blockchain' which is a fully accessible record of all Bitcoin transactions allowing for transparency. A limit of 21 million bitcoins can be issued, while there are 14,120,650 in circulation, as of 2 May 2015 (Blockchain, 2015). This limitation on the quantity makes bitcoin a scarce resource, which is a contrast to fiat money which can be printed by governments at will.

The mechanics of a bitcoin transaction in summary will be as follows:

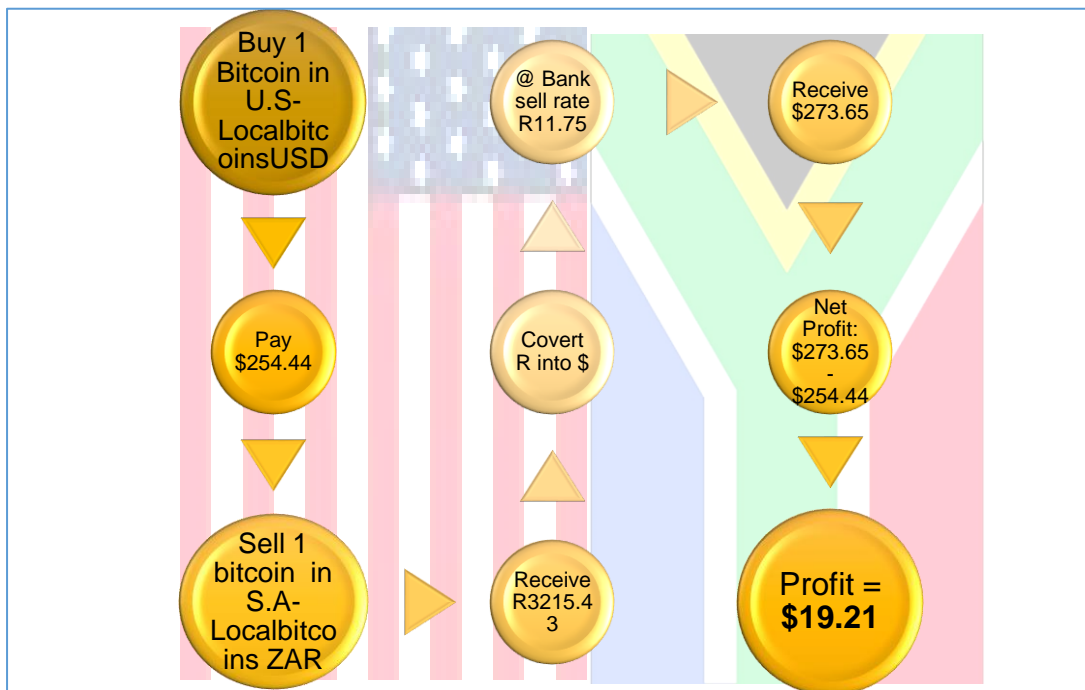
Bitcoin users carry out bitcoin transactions by sending digitally-signed messages with the addresses of the bitcoin sender and receiver to the Bitcoin network. Each address contains two cryptographic keys: the public key (commonly called the address) and the private key. The private key is stored in a virtual wallet and is known only to the bitcoin owner. It is used to prove the bitcoin owner's right to spend bitcoins from the wallet through a cryptographic digital signature affixed to a transaction. The public key is public information and is used by miners to validate transactions and that the bitcoins are not being spent more than once. (Goodspeed, 2014)

### 2.1.2 Definitions:

- Crypto-currency- A digital currency in which encryption techniques are used to regulate the generation of units of currency and verify the transfer of funds, operating independently of a central bank. (Oxford English Dictionary, 2014)
- Cryptography- “A system that uses two keys -- a public key known to everyone and a private or secret key known only to the recipient of the message. When John wants to send a secure message to Jane, he uses Jane's public key to encrypt the message. Jane then uses her private key to decrypt it.” (Webopedia, 2016)
- Fiat currency- Currency that governments declare as legal tender not backed by a commodity.
- Bitcoin (capitalised) refers to the payment system while bitcoin (lowercase) refers to the currency from established convention. (Meiklejohn et al., 2013, p. 2)
- Mining- “Bitcoin mining is the process by which transactions are verified and added to the public ledger, known as the block chain, and also the means through which new bitcoin are released. Anyone with access to the internet and suitable hardware can participate in mining. The mining process involves compiling recent transactions into blocks and trying to solve a computationally difficult puzzle. The participant who first solves the puzzle gets to place the next block on the block chain and claim the rewards. The rewards are the transaction fees as well as newly released bitcoins.” (Investopedia, 2015)

## 2.2 Bitcoin Arbitrage transaction

### Illustration 1.1: Bitcoin arbitrage between United States and South Africa



The potential arbitrage process would take place as follows according to Illustration 1.1 above. The process will be illustrated using one bitcoin and rates as well as prices on 25 May 2015. On Localbitcoins.com, one bitcoin would be purchased on the American version of the website in the United States. This bitcoin is denominated in USD and will cost \$254.44 to purchase. Due to the fact that exchange rates fluctuate throughout the day, the figure that will be used for the translation is the closing exchange rate. Now that one bitcoin is owned, this same bitcoin can be sold on a South African exchange.

This bitcoin will be sold on the South African version of Localbitcoins.com for R 3215.43. The exchange rate to be used will be the rate that a South African bank will buy USD at of R11.75. The individual will receive R3215.43 and will need to translate this Rand amount back into Dollars. Proceeds of \$273.65 will be received for the

bitcoin sold on the South African exchange. This means that since the bitcoin was purchased for \$254.44 and was sold for \$273.65, a profit of \$19.21 can be made on this transaction before transaction costs. This proves the existence of arbitrage within the bitcoin market. If an arbitrageur executes this series of transactions this would go some way to restoring the price equilibrium. This profit however excludes transaction fees on the Localbitcoins.com exchange or on foreign currency.

Transaction fees would amount to 1% of the amount that the bitcoin is sold for, which amounts to R32.15 ( $3215.43 \times 1\%$ ) or \$2.74. The profit after the bitcoin exchange transaction fee is \$16.47 ( $19.21 - 2.74$ ). There is also a currency exchange fee that will be incurred in converting the Rands received from the sale back into USD. The internet allows for the easy execution of this arbitrage transaction without the need to physically exchange the fiat currencies.

The other possible arbitrage process is as follows. An individual in South Africa could also choose to buy one bitcoin on Localbitcoins.com USD for \$254.44. In order to purchase this bitcoin, the South African users Rands must be converted to USD at the banks buying rate of 11.75. Therefore it would cost this user R2, 989.67 to buy \$254.44 USD. Once this bitcoin is purchased, it can now be sold on the South African exchange for R3, 215.43. This leaves a profit of R225.76 before the bitcoin exchange transaction fee, which leaves a profit of R193.61. This dummy transaction does not cover the range of possibilities that an arbitrageur comes across when entering into these transactions. For example, greater liquidity and faster execution of transactions will result in greater profits, as elaborated on in the literature review in Chapter 2.4.

## **2.3 Bitcoin Exchange Characteristics**

LocalBitcoins.com is a peer-to-peer exchange, or what has been termed in this paper as a user-determined price exchange. This is in contrast to buying from a centralised company, which is termed in this paper as an exchange-determined price exchange. On a user-determined price exchange bitcoin's are directly purchased from individuals residing in the same country (Localbitcoins.com, 2016). While Localbitcoins.com provides a pricing model to users, this is merely a suggestion for the price that the user advertises. The users therefore have the discretion to charge more or less than the pricing model. For the other type of exchange, users cannot use their discretion and cannot directly change the prices indicated on these exchanges. Localbitcoins.com claims to have benefits over the exchange-determined price exchanges in terms of being faster due to the proximity of users. (Localbitcoins.com, 2016)

## **2.4 Literature review**

### **2.4.1 Proliferation of bitcoin**

Meiklejohn et. al. (2013, p. 1) have stated that “demand for low friction e-commerce of various kinds has driven a proliferation in online payment systems over the last decade” which seems to be valid due to users reliance on the internet and its services. Another relevant reason could be that trust in banks has deteriorated due to the global recession when American banks participated in reckless lending, leading to similar feelings towards banks around the world (Kemp-Robertson, 2013). This is demonstrated in the Edelman Trust Barometer report 2014 showing that there is 48% trust in financial institutions globally while that sits at 55% in South Africa



(Edelman, 2014). This mistrust is indicated by high levels of interest in bitcoin in Argentina, where there are very strict government exchange control regulations (McLoed, 2013). It is important to remember that no regulation symbolises no certainty over their money, as consumer protection will not be offered by government or banks if money is lost or stolen.

“Digital currencies impose fewer transaction costs” (Plassaras, 2013, p. 10) as a small fee is only sometimes payable to ‘miners’ depending on circumstances and “digital currencies are unique in that they overcome the transaction costs imposed by exchanging one currency for another” (Plassaras, 2013, p. 10). This is a refreshing contrast to the high bank charges as reported on by Pickworth (2012) who found that “SA had the highest average ATM cash withdrawal fees of 27 countries.”

There is a 46.88% internet penetration in South Africa; however 91% of people have mobile telephones (Pew Research, 2014) making access to the internet and digital currencies easier. Bitcoin opens up opportunities to service millions of unbanked people (Bitcoin Foundation, 2014). For the unbanked population in South African, bitcoins overcome the barriers of high cost, distance and improper documentation as well as being used to purchase essential goods and services (Demirguc-Kunt & Klapper, 2012).

Bitcoin however has an anonymity that could be used for fraud, money laundering- and in the case of Silk Road- selling drugs online (Aldridge & Décary-Héту, 2014, p. 1). As a result of the digital nature of the crypto-currency, it is susceptible to cyber-security issues, which could provide a serious deterrent for users (Plassaras, 2013).

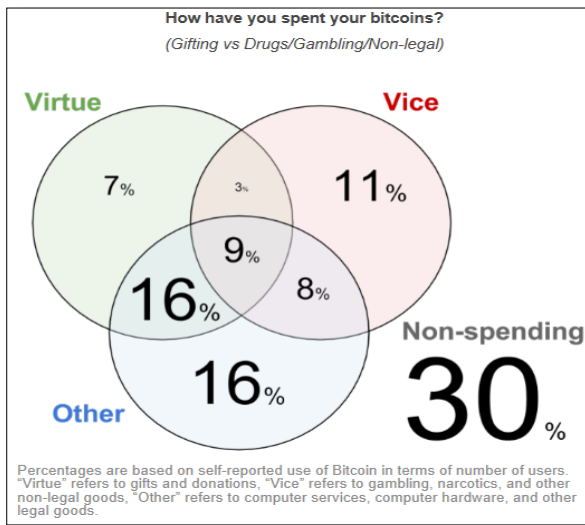
All of the positives noted above could be the drivers for the increase in popularity mentioned. On the other hand, the negatives noted above could be the reason for bitcoin not becoming more prevalent than it already is.

#### **2.4.2 Uses for bitcoin**

According to a study by Bohr & Mashir (2014) freedom from the state, users' political views and banking mistrust are important factors in explaining the popularity of bitcoin today. In determining whether the Law of One Price holds on bitcoins, it is important to understand how users perceive the uses of bitcoin. While it is difficult to gauge users' perceptions, due to the inherent anonymity, Bohr and Mashir (2014) discovered that users who believe in the long term appreciation of the bitcoin see themselves as investors. If users treated their bitcoins as an investment or a financial asset they would find more value in storing them with the hope of capital appreciation rather than the using them as a medium of exchange.

Bohr and Mashir (2014) also discovered that users who had illegal motives regarding bitcoin were more likely to hold more bitcoins, showing that while these individuals are using it as a medium of exchange, it is not a true motive as their focus is on anonymity and would make restoring price equilibrium less important. Whether bitcoin is a currency or not could affect the Law of One Price holding because as Dong and Dong (2014) concluded, investors would capitalise on arbitrage opportunities that existed unless they perceived bitcoin as an investment rather than a currency.

### Illustration 1.2: Diagram showing how bitcoins are spent by users



Source: (Smyth, 2013)

This survey done by Smyth (2013) indicates interesting results for determining users perceptions of bitcoin, even though a small sample size of 1000 respondents was used. Just under a third of users surveyed did not spend the bitcoins that they owned. This indicates that a large percentage of users do not use bitcoin as a currency, but that they are possibly holding onto these bitcoins for investment purposes. The larger proportions of users therefore do spend their bitcoins and take advantage of bitcoins function as a medium of exchange and therefore use it as a currency.

#### 2.4.2.1 Currency

According to Krugman (1984, p 263): "Money, the classical economists argued, serves three functions: it is a medium of exchange, a unit of account, and a store of value." Bitcoin is by definition of a medium of exchange as this digital currency is accepted by many companies as payment for goods or services. Yermack (2013, p.

2) states that “Bitcoin exhibits very high time series volatility and trades for different prices on different exchanges.” This diminishes its function as a unit of account or store of value as prices have gone from \$104 in July 2013 to \$1151 in December 2013 to a price of \$235 on 21 August 2015 although the limited number of bitcoins should stabilise this volatility in the future (Blockchain, 2015). Goods which can be paid for bitcoins are not stated in terms of bitcoins but rather in USD or ZAR as can be seen on (Bitcoin South Africa, 2014) website, showing it is not widely used as a unit of account. According to Sorge & Krohn-Grimberghe (2013, p. 5) the fact that the Bitcoin “system cannot just be used to carry out payments in any existing currency” proving that it is a unit of account even though it is not widely used as one.

Plassaras (2013) claims that the biggest challenge that bitcoin faces as a currency is convincing users to use them and merchants to accept them. It seems that for a user who is not concerned with being anonymous or being independent of the government, bitcoin fails to provide an attractive medium of exchange (Grinberg, 2011). According to Bohme et.al (2015) credit card companies often provide rebates or rewards points which bitcoin cannot offer. The rest of the world has taken to using bitcoin as a form of payment, much better than South Africa, as only 45 merchants are accepting bitcoin in this country as compared to 6498 merchants around the world (Coinmap.com, 2015). Benefits to merchants (Overstock.com) include increases in sales and order quantities, (Sidel, 2014) little or no fees to accept it as a form of payment unlike credit cards, (Bohme, et al., 2015) and instantaneous exchange facilities meaning that they bear no price risk (Luther & White, 2014). In summary bitcoin is not currently a currency as it struggles to meet the theoretical definitions, but does have the potential to be one.

### **2.4.2.2 Financial Asset**

Glaser, Zimmerman, Haferkorn, Weber, and Sterling (2014) compared the total bitcoin transaction volume to the volume of bitcoins being traded. The authors came to the conclusion that the majority of users do not use their bitcoins as a currency. This would imply that the transaction volume of bitcoins is significantly lower than the trade volumes. This could be due to the fact that only a small proportion of companies accept bitcoin as a form of payment. “Bitcoin investments seem to offer diversification benefits” according to Brière, Oosterlinck, and Szafarz (2013). This could prove to be useful for investors wanting to construct asset portfolios by capitalising on bitcoins negative correlation with other assets. This further suggests that bitcoin is used as a financial asset rather than a currency.

### **2.4.3 Law of one price theory**

The law of one price theory states that “identical goods must have identical prices” (Lamont & Thaler, 2003, p. 191). Since a bitcoin in South Africa is identical to a bitcoin in Japan which would be identical to a bitcoin in Australia, the absolutely identical nature of a bitcoin should aid the validity of the Law of One Price theory. Many goods suffer from the fact that they are not completely identical due to differing quality, weight or other defining characteristics. This is not a problem for bitcoin since cryptology ensures that each bitcoin is created the same. A practical example of this using a commodity is where an ounce of gold should cost the same amount (denominated in USD) in South Africa as it does in the United States, otherwise gold would move from the cheaper country to the more expensive one (Lamont & Thaler, 2003). If this logic is applied to bitcoins, a bitcoin denominated in USD should cost the same amount as a bitcoin denominated in ZAR. The Law of One Price theory

should be valid after considering exogenous variables such as transport costs and tariffs (Delpachitra & St Hill, 1993). Trade costs drive a natural wedge between relative prices in different locations, leading to deviations from the Law of One Price for traded goods (Lee, 2004). It would therefore be important to accurately note the applicable types of transaction costs that are relevant in determining whether the Law of One Price theory holds. If comparing the Law across the Localbitcoins.com exchanges, bitcoin exchange transaction costs become irrelevant however across different exchanges the transaction costs will only become relevant where costs charged differ.

Taylor (2000) found that there is no proof that the Law holds in practice, while Lee (2004) showed that the empirical literature proves that prices across countries do not converge and these diversion last for the long-run. Sorkin (2012) contends that the Law cannot be proved in reality while Buharumshah and Habibullah (1995) state that trade analysts are positive that the theory holds.

According to Buharumshah & Habibullah (1995) there is little empirical evidence to prove that the Law of One Price theory holds. This is troubling because, as mentioned before, it serves as the basis for most economic theory and could indicate serious market weaknesses and a lack of international integration. The electronic nature of bitcoin should overcome many of the difficulties faced by physical commodities in adhering to the Law of One Price theory. The method of testing of the Law of One Price theory is vital, as there has been much criticism of the testing in recent years which indicates an incorrect method as the downfall of the theory (Buharumshah & Habibullah, 1995). It is important to decide whether the analysis is

intended to be in the short-term, where the Law of One Price theory is considered not to hold, or long-term where this is not the case (Protopapadakis and Stoll 1986). This seems to indicate that the law of one price theory takes time to be effective, which indicates a lack of an efficient market. The long-run therefore seems like a more appropriate time frame to test the theory within (Buharumshah & Habibullah, 1995). According to Buharumshah & Habibullah (1995) disaggregated data needs to be used in the empirical tests to avoid inaccurate results. Even still, it has been found that the majority of the evidence seems to reject the Law of One Price either at the level of general price indices or at a more disaggregated level (Buharumshah & Habibullah, 1995). Bitcoin does not face the problem of aggregated data as the price data available is on a per unit basis. Lastly the econometric model being used is important in obtaining valid results in the empirical tests. The methodological issues are detailed in Chapter 3.

#### **2.4.4 Arbitrage and its Impediments**

The Law of One Price theory validates the existence of arbitrage, “otherwise, smart investors could make unlimited profits by buying the cheap one and selling the expensive one” (Lamont & Thaler, 2003, p. 192). Arbitrage is therefore the force that drives prices back to equilibrium. Arbitrage is the “simultaneous buying and selling of the same security for two different prices, is perhaps the most crucial concept of modern finance” (Lamont & Thaler, 2003, p. 192). Arbitrage opportunities are considered achieve risk-free profits which can occur across different markets as long as they are on identical items (Marshall, et al., 2008). In the case of bitcoins, if the USD denominated bitcoin was cheaper than the ZAR denominated bitcoin the forces of arbitrage would equalise the prices. The arbitrageur would buy the bitcoins where

they were cheaper (on the United States exchange) and sell it where it's more expensive (on the South African exchange). The forces of demand and supply will align the prices. Since the cheaper bitcoin will be in higher demand, the price of the USD bitcoin will increase and since the more expensive bitcoin will be in high supply the price of the ZAR bitcoin will decrease.

Gandal and Halaburda (2014) studied the relationship between actual exchange rates and digital currencies including bitcoin to establish "comovement and identify opportunities for triangular arbitrage." Early results, also using the daily closing prices, showed that there is a small opportunity for triangle arbitrage. The authors however feel that this may be as a result of the infrequency of the data set used for the study which perhaps does not capture the fact that arbitrageurs capitalise on these opportunities much quicker (Gandal & Halaburda, 2014). Dong and Dong (2014) have also performed a test of triangle arbitrage. Dong & Dong (2014) tested the relationship between the implied bitcoin exchange rate and the actual exchange rate for the USD relative to the Yen, Euro, British Pound, Australian Dollar, Canadian Dollar and Chinese Yuan. The findings showed that even though arbitrage opportunities exist on many of the currencies, investors are discouraged from capitalising on it. Yermack (2013) has stated that bitcoin does not allow for arbitrage opportunities; however it is unclear whether the author means that the Law of One Price theory holds or, whether it does not hold but that there are impediments to carrying it out.

According to Lamont and Thaler (2003) the main reasons that arbitrage would not prevail is if people incorrectly perceive differences between identical goods and if



there are obstacles to restoring prices to equilibrium. There is no possibility that customers can believe that the bitcoin itself is different in any way. There could however be a difference in the services provided by bitcoin exchanges, making customers willing to pay a higher price, such as a better reputation, however this is likely to be catered for in the transaction fees charged. Therefore it is highly unlikely that customers could perceive any difference between a bitcoin traded in South Africa and the United States. There seem to be few impediments to carrying out arbitrage, as the electronic nature of bitcoin and bitcoin trading lends it to being easily traded online. An issue with bitcoin is the time it takes to execute a transaction as the key to benefiting from arbitrage is how quickly the arbitrageur can complete a transaction. If another arbitrageur can execute a transaction quicker, they can find the arbitrage opportunity before it is taken advantage of and steal the opportunity (Donier & Bonart, 2014). The time taken to purchase or sell a bitcoin on an exchange can, on average, be between 6 and 11.5 minutes (Blockchain, 2015). This length of time could eliminate the possibility of arbitrage because the price mismatch cannot be capitalised on quickly enough.

The advantage that bitcoin does have is that even though the trades would need to be executed on different countries' exchanges, this can be done without physically needing to be in these countries (Marshall, et al., 2008). The execution time also relates to the liquidity of the market because willing buyers and sellers need to be readily available when the opportunity is found. Liquidity is vital to carrying out arbitrage because "the required transactions can be completed without having an impact on price" (Marshall, et al., 2008). Liquidity in the foreign exchange market is

very high with the ZAR being one of the most traded currencies in the world, making liquidity in the bitcoin market of high relevance (Marshall, et al., 2008).

According to Donnier and Bonart (2014) the “implementation of limit order books, the electronisation of trade exchanges, the rise of high-frequency trading, and the introduction of algorithmic and automated executions are the most emblematic features of the new financial economy.” These features all seem to be a facilitator for arbitrage to take place regardless of the commodity being traded. The features are highly applicable to trading bitcoin as the digital nature of bitcoin implies that it is traded on electronic exchanges making the consideration of transportation costs irrelevant. The digital element also allows for high frequency trading and automated trades due to the advanced nature of computers and software technology which should also aid the capitalisation of arbitrage opportunities on bitcoin. In an efficient market, available trade information should be reflected in the market prices, the anonymity of bitcoin may hinder this, however, the “Blockchain” may improve information available due to the public ledger of all bitcoin trades Kyle 1985 as cited by Donier & Bonart (2014). If this information did not reflect immediately in the market prices of bitcoin this could allow for a violation of the Law of One Price theory and the non-capitalisation of arbitrage opportunities.

According to Marshall et. al (2008) the following are other relevant reasons why arbitrage opportunities are not capitalised on, namely that traders may keep prices apart due to the nature of their trading activity, or a lack of market synchronisation could cause price divergence. The lack of market synchronisation could be due to the different uses for bitcoin, with some users having ulterior motives for using

bitcoin such as bypassing government regulation. Tax considerations should also be taken into account as individuals will act in a way which maximises their profits.

The literature backs up the profit achieved from the arbitrage process illustrated in chapter 2.2, where only a small or insignificant profit is achieved after transaction costs (Marshall, et al., 2008). If the profit that can be achieved from bitcoin arbitrage is insignificant it will not be worth the time and effort that it takes to find the opportunities and restore the Law of One Price theory. The implementation costs, which include the cost of finding and carrying out the arbitrage transaction, could be a hindrance to arbitrage (Marshall, et al., 2008). Again, the digital nature of bitcoin and websites like Bitcoincharts.com allow for easy and minute-by-minute comparisons of prices even though they exist across different countries. This makes finding the opportunity fairly costless, however transaction costs could have a larger impact on whether to take up an opportunity or not. Bitcoin transaction fees are generally low as mentioned in the introduction; however a fee of 1% can be significant given the high value of bitcoins. International bank charges can also be costly and may cause the Law of One Price theory to be violated. The violation of the Law of One Price theory could be due to factors that are outside arbitrageurs control including government regulation, however this is an issue that bitcoin should overcome as a result of the lack of government control over bitcoin. If bitcoins were however banned from being traded in a particular country this could impact whether arbitrage is capitalised on or not.

### **CHAPTER III: Methodology**

**3.1 Aim:** The aim is to identify whether a statistical long-run relationship can be identified between the actual ZAR price of one bitcoin and the converted price of one bitcoin from a foreign currency into ZAR for the four countries being tested. It is not enough to just identify a relationship, but this relationship needs to be meaningful in the economic sense which is reliant on the choosing an appropriate econometric model.

**3.2 Method overview:** If the Law of One Price were to hold this would mean that there exists cointegration between the prices of bitcoin in South Africa, the United States, Europe and the United Kingdom (University of Washington, 2016). In statistics, it is problematic to perform a simple regression on time series that are non-stationary. A stationary relationship is one that is random and does not exhibit a trend across all time. This is because time series which exhibit no genuine relationship with each other could statistically result in a linear relationship. This is what is known as spurious regression and provides useless information for identifying whether the Law of One Price holds.

Cointegration is a method which enables the long-run relationships between time series to be kept with regards to price equilibriums while avoiding spurious regression (Engle & Granger, 1987). Since the Law of One Price is considered to hold in the long-run, cointegration is deemed to be an appropriate methodology as indicated by its use in Pippenger & Phillips (2007), Piesse & Hearn (2011) and Katrakilidis (2008). Cointegration is a method whereby the difference between the time series results in a stationary process which indicates that there is a meaningful economic linear relationship between the time series.

$X_t$  represents the actual 'buy' ZAR price of one bitcoin while  $Y_t$  represents the converted foreign currency price of one bitcoin in ZAR at the banks closing 'sell' spot exchange rate. Equation 1 represents the outcome of two time series if they are cointegrated.  $\varepsilon_t$  represents the error term while  $\beta$  is beta.

$$Y_t - \beta X_t = \varepsilon_t = I(0) \quad (\text{Eq. 1})$$

$$H_0: \beta=0 \text{ and } H_1: \beta \neq 0 \quad (\text{Eq. 2})$$

Ordinary least squares (OLS) regression will be run to estimate beta that will make a combination of the time series a linear stationary relationship.

$$\text{OLS: } Y_t = \alpha + \beta X_t + U_t \quad (\text{Eq. 3})$$

Where  $U_t$  is the error term, which should be  $I(0)$  (meaning it is stationary) itself.

The level of significance that will be set is 5 % in evaluating the results of the Augmented Dickey-Fuller test as well as Johansen's Cointegration. Another method considered was the Engle-Granger method however this only deals with one linear stationary relationship which is inappropriate for the purposes of this test (Engle & Granger, 1987).

If the time series was not stationary it could be differenced, using Box and Jenkins method, to get it to a stage where it could be suitable for linear regression as is appropriate for Johansen's Cointegration (Buharumshah & Habibullah, 1995). The approaches to test whether the unit root is stationary include the Dickey-Fuller,

Augmented Dickey-Fuller and Phillips-Perron models. The Augmented Dickey-Fuller method is used as used by Katrkilidis (2008) and will be evaluated at a 5% level of significance. The advantage that this method has over the original Dickey-Fuller model is that it includes lags to correct the downfalls in the original method (Armstrong Wharton, 2015). The Phillips–Perron test performs worse in finite samples than the Augmented Dickey–Fuller test (Davidson & Mackinnon, 2004), validating the choice to use the Augmented Dickey-Fuller method.

The lag length can be statistically calculated using a number of methods. The most common methods include the Bayesian Information Criterion (BIC) and Aikake Information Criterion. The Aikake Information Criterion was used in Pippenger & Phillips (2007) and will accordingly be used in this study.

**3.3 Population and Sample:** The closing bitcoin prices amongst the 4 South African bitcoin exchanges in existence as well as the closing bitcoin prices amongst the 48 USD denominated exchanges, 14 GBP denominated exchanges and 32 Euro denominated exchanges in existence will serve as the population for the implied bitcoin exchange rates. The sample of the closing prices used to calculate the implied bitcoin exchange rates are summarised in the table below. The other population tested is the actual closing buy interbank exchange rates between the USD: ZAR, EUR: ZAR and GBP: ZAR. The interbank rates used will be  $\pm 3\%$ , which is the standard rate used on credit card transactions. This  $\pm 3\%$  is the margin put on the exchange rates and would represent the ‘buy’ and ‘sell’ exchange rates that banks quote. These actual exchange rates represent the exchange rates per working day. Therefore it is assumed that the exchange rate on a Friday will hold over the

weekend and the exchange rate before a public holiday will hold for the public holiday.

There will be two sets of samples chosen for the purpose of this thesis. The first sample will consist of a comparison between Localbitcoins.com denominated in ZAR against the USD, EUR and GBP. This is because the Localbitcoin.com exchange is a platform where users dictate the prices of bitcoins, by offering and bidding at prices that users have determined. The second sample will consist of a comparison of bitcoin exchanges where the exchange themselves control bitcoin prices. Both types of bitcoin exchanges will be considered in the testing to account for any differences in prices determined directly by customers themselves versus those determined by the exchange.

**Table 1.1: X and Y variables used in Cointegration testing, showing relationships 1 to 6**

	Exchange	Start date	End date	Exchange	Start date	End date
	<i>User-determined rate</i>					
<b>1</b>	LocalbitcoinZAR	19/05/2014	30/10/2015	LocalbitcoinUSD	19/05/2014	30/10/2015
<b>2</b>	LocalbitcoinZAR	19/05/2014	30/10/2015	LocalbitcoinEUR	19/05/2014	30/10/2015
<b>3</b>	LocalbitcoinZAR	19/05/2014	30/10/2015	LocalbitcoinGBP	19/05/2014	30/10/2015
	<i>Exchange-determined rate</i>					
<b>4</b>	BitXZAR	19/05/2014	30/10/2015	HitBTCUSD	19/05/2014	30/10/2015
<b>5</b>	BitXZAR	19/05/2014	30/10/2015	HitBTCEUR	19/05/2014	30/10/2015
<b>6</b>	BitXZAR	19/05/2014	30/10/2015	CoinfloorGBP	19/05/2014	30/10/2015

Source: Bitcoincharts.com/charts

**3.4 Sample size:** The sample size for this test started from 19 May 2014, as this is the furthest date back from which continuous and accurate data can be collected. The data collected from Bitcoincharts.com has certain days where inconclusive data is available. This lack of data might cause problems if included within the sample size so has been omitted for a more accurate outcome. Therefore the start date determined in Table 1.1 is the earliest date without ambiguous or missing data results. On 6 December 2014 however, for the Coinfloor exchange, there is a missing data value. This missing data value had to be calculated using interpolation, by assuming that there is a linear growth trend. The end date of the sample was 30 October 2015 which is a 529 day period being sampled. The actual closing bank 'sell' interbank exchange rates for the respective currencies were also be sampled for the period 19 May 2014 to 30 October 2015. The sample size of the implied exchange rate data as well as the corresponding actual exchange rate data were tested using the above method overview.

**3.5 Sources of data:** The actual interbank 'sell' exchange rate data were collected from the OANDA website, <http://www.oanda.com/currency/historical-rates/> (OANDA, 2015). The bitcoin prices were obtained from Bitcoincharts.com, a website that stores data from all of the bitcoin exchanges that are and were in existence across the world (Bitcoincharts.com, 2015).

**3.6 Collection of data:** The collection involved using Google to find the historical exchange rates from OANDA.com, who has interbank rates with various spreads available for download for a period of up to 5 years. The data is downloadable in



Microsoft Excel for the custom sampled time period in a daily format. This data was downloaded for the USD: ZAR, the EUR: ZAR and the GBP: ZAR respectively. The website Bitcoincharts.com was used to collect raw data for Localbitcoins.com on the USD, EUR, GBP and ZAR denominated exchanges as well as the BitX, HitUsd, HitEur and Coinfloor exchanges. On the website, the charts tab can be selected to create charts for a custom time period. The charts were individually created for the bitcoin exchanges in Table 1.1, for the sample period of 19 May 2014 to October 30 2015. After the creation of the charts, the raw data for each exchange was downloaded to Microsoft Excel (Bitcoincharts.com, 2015).

**3.7 Data management:** The raw data loaded from Bitcoincharts.com for the sampled closing prices and actual interbank exchange rates was managed in Microsoft Excel. For each relationship numbered 1 to 6 in Table 1.1, the ZAR converted bitcoin price was calculated. Each relationship was calculated on a separate tab in Microsoft Excel to avoid confusion. The bitcoin exchanges within the respective relationships was used to calculate the ZAR converted bitcoin price (for example relationship 1) by taking the closing USD price for one bitcoin and multiplying it by the closing exchange rate on the day. The data was put side by side with the actual ZAR price of one bitcoin.

The Augmented Dickey-Fuller test and Johansen Cointegration was performed using a reputable statistical package called Eviews. The Microsoft Excel sheets with the price data were loaded into Eviews. In Eviews, the time series of the eight sampled bitcoin exchange prices can be individually analysed or analysed in a group. Each of the eight time series had a unit root test performed on it, with the method selected

being the Augmented Dickey-Fuller test. Under the options for the Augmented Dickey-Fuller test, the selection was made to calculate the lag length using the AIC and to test for a unit root without differencing the time series.

After the first unit root test was performed a second test was performed under identical conditions for the eight time series, however it was now performed at the first difference level. After determining the stationarity of the time series individually a group analysis was performed. There were two group analyses performed, one being on the user-determined price exchanges and one on the exchange-determined price exchanges. Johansen Cointegration was chosen to be performed based on all five assumptions so as to not bias the result of the test by choosing a particular assumption. The five assumptions include using no data trend and no intercept, no data trend and an intercept, a linear data trend and an intercept, no linear data trend and an intercept and finally a quadratic data trend and an intercept. The time series within the exchange-determined series were grouped for the BitX, Coinfloor, HitBTCEuro and HitBTCUSD exchanges, while the user-determined exchanges were grouped for the Localbitcoins.com ZAR, USD, EUR and GBP denominated exchanges.

**3.8 Data Analysis:** Before the Johansen Cointegration can be tested the Augmented Dickey-Fuller unit root test needed to be performed. The null hypothesis being tested is that there is a unit root ( $H_0: y = 0$ ) and the alternative hypothesis is that there is no unit root and therefore the time series is stationary ( $H_A: y \neq 0$ ). The results of the test will identify whether the null hypothesis will be accepted or rejected using p-values, as described below, in relation to the significance level selected. If the null

hypothesis is rejected, this means that the time series tested will be stationary and therefore can be tested for Johansen Cointegration. The outcome of the AIC will determine the number of lags to be used in the Grangers Causality test; these lags will be chosen by which lag-length shows the lowest AIC. In proceeding with Johansen Cointegration, the outcome of the test will result in an f-test statistic which can be easily interpreted using p-values. The method of interpreting the cointegration test involves a process of testing a null and alternative hypothesis of the number of cointegrating vectors ( $v$ ), until the null cannot be rejected. First test  $H_0$  ( $v = 0$ ) against  $H_1$  ( $v > 0$ ). If this null is not rejected then it is concluded that there are no cointegrating vectors. If  $H_0$  ( $v = 0$ ) is rejected then there is at least one cointegrating vector and proceed to test  $H_0$  ( $v = 1$ ) against  $H_1$  ( $v > 1$ ). This will be done by comparing the test statistic to the critical value (University of Washington, 2016).

In interpreting the null hypothesis the alternative method is to use the p-value to accept or reject it. The null hypothesis will be rejected if the p-value indicates that there is a minimal chance that the null hypothesis is true. If the null hypothesis is rejected this means that the alternative hypothesis holds true. If the p-value is less than or equal to the level of significance set, the null hypothesis can be rejected. If the null hypothesis is rejected this means that there is a relationship between the variables being tested.

**3.9 Limitations:** The bank 'sell' interbank exchange rates obtained, while including a margin; do not represent the full extent of administration fees charged on foreign exchange transactions.

## Chapter IV: Results

### 4.1 Unit Root Tests

The Augmented Dickey Fuller needed to be performed upfront to determine whether the sampled bitcoin prices were stationary. The results of the unit root tests performed are attached in Appendix 1. The results show that at the 5% level the null hypothesis, that the eight sampled time series have a unit root, cannot be accepted. That is because the p-values are greater than 5% for each of the eight sampled time series. Therefore there is a 95% chance or less that the null hypothesis is not valid. This means that the sampled time series do have a unit root and are not stationary.

The next procedure that was carried out was to difference the time series. The results of the second unit root test can be found in Appendix 2. The Augmented Dickey-Fuller unit root test was then carried out on the time series again after differencing the series once. The null hypothesis, that the eight sampled time series have a unit root, at the 5% level can be rejected. That is because the p-values are less than 5% for each of the eight sampled time series and are in fact 0%. Therefore there is a 100% chance that the null hypothesis is not valid. The sampled time series do not have a unit root and are stationary after being differenced at the first level ( $I(1)$ ). This is a pre-requisite for performing the cointegration analysis.

### 4.2 Cointegration

Two cointegration analyses were performed, one on the user-determined price exchanges and one on the exchange-determined price exchanges.

The result of the test on the user-price determined exchanges is shown in extract 1.17 (Appendix 3). The results found that there were three cointegrating relations amongst the Localbitcoins.com ZAR, USD, GBP and EUR exchanges. This is indicated by the fact that the trace statistic and the Max-Eigen statistic show three Cointegrating Relations by model. That is, at the 5% level the null hypothesis was rejected where the alternative hypothesis was greater than 0 cointegrating vectors ( $H_1: r > 0$ ), 1 cointegrating vector ( $H_1: r > 1$ ) and 2 cointegrating vectors ( $H_1: r > 2$ ). Where  $r$  represents the number of relations. Where the  $H_0: r=3$  and  $H_1: r>3$  however, the null hypothesis was not rejected and the number of cointegrating vectors or relations was 3. For the null hypothesis to be rejected at any level, the critical values must be less than the Johansen Max-Eigen test statistic.

The result of the test on the exchange-price determined exchanges is shown in extract 1.18 (appendix 3). The results indicated that there was one cointegrating relation amongst the BitX, HitBTCEuro, HitBTCUSD and CoinfloorGBP exchanges. This is indicated by the fact that the trace statistic and the Max-Eigen statistic show one Cointegrating Relation by model. That is, at the 5% level the null hypothesis was rejected where the alternative hypothesis was greater than 0 cointegrating vectors ( $H_1: r > 0$ ). Where the  $H_0: r=1$  and  $H_1: r > 1$  however, the null hypothesis was not rejected and the number of cointegrating vectors or relations was 1.

## **Chapter V: Conclusion**

## **5.1 Summary**

The Law of One Price theory is considered to be the foundation of finance around the world and is therefore a vital lesson taught to all undergraduates during their finance studies. It is however questionable whether this is just a theoretical Law or whether it does truly exist in practise. If it does exist it should be applicable to all goods including a digital currency in the form of bitcoin. For the Law of One Price to hold, the concept of arbitrage is crucial as it is the force that drives prices back to equilibrium. The unique factors specific to bitcoin include its intangibility, lack of regulation and reportedly low transaction fees which should logically aid the conformity to the Law as these factors have been noted from past literature to increase conformance. The Law of One Price has been contentiously tested in past literature with negative results. The cointegration method used in this paper is however commonly thought to be appropriate to test the Law according to the literature reviewed. Cointegration analysis is a method of extracting the long-term economic relationships or information out of time series. This long-term information identifies whether prices move together and therefore if the time series of bitcoin prices were cointegrated, the Law of One Price theory would hold.

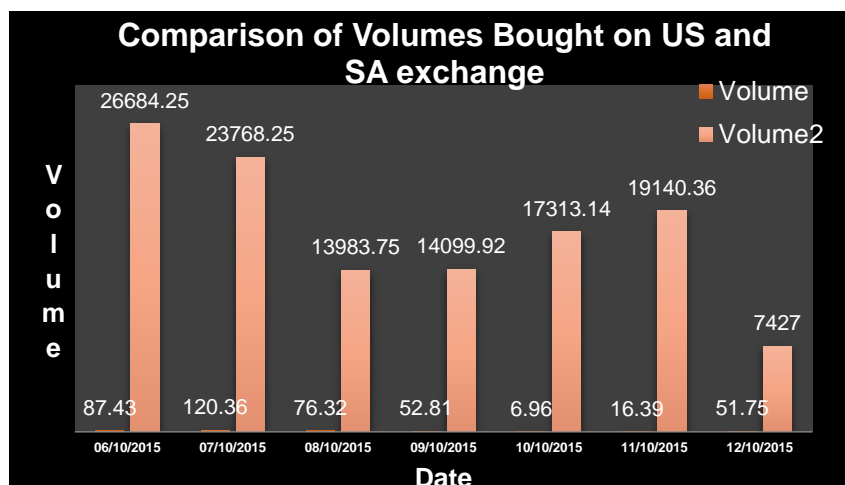
## **5.2 Discussion**

### **5.2.1 Volume**

One of the reasons for the Law of One Price theory failing could include trading volumes across exchanges. The South African bitcoin market is fairly young in comparison to more established markets in the United States and the United Kingdom. There are four bitcoin exchanges in existence in the country, the earliest of

which was only established in 2013. This indicates a much smaller market than is present in the rest of the world. The local market has fairly low trade volumes in comparison to the other bitcoin markets around the world. In the week of 6 October 2015 to 12 October 2015 the total trade volume on one of the South African exchanges has been 412.02 bitcoins, with an average of 58.86 bitcoins traded per day. If this is compared to the total trade volume on one of the American exchanges, this amounted to 122,416.67 with an average of 17488.10 bitcoins traded per day. The South African exchange trades at 29,611% lower than the American exchange based on the total weekly volume. These low volumes point to the illiquidity in the South African bitcoin market. This illiquidity could provide a hindrance to arbitrage opportunities being capitalised on leading to the Law of One Price not holding. For arbitrage opportunities to be capitalised on the arbitrageur needs to be able to buy and sell bitcoins immediately as and when is needed. If the trade volumes are low, this could mean that when the arbitrage opportunity is found, there are no willing buyers or sellers to execute the transactions between. If this is the case, the possibility of arbitrage is greatly diminished meaning that the chance of restoring the price equilibrium is diminished.

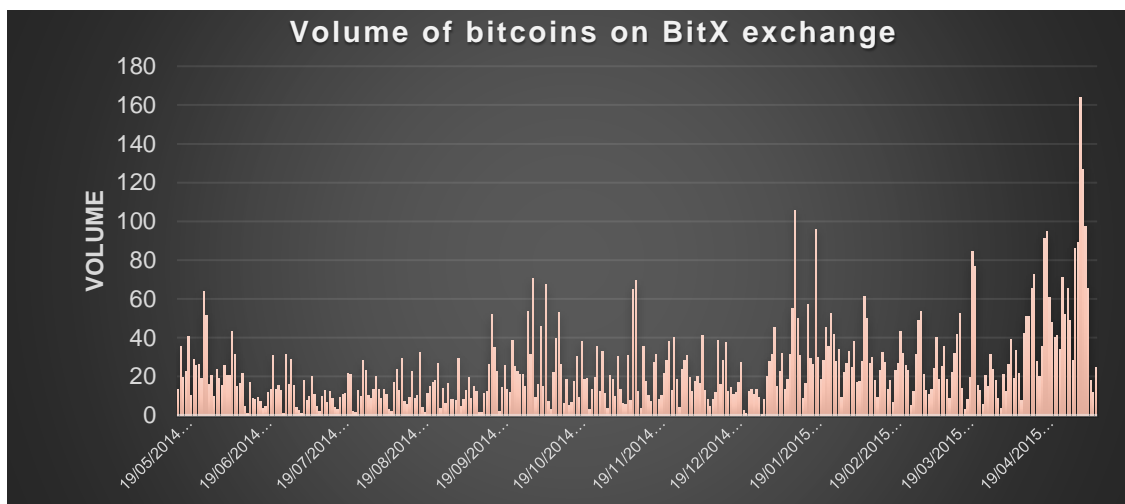
**Chart 1.1: Volume of bitcoins bought on BitX from 6/10/2015 till 12/10/2015**



Source: *BitX.com and Bitcoincharts.com*

A long term analysis of the bitcoin volumes traded shows that a total of 8564.72 bitcoins were bought from the exchange between the 19 May 2014 and 11 May 2015 which is an average of 23.87 bitcoins per day. This volume over the long-term seems to be low and is consistent with low volumes over the past week. It should be noted however that these are the trade volumes on one of the four South African exchanges. On the Localbitcoins.com exchange the trades for the week 6-12 October totalled 1236.73 bitcoins which is an average of 176.68 bitcoins traded per day.

**Chart 1.2: Volume of bitcoins bought on BitX from 19 May 2014 till 19 May 2015**



Source: Bitcoincharts.com

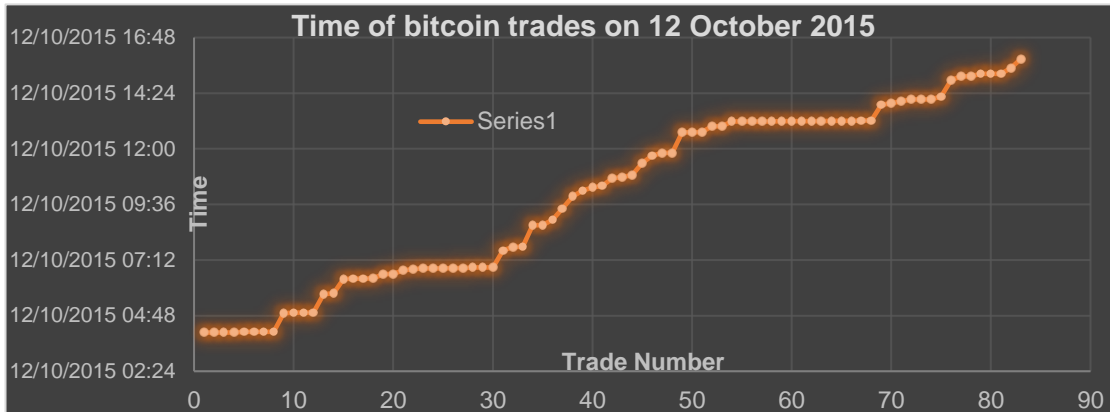
## 5.2.2 Time

It would be worthwhile to investigate the time between bitcoin transactions in addition to the transaction volumes. This is because as mentioned in chapter 2.4.4 the execution time of transactions is crucial to capitalising on arbitrage opportunities and



therefore restoring the Law of One Price. As can be seen from chart 1.3 below, trades are regularly carried out on the BitX exchange.

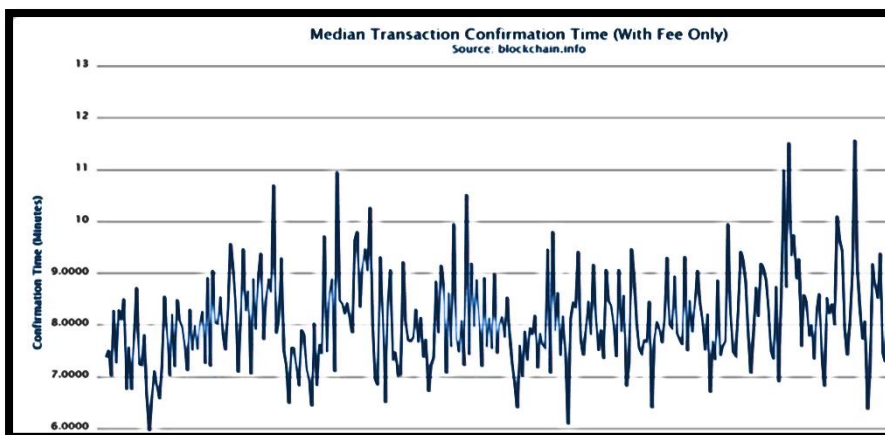
**Chart 1.3: Chart showing the times of bitcoin trades on 12 October 2015**



Source: BitX.com

Between the hours of 13:00 and 14:00 17 transactions were carried out on the exchange. This seems to be a low number of transactions which may not help an arbitrageur when they want to execute an arbitrage transaction.

**Chart 1.4: Median Transaction Confirmation Time for bitcoins**



Source: (Blockchain, 2015)

What is even more important is the time that it takes to confirm or complete a bitcoin transaction. While chart 1.4 does not relate to a specific bitcoin exchange, it does give an idea of how long users could expect a transaction could take to execute. Chart 1.4 shows that a bitcoin transaction does not get confirmed any quicker than 6 minutes on average. This is highly contrasted to an online banking transaction that is confirmed almost immediately or a transaction in the currency market that is executed within milliseconds which is substantially quicker than the bitcoin market according to (FXCM, 2016).

The time that it takes to execute a transaction could provide a further hindrance because this is not the standard time that it takes for every transaction. This is rather an average, meaning that some transactions will take much longer and some transactions will be executed much quicker. If the one arbitrageur happens to achieve a transaction time that is below the average and the other arbitrageur achieves a transaction time that is above the average, this gives the advantage to the arbitrageur who achieves the faster transaction time.

### **5.2.3 Price**

A comparison bitcoin prices across South African exchanges could also provide a visual aid to help identify whether prices are consistent across exchanges within the same country. Even though this is not the focus of this paper, if prices are roughly the same within the country it stands to reason that it could exist across borders. A single day comparison will be used to identify whether there is a relationship between the bitcoin prices on the AltCoin, BitX and Localbitcoins exchanges.

**Chart 1.5 Localbitcoins.com ZAR Closing Prices per Trade for 14 October 2015**



Source: Altcointrader.co.za

**Chart 1.6 Altcoin Exchange Closing Prices per Trade for 14 October 2015**



Source: Bitcoincharts.com

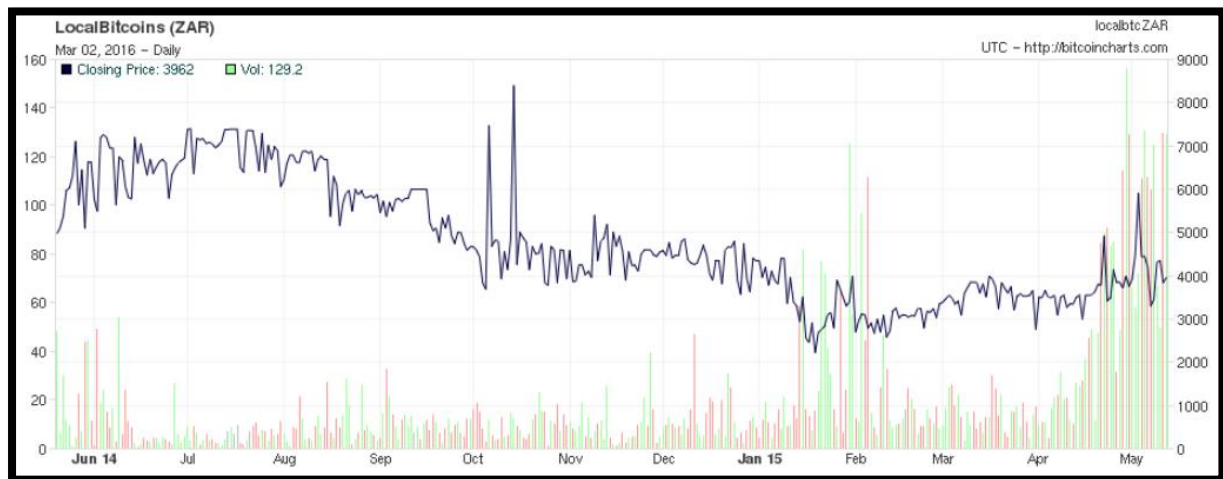
**Chart 1.7 BitX Exchange Closing Prices per Trade for 14 October 2015**



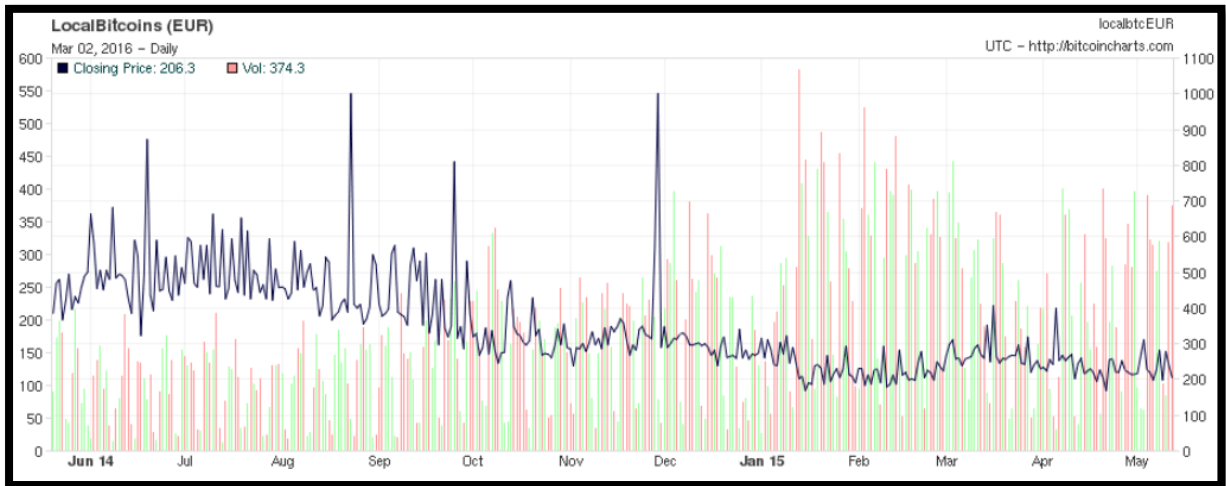
Source: Bitcoincharts.com

The bitcoin prices across the three exchanges represented in the graphs are fairly common on the majority of the transactions. The range of bitcoin prices for the Altcoin exchange is from R3650 to R3692.98, while the range for Localbitcoins exchange is R3527.30 to R5000 and the range for BitX is R3612 to R3650. The Localbitcoins exchange seems to have a much wider range of prices than the other exchanges. This could be because this is a user-determined exchange where the numerous buyers and sellers display the prices that they have set. This explains why R5000 was paid for one bitcoin on that exchange on the 14 October 2015. The price discrepancies can at times be large as the bitcoin could have bought for R3660 on Altcointrader.co.za and sold on Localbitcoins.com for R5000, resulting in a R1340 difference, which should be eliminated by arbitrage.

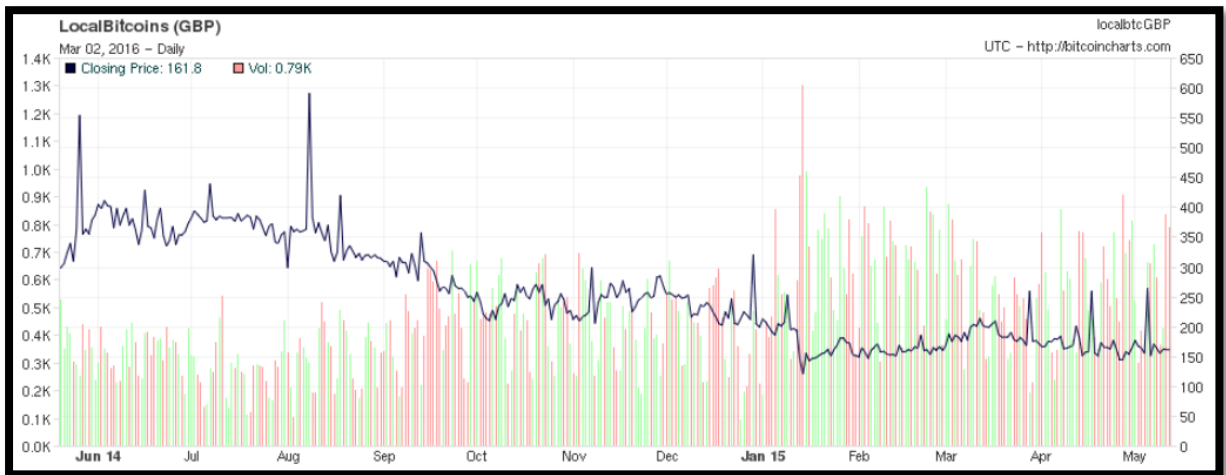
**Chart 1.5: Trade volumes and Bitcoin closing Prices on Localbitcoins.comZAR**



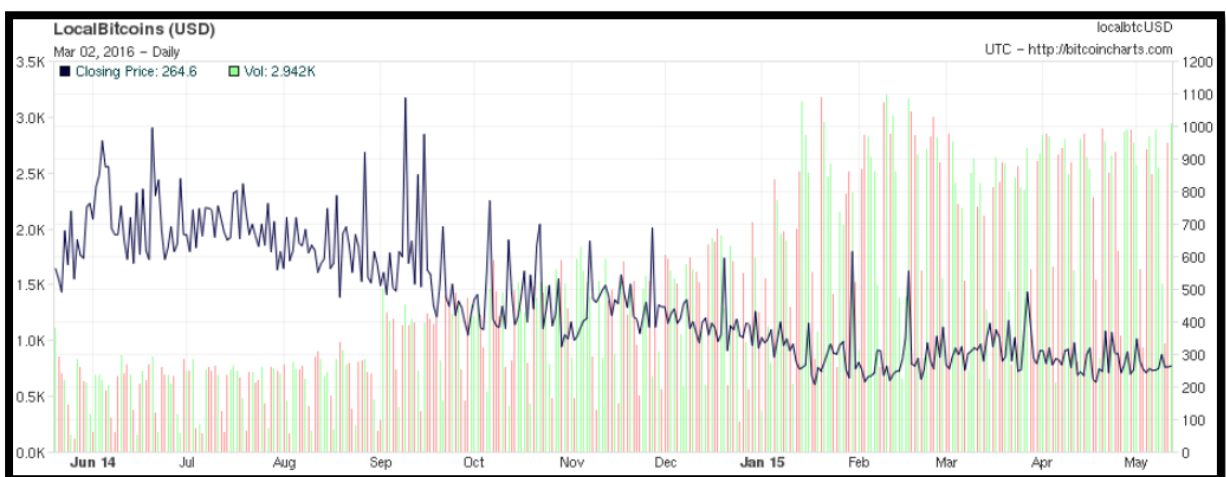
**Chart 1.6: Trade volumes and Bitcoin closing Prices on Localbitcoins.com EUR**



**Chart 1.7 Trade volumes and Bitcoin closing Prices on Localbitcoins.com GBP**



**Chart 1.8 Trade volumes and Bitcoin closing Prices on Localbitcoins.com USD**



**Chart 1.9 Trade volumes and Bitcoin closing Prices across BitX exchange**



**Chart 1.10 Trade volumes and Bitcoin closing Prices on HitBTC USD exchange**



**Chart 1.11 Trade volumes and Bitcoin closing Prices on HitBTC EUR exchange**



**Chart 1.12 Trade volumes and Bitcoin closing Prices on Coinfloor exchange**



Source: [Bitcoincharts.com/charts/](http://Bitcoincharts.com/charts/) (ALL)

A comparison of the different exchanges being used in the empirical tests should provide useful information about the relationship between the bitcoin prices across these exchanges. This relationship may hint at a correlation between prices, which is confirmed using Johansen Cointegration. Visually useful information could still be extracted from comparing closing bitcoin prices across the ZAR, USD, EUR and GBP exchanges using charts 1.5-1.8 and 1.9-1.12 above. The price comparison is for a one year period from 19 May 2014 till 18 May 2015. All of the exchanges took a dip in prices on in January 2015 and early October 2014 and mid-August 2014. The Localbitcoins.com exchanges seem to have more price volatility and have a generally larger range of prices which can be explained by customers' setting bid and ask prices. These price movements, as depicted in charts 1.5-1.8, follow a similar general pattern except for large price deviations on particular days. This large deviation is shown by the price being roughly R5000 in chart 1.5 and 1000 euros in chart 1.7 near the end of August 2015.

The exchange-determined exchanges seem to have price movements which are much closer aligned. The bitcoin prices on these exchanges in charts 1.9-1.12 seem to have a strong price relationship. The general matching of price fluctuations is to be expected as a result of the law of one price theory that will be described below. This poses a good sign for the efficiency of these bitcoin exchanges across countries. However the slight mismatches between the exchanges does not dispel the theory but will lead to the theory holding if arbitrated away.

The results from the first cointegration test, in Extract 1.17 (Appendix 3), indicated three cointegrating relationships. The existence of three cointegrating vectors amongst the Localbitcoins.com ZAR, USD, EUR and GBP exchanges indicates that there is a common trend amongst the four bitcoin exchanges tested. It can therefore be said that the four bitcoin exchanges tested are cointegrated and as such the Law of One Price theory holds across these exchanges for the South African, European, United States and Great Britain markets. This points to an efficient bitcoin market existing across a single bitcoin exchange, being the Localbitcoins.com platform. Simply put this would mean that the Euro price of a bitcoin on the Localbitcoins.com Europe exchange has a relationship with the converted price of one bitcoin on the Localbitcoins.com Pound exchange. As a result of this relationship, the two prices move together and therefore statistically the Law of One Price holds.

It must be pointed out that the same platform was being tested amongst the four different currencies, which could increase the chance of the Law of One Price holding. This could be because of the easy access to the information of the different countries/currencies on the same trading platform. That is, if the same user wanted



to enter into bitcoin arbitrage, it is likely that he would arbitrage across the same exchange due to the familiarity of transacting on an exchange that he can easily navigate. This provides the ease of using a single platform to carry out the series of transactions thereby avoiding the need to switch exchanges that may involve different trading rules. This also avoids incurring extra transaction costs or time delays as a result of switching to a different exchange to carry out the arbitrage transaction and restore the price equilibrium. The lack of time delays could aid price integration due to the fact that execution times on the Localbitcoins.com exchanges are identical. The transaction costs across the same exchange would be identical and therefore do not pose a threat to the conformity to the Law of One Price theory. The similarity of the price movements across these currencies is therefore a valid expectation. This can be evidenced by the visual similarities found in Chapter 5.2.3 with regards to the Localbitcoins.com exchanges.

The conformance to the Law of One Price theory could indicate that users of this bitcoin exchange generally consider bitcoin to function as a currency. This perception can be vital to the conformity of the Law of One Price theory because if bitcoin is traded as a currency it is more likely to have greater liquidity. As mentioned in Chapter 2.4.4 the greater the liquidity the greater the chance that arbitrage is carried out and price equilibrium is restored.

The results from the second cointegration test, from Extract 1.18, indicate the existence of one cointegrating vector. This means that there is only a single relationship that exists between one of the HitBTC Euro, HitBTC Dollar, Coinfloor and BitX exchanges. This shows a lack of price integration between the sampled exchanges. The possible relationship that exists for the exchange-determined price

exchanges could be due to the fact that the HITBTC exchange has been used twice in this analysis, for the EUR and USD exchanges. Therefore using the same exchange but amongst different currencies seems to provide a stronger relationship amongst the time series tested and therefore causes the Law of One Price theory to hold. This can be backed up by the fact that the Law of One Price held on the Localbitcoins.com exchanges amongst the different currencies tested in Extract 1.17.

From an investigation of the closing bitcoin prices and volumes in Chapter 5.2.3 and the literature review it was noted that a liquid market is vital to price equilibrium. The trade volumes of the exchange-determined bitcoin exchanges are generally lower than the Localbitcoins.com exchanges. This is indicated for example by the fact that on average 510.9 bitcoins are traded per day on HitBTC USD as compared to 1375.1 on average on Localbitcoins.com USD, while 100.1 bitcoins are traded on average on the Coinfloor exchange versus 455.8 on average on the Localbitcoins.com GBP exchange. This lower market liquidity poses a threat to the successful arbitraging away of price disequilibrium.

Furthermore the low trading volumes could imply that customers on these exchanges are holding onto their bitcoins as an investment rather than for short term gains or use as a currency. As indicated by Dong and Dong (2014), the fact that bitcoin is perceived as not being a currency in chapter 2.4.2 could cause price disequilibrium. While the theoretical application of bitcoin as a currency seems plausible, in reality it is not currently a currency simply because customer and merchant acceptance of it is not globally wide-spread. The fact that different customers using different exchanges perceive the uses of bitcoin differently is

entirely possible due to bitcoin being heavily dependent on customers and their choice to use them.

The concept of purposefully inefficient behaviour should also be strongly considered as a reason for the lack of price equilibrium. Illegal motives are high on the agenda for many bitcoin users as it could aid money-laundering or the funding of terrorism as discussed in Chapter 2.4.1. Using bitcoin to get money off of the radar of the government, for example by evading tax or exchange control regulations is also a possible use for the cryptocurrency given its unique characteristics. It is therefore highly plausible that this behaviour could account for the difference in bitcoin prices. The anonymity as mentioned in Chapter 2.4.1 however prevents us from ever fully identifying this purposefully inefficient behaviour.

Overall it however cannot be claimed that the Law of One Price holds for the bitcoin exchanges tested. This is because a test has not been carried out on regional bitcoin markets as a whole, which could be an area for further research as discussed in Chapter 5.3. Therefore an opinion on the user-determined exchanges of Localbitcoins.com for the United States, South Africa, Europe and Great Britain can be determined to show that the Law of One Price holds across these exchanges. The Law of One Price does not hold for the exchange-determined exchanges for a sample of platforms in the United States, South Africa, Europe and Great Britain.

The Law of One Price theory does not hold for all the bitcoin exchanges tested. It cannot be said conclusively that price integration exists amongst the bitcoin exchanges tested, but rather that price integration is heavily dependent on using the same bitcoin exchange with similar price volatility, market liquidity, transaction costs

and execution times. The non-conformance is consistent with the majority of literature as summarised by to Buharumshah & Habibullah (1995) in the literature review. This inconclusive finding means that the methodological issues that were supposedly solved by prior literature have possibly not been successfully resolved. This could mean that there is room for further improvement on the methodology. The lack of conformance to the law should have been aided by the completely identical and non-physical nature of bitcoins. The non-conformance may prove that the nature of bitcoins may not be the most influential factor for conformance as the low trade volumes globally as well as the other motives for using bitcoin may drive the price equilibrium.

### **5.3 Recommendations**

The methodology could be improved by taking into account the fact that the closing prices of bitcoins while all at midnight in their respective countries, are hours apart. This time difference is significant for the United States, however does not represent as big of an issue for the United Kingdom who are between 1-2 hours behind South Africa and does not represent an issue for Europe which is generally on the same time zone as South Africa. In the future it should be considered whether a test of the South African bitcoin market as a whole in comparison to other countries bitcoin markets as a whole exists. A future area of research that would be useful to identifying whether the Law of One Price theory holds for bitcoins would be a deeper study into bitcoin market volatility and liquidity. If a statistical understanding of bitcoin price volatility as well as liquidity can be identified this will aid the understanding of

bitcoin arbitrage. Directly testing bitcoin market efficiency is also an area of interest which could be accomplished through random walk studies.

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## APPENDIX 1: Unit Root Tests on Price data

### Extract 1.1: Augmented Dickey-Fuller Unit Root Test on BitX Exchange Prices (ZAR)

Augmented Dickey-Fuller Unit Root Test on CLOSE01		
Null Hypothesis: CLOSE01 has a unit root		
Exogenous: Constant		
Lag Length: 2 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.271493	0.6442
Test critical values:		
1% level	-3.442530	
5% level	-2.866805	
10% level	-2.569635	
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(CLOSE01)		
Method: Least Squares		
Date: 02/20/16 Time: 18:00		
Sample (adjusted): 4 530		
Included observations: 527 after adjustments		

### Extract 1.2: Augmented Dickey-Fuller Unit Root Test on HitUSD Exchange Prices (USD)

Augmented Dickey-Fuller Unit Root Test on HITUSDCLOSE		
Null Hypothesis: HITUSDCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 4 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.498912	0.5336
Test critical values:		
1% level	-3.442578	
5% level	-2.866826	
10% level	-2.569646	
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(HITUSDCLOSE)		
Method: Least Squares		
Date: 02/20/16 Time: 17:59		
Sample (adjusted): 6 530		
Included observations: 525 after adjustments		

Extract 1.3: Augmented Dickey-Fuller Unit Root Test on HitEuro Exchange Prices (EUR)

Augmented Dickey-Fuller Unit Root Test on HITEURCLOSE		
Null Hypothesis: HITEURCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 5 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.520287	0.5227
Test critical values:	1% level	-3.442601
	5% level	-2.866836
	10% level	-2.569652
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(HITEURCLOSE)		
Method: Least Squares		
Date: 02/20/16 Time: 18:01		
Sample (adjusted): 7 530		
Included observations: 524 after adjustments		

Extract 1.4: Augmented Dickey-Fuller Unit Root Test on Coinfloor Exchange Prices (GBP)

Augmented Dickey-Fuller Unit Root Test on COINFLOORCLOSE		
Null Hypothesis: COINFLOORCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 2 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.310523	0.6261
Test critical values:	1% level	-3.442530
	5% level	-2.866805
	10% level	-2.569635
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(COINFLOORCLOSE)		
Method: Least Squares		
Date: 02/20/16 Time: 18:01		
Sample (adjusted): 4 530		
Included observations: 527 after adjustments		

Extract 1.5: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange Prices

(ZAR)

Augmented Dickey-Fuller Unit Root Test on LZARCLOSE		
Null Hypothesis: LZARCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 8 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.612211	0.4756
Test critical values:		
1% level	-3.442673	
5% level	-2.866868	
10% level	-2.569669	
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LZARCLOSE)		
Method: Least Squares		
Date: 02/21/16 Time: 14:47		
Sample (adjusted): 10 530		
Included observations: 521 after adjustments		

Extract 1.6: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange Prices

(GBP)

Augmented Dickey-Fuller Unit Root Test on LGBPCLOSE		
Null Hypothesis: LGBPCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 5 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.502177	0.5319
Test critical values:		
1% level	-3.442601	
5% level	-2.866836	
10% level	-2.569652	
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LGBPCLOSE)		
Method: Least Squares		
Date: 02/21/16 Time: 14:47		
Sample (adjusted): 7 530		
Included observations: 524 after adjustments		

Extract 1.7: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange Prices

(USD)

Augmented Dickey-Fuller Unit Root Test on LUSDCLOSE		
Null Hypothesis: LUSDCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 16 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-2.105930	0.2425
Test critical values:	1% level	-3.442869
	5% level	-2.866954
	10% level	-2.569715
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LUSDCLOSE)		
Method: Least Squares		
Date: 02/21/16 Time: 14:47		
Sample (adjusted): 18 530		
Included observations: 513 after adjustments		

Extract 1.8: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange Prices

(EUR)

Augmented Dickey-Fuller Unit Root Test on LEURCLOSE		
Null Hypothesis: LEURCLOSE has a unit root		
Exogenous: Constant		
Lag Length: 13 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.698630	0.4314
Test critical values:	1% level	-3.442795
	5% level	-2.866922
	10% level	-2.569697
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LEURCLOSE)		
Method: Least Squares		
Date: 02/21/16 Time: 14:47		
Sample (adjusted): 15 530		
Included observations: 516 after adjustments		

## APPENDIX 2: Unit Root Tests after First Difference on Exchange Prices

### Extract 1.9: Augmented Dickey-Fuller Unit Root Test on BitX Exchange Prices (ZAR)

Augmented Dickey-Fuller Unit Root Test on D(CLOSE01)		
Null Hypothesis: D(CLOSE01) has a unit root		
Exogenous: Constant		
Lag Length: 1 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-21.38592	0.0000
Test critical values:		
1% level	-3.442530	
5% level	-2.866805	
10% level	-2.569635	
*MacKinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(CLOSE01,2)		
Method: Least Squares		
Date: 02/21/16 Time: 14:52		
Sample (adjusted): 4 530		
Included observations: 527 after adjustments		

### Extract 1.10: Augmented Dickey-Fuller Unit Root Test on Coinfloor Exchange Prices (GBP)

Augmented Dickey-Fuller Unit Root Test on D(COINFLOORCLOSE)		
Null Hypothesis: D(COINFLOORCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 8 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-7.935381	0.0000
Test critical values:		
1% level	-3.442698	
5% level	-2.866879	
10% level	-2.569674	
*MacKinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(COINFLOORCLOSE,2)		
Method: Least Squares		
Date: 02/21/16 Time: 14:52		
Sample (adjusted): 11 530		
Included observations: 520 after adjustments		



Extract 1.11: Augmented Dickey-Fuller Unit Root Test on HitEuro Exchange Prices (EUR)

Augmented Dickey-Fuller Unit Root Test on D(HITEURCLOSE)		
Null Hypothesis: D(HITEURCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 4 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-10.17789	0.0000
Test critical values:	1% level	-3.442601
	5% level	-2.866836
	10% level	-2.569652
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(HITEURCLOSE,2)		
Method: Least Squares		
Date: 02/21/16 Time: 14:52		
Sample (adjusted): 7 530		
Included observations: 524 after adjustments		

Extract 1.12: Augmented Dickey-Fuller Unit Root Test on HitUSD Exchange Prices (USD)

Augmented Dickey-Fuller Unit Root Test on D(HITUSDCLOSE)		
Null Hypothesis: D(HITUSDCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 3 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-11.10147	0.0000
Test critical values:	1% level	-3.442578
	5% level	-2.866826
	10% level	-2.569646
*Mackinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(HITUSDCLOSE,2)		
Method: Least Squares		
Date: 02/21/16 Time: 14:52		
Sample (adjusted): 6 530		
Included observations: 525 after adjustments		

Extract 1.13: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange

Prices (EUR)

Augmented Dickey-Fuller Unit Root Test on D(LEURCLOSE)		
Null Hypothesis: D(LEURCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 12 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-11.06067	0.0000
Test critical values: 1% level	-3.442795	
5% level	-2.866922	
10% level	-2.569697	
*MacKinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LEURCLOSE,2)		
Method: Least Squares		
Date: 02/20/16 Time: 18:03		
Sample (adjusted): 15 530		
Included observations: 516 after adjustments		

Extract 1.14: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange

Prices (USD)

Augmented Dickey-Fuller Unit Root Test on D(LUSDCLOSE)		
Null Hypothesis: D(LUSDCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 18 (Automatic - based on AIC, maxlag=18)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-9.211304	0.0000
Test critical values: 1% level	-3.442945	
5% level	-2.866988	
10% level	-2.569733	
*MacKinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LUSDCLOSE,2)		
Method: Least Squares		
Date: 02/20/16 Time: 18:02		
Sample (adjusted): 21 530		
Included observations: 510 after adjustments		

Extract 1.15: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange

Prices (GBP)

Augmented Dickey-Fuller Unit Root Test on D(LGBPCLOSE)		
Null Hypothesis: D(LGBPCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 4 (Automatic - based on AIC, maxlag=18)		
		t-Statistic      Prob.*
<hr/>		
Augmented Dickey-Fuller test statistic		-15.33652      0.0000
Test critical values:	1% level	-3.442601
	5% level	-2.866836
	10% level	-2.569652
<hr/>		
*MacKinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LGBPCLOSE,2)		
Method: Least Squares		
Date: 02/20/16 Time: 18:02		
Sample (adjusted): 7 530		
Included observations: 524 after adjustments		

Extract 1.16: Augmented Dickey-Fuller Unit Root Test on Localbitcoins.com Exchange

Prices (ZAR)

Augmented Dickey-Fuller Unit Root Test on D(LZARCLOSE)		
Null Hypothesis: D(LZARCLOSE) has a unit root		
Exogenous: Constant		
Lag Length: 7 (Automatic - based on AIC, maxlag=18)		
		t-Statistic      Prob.*
<hr/>		
Augmented Dickey-Fuller test statistic		-11.29895      0.0000
Test critical values:	1% level	-3.442673
	5% level	-2.866868
	10% level	-2.569669
<hr/>		
*MacKinnon (1996) one-sided p-values.		
Augmented Dickey-Fuller Test Equation		
Dependent Variable: D(LZARCLOSE,2)		
Method: Least Squares		
Date: 02/20/16 Time: 18:02		
Sample (adjusted): 10 530		
Included observations: 521 after adjustments		

## APPENDIX 3: Cointegration Results

### Extract 1.17: Cointegration test on Localbitcoins.com for ZAR, USD, GBP and EUR

#### Exchanges.

Johansen Cointegration Test Summary					
Date: 02/20/16 Time: 18:06					
Sample: 1 530					
Included observations: 525					
Series: LZARCLOSE LEURCLOSE LGBPCLOSE LUSDCLOSE					
Lags interval: 1 to 4					
Selected (0.05 level*) Number of Cointegrating Relations by Model					
Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	3	3	3	3	3
Max-Eig	3	3	3	3	3
*Critical values based on MacKinnon-Haug-Michelis (1999)					
Information Criteria by Rank and Model					
Data Trend:	None	None	Linear	Linear	Quadratic
Rank or No. of CEs	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Log Likelihood by Rank (rows) and Model (columns)					
0	-16696.26	-16696.26	-16696.20	-16696.20	-16695.86
1	-16630.59	-16629.13	-16629.07	-16628.09	-16627.75
2	-16592.79	-16588.11	-16588.05	-16586.14	-16585.80
3	-16577.31	-16565.05	-16565.00	-16562.99	-16562.66
4	-16577.04	-16563.75	-16563.75	-16561.52	-16561.52
Akaike Information Criteria by Rank (rows) and Model (columns)					
0	63.84859	63.84859	63.86361	63.86361	63.87755
1	63.62891	63.62715	63.63838	63.63844	63.64857
2	63.51530	63.50517	63.51250	63.51200	63.51023

Source: Eviews Statistical Package

### Extract 1.18: Cointegration test on BitX, Coinfloor, HitUS and HitEur Exchanges

Johansen Cointegration Test Summary					
Date: 02/20/16 Time: 18:09					
Sample: 1 530					
Included observations: 525					
Series: HITEURCLOSE HITUSDCLOSE COINFLOORCLOSE CLOSE01					
Lags interval: 1 to 4					
Selected (0.05 level*) Number of Cointegrating Relations by Model					
Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	1	1	1	1	1
Max-Eig	1	1	1	1	1
*Critical values based on MacKinnon-Haug-Michelis (1999)					
Information Criteria by Rank and Model					
Data Trend:	None	None	Linear	Linear	Quadratic
Rank or No. of CEs	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Log Likelihood by Rank (rows) and Model (columns)					
0	-12744.28	-12744.28	-12743.88	-12743.88	-12742.99
1	-12711.23	-12708.33	-12707.93	-12707.22	-12706.33
2	-12706.93	-12702.07	-12701.69	-12698.98	-12698.11
3	-12704.17	-12698.17	-12698.16	-12694.49	-12693.64
4	-12704.10	-12697.09	-12697.09	-12693.38	-12693.38
Akaike Information Criteria by Rank (rows) and Model (columns)					
0	48.79346	48.79346	48.80715	48.80715	48.81899

Source: Eviews Statistical Package