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LIQUIDITY AND MARKET EFFICIENCY: THE CASE OF BITCOIN DERIVATIVES

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ABSTRACT

This thesis seeks to discover how Bitcoin's lack of liquidity causes its financial derivatives to behave differently than one would expect. This paper will specifically examine the regulated options and futures markets for Bitcoin.

Options offered at LedgerX provide insight into Bitcoin's liquidity by examining its term structure of volatility and volatility smiles. The difference between the implied volatilities for calls and puts suggest there is not enough trading for these options to have competitive pricing. This is further confirmed by studying volatility smiles that indicate there are call options trading at 0% implied volatility, when an investor should expect to pay for 80-100% volatility.

This thesis then considers the futures market for Bitcoin. The futures curves appear to accurately represent investor sentiment toward Bitcoin at the time. However, the prices of the futures contract do not favor a positive or negative convenience yield. This indicates the futures contracts are not competitively priced either. This is further solidified by the numerous arbitrage opportunities available upon expiration.

The thesis finds that the lack of liquidity is inhibiting Bitcoin from transitioning into a more mature market. This is an important topic of research for anyone considering investing in Bitcoin or its derivatives.

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Chapter 1 Introduction

Bitcoin has been a popular topic of discussion since its introduction in 2009. It caught the attention of many individuals, investors, and the average person alike, as its price exceeded $1,000 in January 2017 to its all-time high of $20,000 in December 2017.

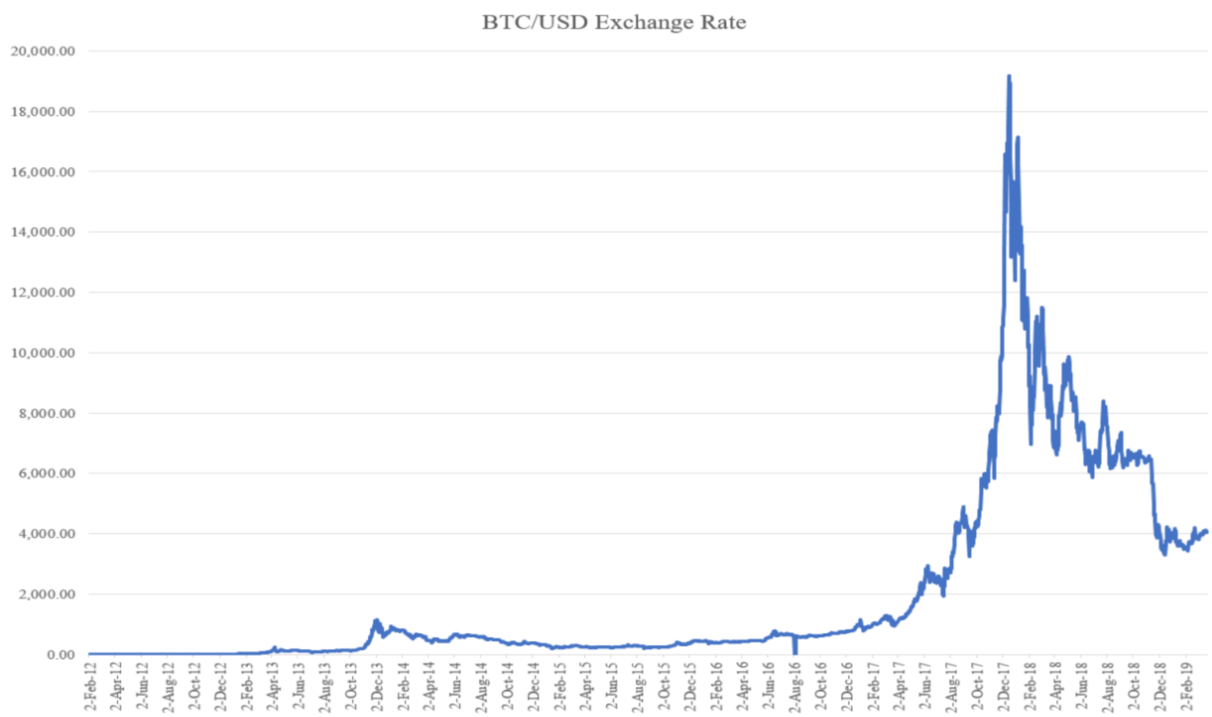

Figure 1. Bitcoin - USD Exchange Rate over Time

During the time, when bitcoin prices were reaching these all-time highs, these new and innovative digital assets were intertwining with the long established U.S. financial markets. In October 2017, LedgerX became the first federally regulated exchange to offer option contracts on Bitcoin. Then in mid-December 2017, the Chicago Mercantile Exchange (CME) and the Chicago Board of Options Exchange (CBOE) introduced their own Bitcoin futures contracts.

Sceptics of Bitcoin were excited to finally have an avenue to short the digital asset, believing the futures contracts would lead to more fairly priced bitcoins. Bullish investors were happy to have another avenue to invest in Bitcoin, rather than simply holding the digital currency. With these contracts being sold on two of the biggest derivative exchanges in the world, there has been increased pressure from the SEC to establish Bitcoin as an asset class.

Simply offering these derivatives may not be enough to intertwine the cryptocurrency and U.S. financial markets if there are not enough investors who trade these contracts. This thesis works to analyze the liquidity of these markets to gauge investor interest. The rest of the thesis is organized as follows: Chapter 2 summarizes what Bitcoin is, Chapter 3 discusses some models on how Bitcoin's price is determined along with the risks involved in investing in Bitcoin including fraud, Chapter 4 examines the volatility of Bitcoin through option contracts, Chapter 5 summarizes the futures market, Chapter 6 analyzes futures curves and the cost of carry, Chapter 7 breaks down its use as a financial asset including arbitrage opportunities, and Chapter 8 is the concluding section that also includes a discussion for further research.

Chapter 2 Introduction to Bitcoin

Bitcoin is a virtual currency that eliminates the necessity for a central authority or bank by utilizing peer-to-peer technology to manage transactions (Satoshi, 2008). Bitcoin is public, therefore it is not owned by anyone, and everyone can partake. Its rules were designed by engineers with little influence from lawyers and regulators. Bitcoin does not use a single server or set of servers to store transactions, but rather employs the use of a transaction log that is distributed across a network of participating computers. The system rewards honest participation and seeks to guard against any concentration of power. Any Bitcoin transactions are irreversible and published to a public record.

Bitcoin Technology and Processes

The “Bitcoin core” software can be freely downloaded at https://bitcoin.org/en/chooseyour-wallet. The standard software includes numerous features such as a “wallet” file to store bitcoins. This software creates an individual node in the peer-to-peer network and provides access to the “block chain” data that verifies all past Bitcoin activity.

Bitcoins are recorded as transactions, rather than as a physical asset. Rainer Bohme, Dominic Breuker, and Malte Moser (2013) describes a bitcoin transaction with users Charlie, Bob, and Alice. Consider some user Charlie. He does not simply “hold” three bitcoins. Instead, Charlie participates in a publicly verifiable transaction that shows he received three bitcoins from Bob. Charlie is able to receive this transaction because he can verify that Bob made a prior transaction where he received three bitcoins from Alice. There was no prior transaction in which Bob spent these bitcoins.

Every bitcoin is traceable through all transactions dating back to the inception of its circulation. Due to the public nature of the widely replicated data structure in which bitcoins are stored, everyone can read past transactions. New transactions that are published to the Bitcoin network are periodically grouped together in a “block.” The block will be compared to the most recently published block. This creates a sequence of blocks or a “block chain.” A new block is added to the block chain every ten minutes. A Bitcoin transaction will not clear, and is therefore invalid, until it has been added to the block.

Incentives in the Bitcoin Network

There are several incentives integrated within the Bitcoin technologies and processes in order to encourage honest and productive behavior. Bitcoin mining is simply the process of adding records to the block chain. The miners that are able to solve mathematical problems and verify the block chain are rewarded with bitcoins (Bohme et al., 2013). These rewards are automatically rewarded when the miner solves the proof-of-work problem, rather than being controlled by a physical, governing entity. A proof-of-work is a piece of data that was difficult to produce. The costs of processing power refer to hardware, energy, and time. When Bitcoin was first introduced, miners were rewarded with 50 bitcoins for solving the puzzle. The reward is cut in half every 210,000 blocks, or approximately 4 years. Currently, the reward stands at 12.5 bitcoins. Once 21 million bitcoins are minted, the reward will fall to zero and no more bitcoins will be created. Mining difficulty ensures this limited supply isn’t reached too quickly. Mining difficulty is a measure of how difficult it is for a miner to add a new block compared to the easiest it could ever be. As more miners join, the rate of block creation will go up and the mining difficulty will rise in order to push the rate of block creation back down.

However, miners have a second source of revenue. When a buyer and seller list a transaction, miners can offer to pay a transaction fee, which is a bonus payment to any miner that solves the puzzle that verifies the transaction.

Decentralization in the Bitcoin Ecosystem

As previously mentioned, Bitcoin has no central governance structure, which has several implications for the functioning of the system. First, Bitcoin does not use any financial institution, payment processor, or other intermediary to verify a user's identity. Second, Bitcoin imposes no prohibition on sales of particular items, unlike credit card companies who restrict the sale of goods that are illegal in nature. Finally, all Bitcoin transactions are irreversible, which means there is no way for a payer to reverse an accidental or unwanted transaction.

The implications of these decentralized core technologies exemplify how Bitcoin is different than other virtual currencies. Decentralization has various advantages that drew early adaptors to use bitcoin over other virtual currencies. These advantages are comprised of the exclusion of power in order to prevent the concentration of power, which would allow one person or an organization to take control. Furthermore, Bitcoin offers more privacy for users than its counterparts. In theory, any eavesdropper (someone looking through the public record) could not observe an entire transaction across the whole system by targeting a single point or server. Despite this advantage, other privacy concerns remain.

To promote greater privacy in the system, Bitcoin uses mixers. Since the Bitcoin transaction log shows each transaction made, anyone who knows the identity of the user can track that user's other transactions. Mixers let users pool sets of transactions in unpredictable combinations. All transaction records are still publicly available, but the identity of those involved in the transactions are harder to maintain. Using Bohme, et al's (2013) same transaction explanation as before, suppose Alice wants to pay Bob one bitcoin and Charles wants to pay Daisy one bitcoin. Alice and Charles could both pay a mixer "Minnie" and tell Minnie to pay Bob and Daisy one bitcoin each. An observer of these cash flows would not be able to tell if Alice paid Bob one bitcoin or if Alice paid Daisy one bitcoin. Mixers charge 1 to 3 percent of the amount sent, which increases the costs for anyone involved in the transaction.

Uses of Bitcoin

Early users of Bitcoin consisted of businesses that wanted greater anonymity and fewer rules and regulations regarding the commodity being bought and sold. Prominent examples include the online sale of narcotics, marijuana, and prescription drugs. According to the government's evidence in the case against Ross Ulbricht, 9.9 million bitcoins or $214 million were used to buy illegal items on the Silk Road, an online platform (Bohme et al., 2013). The Silk Road was taken down due to law enforcement, but more than 30 competitors took its place.

In addition to sites such as The Silk Road, gambling sites also use Bitcoin as a currency. These sites seek to protect customer privacy, as well as provide customers who are unable to make payments with other payment methods. In 2012 the most popular bitcoin gambling site was Satoshi Dice, but now more than 100 casinos, poker sites, dice games, and lotteries use Bitcoin.

Bitcoin has also caught the attention of merchants as a result of the unappealing high fees charged by its competitors, such as credit and debit card companies. Subsequently, Bitcoin may pressure card companies to lower their fees charged to merchants. Consumers, on the other hand, may not benefit as much from paying with Bitcoin. Major credit card companies offer cash back to their customers from 1 percent, 2 percent, or more, in addition to similar benefits such as frequent flyer points. If a consumer uses Bitcoin, they forfeit these benefits. Benjamin Edelman (2014) emphasizes that a consumer would be better off making their purchase on a 1.5 percent cash back credit card as opposed to paying 1 percent to convert their bitcoins to dollars and using them to pay the credit card bill.

It is exceedingly difficult to foresee Bitcoin being utilized for general-purpose transactions and day-to-day payments. Every Bitcoin transaction must be copied into all future versions of the block chain. If Bitcoin were to be used in this manner, storage would become a burden. Additionally, the block chain requires updates in order for a Bitcoin transaction to be completed, which is too slow for in person purchases.

Some consumers see Bitcoin becoming an all-purpose payment merchant, but others contend Bitcoin's potential lies in its ability to create a decentralized record for almost anything. Marc Andreessen (2014) explains this technological opportunity. "Bitcoin gives us, for the first time, a way for one Internet user to transfer a unique piece of digital property to another Internet user, such that the transfer is guaranteed to be safe and secure, everyone knows that the transfer has taken place, and nobody can challenge the validity of the transfer." He highlights the necessity of this feature in terms of digital signatures, digital contracts, digital ownership of physical assets (cars and houses), digital stocks and bonds, and digital money. So far, there has been minimal use of Bitcoin outside of payments.

Chapter 3 Price Determinants

Risks in Bitcoin

Bitcoin, along with other numerous virtual currencies, has several risks that are not associated with traditional paper currency. Bohme, et al. (2013) describes these unique risks as market risk, the shallow market problem, counterparty risk, transaction risk, operational risk, privacy-related risk, and legal and regulatory risk, all of which will be expounded upon within the next few pages.

Market risk is faced by any user holding bitcoins as a result of the fluctuations in the exchange rate between bitcoin and traditional currencies. The Bitcoin—USD exchange rate has experienced significant spikes in price since Bitcoin's introduction in 2009. Users are quick to dismiss the fluctuation before mid-2013 as the risk of using a new currency, but the continuous, large price fluctuations since then are alarming. Users who want to use Bitcoin for transactional purposes, and users who hold Bitcoin as a store of value, should be concerned.

Another risk that is typically absent from traditional currencies is the shallow market problem. This problem is resultant of the relatively low daily trading volumes, which means a person wanting to trade a large amount of bitcoin typically cannot do so without affecting the market price. In 2018, the daily trading volume of Bitcoin was between $160 million and $500 million (blockchain.com, 2018). In contrast, the average EUR—USD daily trading volume is $575 billion.

Counterparty risk has become substantial in the Bitcoin ecosystem given the centralization of exchanges. Bitcoin.org lists 67 exchanges that operate in specific countries around the world, along with 4 exchanges that operate internationally. The website also articulates a warning that reads as follows: "[e]xchanges provide highly varying degrees of safety, security, privacy, and control over your funds and information. Perform your own due diligence and choose a wallet where you will keep your bitcoin before selecting an exchange," (2018). Tyler Moore and Nicolas Christin (2013) studied Bitcoin currencies exchanges and found high volume exchanges were likely to close because of a security breach, while low volume exchanges were likely to close without an explanation or warning. Of the exchanges that closed, 46 percent did not reimburse their customers for the bitcoins they held on the exchange. If users attempt to alleviate this risk by not holding bitcoins on an exchange, but in a digital wallet service, other risks will arise. Digital wallet services have become targets for cybercriminals. For example, 4,100 bitcoins were taken from Bitcoin wallets in November 2013 (Bohme, et al., 2015).

Due to the irreversibility of Bitcoin payments, Bitcoin has higher transaction costs. If a user sends bitcoins due to error or fraud, the system has no mechanism to undo this transaction. The only way to get the bitcoins back in this scenario is for the buyer and seller to voluntarily agree to correct the error. All else equal, a consumer should always prefer a payment system that allows for the reversal of unwanted or incorrect charges.

By design, the receiving of payment in Bitcoin is also accompanied by transaction risks. As discussed above, a Bitcoin transaction is not considered complete until it has been added to the block chain. This creates two main sources of risk: a block chain getting cancelled, and double spending. First, there is a low, but persistent, risk of a block chain that was once viewed as the authoritative block chain being cast aside, causing all transactions on that block chain to be cancelled. Second, malevolent users could attempt to double spend bitcoins through rapid transactions before the block chain has been officially updated (Bohme et al., 2013).

Operational risk involves any action that undermines Bitcoin’s core technological infrastructure and protocols. By nature, all users attempt to keep their private key secure, but there are still vulnerabilities such as operator error, security flaw, and malware. The whole Bitcoin platform additionally faces operational risk through vulnerabilities within the protocol design. Attention has been given to the “51 percent attack,” which would occur if a single group were to take control of the network by controlling 51 percent of the computational power (Bohme et al., 2013). The Bitcoin community might be able to raise defenses if such an attack were to occur, but it would undermine trust in Bitcoin.

Privacy risk becomes a concern if a transaction can be traced back to the people who made them. Bitcoin transactions cannot be completely anonymous, but to compensate for the lack of total anonymity, pseudonymous is used instead. Every transaction discloses account information and the block chain publishes all transactions by that user identifier. An observer of the transaction may be able to discern the user's real identity by looking at mailing addresses on retail purchases or currency exchanges (Bohme et al., 2013). The observer will then know all other transactions made by that same person.

Finally, regulatory risks are a concern for many who invest in Bitcoin. For example, a user could lose funds if an entire exchange is shut down or frozen due to criminal activity, even if that user was not doing anything illegal. Regulations and taxes are also uncertain, which makes financial planning more difficult, if not impossible.

Interest Rates and Monetary Policy

Another issue with Bitcoin is the lack of discretionary monetary policies in Bitcoin's ecosystem, making it hard to measure and define Bitcoin's inflation rate. This is primarily resultant of the difficulty of tracking and measuring commercial activities. Bitcoin supply, on the other hand, follows a fixed schedule. It follows Milton Friedman's "k-percent rule," which fixes the annual growth rate of money supply to a fixed growth rate. In theory, growth rate k may become negative in the future if bitcoins are irreversibly destroyed when users forget their private keys. The total number of bitcoins in circulation will be capped at 21 million. Therefore, the current supply may indicate the relative scarcity of future supply (Li and Wang, 2017).

The introduction of Bitcoin may change the future of monetary policy and central banking completely. An enormous benefit of Bitcoin is offering consumers in countries that struggle with mismanaged monetary supply a way to create stability (Li and Wang, 2017). Argentina provides a concrete example of this benefit. Before 2015, the country was experiencing double digit inflation.

Consumers in the country started to use Bitcoin as a way to evade the country's currency controls amid the large financial instability.

There is a cost to competing with digital currencies, and that predominately manifests in the form of undermining the central bank's ability to conduct monetary policy as a monopolist. Central banks typically operate under legal tender laws. Legal tender laws compel citizens to accept their notes by not legally protecting those who refuse the legal tender for repayment of debts. These laws give monopoly privileges to the government over the printing press. If substitutes to this legal tender are available in the market place, then the central bank's ability to effectively conduct monetary policy will be diminished.

Beate Sauer (2016) argues that the completion of Bitcoin with a national currency will endanger price stability in three ways: virtual currencies modify the money supply, virtual currencies influence the velocity of money, and the use of virtual currencies in the tangible economy. As a result of the modification of money supply, central banks will need to reduce their expected demand, and therefore shrink monetary supply. Then, virtual currencies will influence the velocity of money by depleting the predictability of money demand, which occurs when more than one currency is on the market. The central bank, therefore, would lose part of their control over short-term interest rates. Finally, virtual currencies are used in physical transactions that take place in the physical economy (the economy that exists outside the virtual realm). As Bitcoin becomes more integrated into the physical economy, price instability in Bitcoin could affect the stability of other aspects in the economy. Currently, Bitcoin is far too insignificant in the global economy to effect economic indicators, but it still bears the possibility of doing so in the future, which creates a general threat

Securities and Fraud at Mt. Gox

In addition to posing threats to the economy as a whole, Bitcoin serves as a cause for concern for the individual user. A main concern for Bitcoin users, especially for early adaptors, is fraud and price manipulation within the Bitcoin ecosystem. The most well-known example is the securities fraud that occurred at the Mt. Gox exchange. Mt. Gox was a bitcoin exchange that operated out of Tokyo, Japan. It opened in July 2010 that handled about 70% of all bitcoin transactions during its operation. On February 7, 2014 the exchange halted all withdrawals and, by February 24, suspended all trading, as well as shut down its website. In the following year, there was extreme speculation as to what actually happened.

Mt. Gox cited insolvency due to 850,000 missing bitcoins, valued at $473 million at the time, as the reason for shutting down. People started to speculate as to whether or not these missing bitcoins actually existed. Kim Nilsson (2015) led an investigation using leaked data from Mt. Gox to answer this question. He found that in early 2011 small discrepancies between expected BTC holdings (the sum of all customer deposits on the exchange) and actual BTC holdings on the exchange (how much the exchange actually holds in storage) started to appear. By the end of 2011, this discrepancy reached several hundred thousand BTC. It continued to grow over time until there were no spendable bitcoins left at Mt. Gox by mid-2013. This meant Mt. Gox was technically insolvent since 2012.

Nilsson (2015) matched up most deposit/withdrawal logs early on in his investigation, which rules out the possibility of large-scale fraudulent deposits. This means bitcoins going into Mt. Gox were real and the discrepancy is likely due to the lack of valid withdrawals for bitcoins leaving Mt. Gox.

Nilsson (2015) found a reoccurring pattern that stood out as unusual within the data. Mt. Gox bitcoins would get sent to a non-Mt. Gox address without going through a withdrawal log entry. This would typically happen with a few hundred bitcoins at a time. These non-Mt. Gox addresses would then be compiled into bigger addresses, which would hold a few thousand bitcoins. From there, the bitcoins would be deposited in chunks of a few hundred bitcoins across several exchanges. An estimated 300,000 bitcoins were taken out of Mt. Gox in this fashion between late 2011 and the end of 2012.

Investors found it hard to believe that anyone could manage to steal all of Mt. Gox's bitcoins. It appears intuitive that the majority of the exchange's bitcoins would be secured in cold storage, which is where exchanges typically keep a majority of their reserves in order to prevent them from being stolen. It is not present on the web server, or any other computer, and is kept in a variety of ways including: on a USB drive, in a paper wallet, in physical bitcoins, or on an offline Bitcoin Hardware wallet. However, no one individual knows enough details about the exchange's handling of bitcoins in cold storage. As a result, the conjectures are merely theoretical in nature. One theory asserts that cold storage was simply compromised either physically by someone with onsite access or electronically through a security flaw.

It is believed that Mt Gox did not have continuous monitoring of its cold storage. The cold storage used paper wallets that were generated ahead of time and stored away. Paper wallets refer to a method of storing bitcoins in which private keys are printed out on paper. These secure paper wallets would gradually and automatically be filled one by one on the system by taking surplus coins out of the hot wallet, which is any type of Bitcoin wallet that is connected to the Internet. This also occurs vice versa, where staff would manually refill a hot wallet that was running low using bitcoins stored in the paper wallet. Another theory states that without continuous monitoring, Mt. Gox staff could have blindly poured their cold storage into their leaking hot wallets while assuming cold storage would automatically be refilled at the same rate.

Since these bitcoins were real and stolen and said stolen bitcoins were at significant risk of already being spent, there is little hope that creditors with good intentions will ever get the bitcoins they lost at Mt Gox back. Despite the alarming occurrence at Mt. Gox, it is unlikely that something of this magnitude will ever happen again in bitcoin's lifetime. In present day, exchanges are more scrutinized and the distribution of transactions is much wider.

Even with all the extra measures taken by exchanges to keep their bitcoins safe from theft, it still happens today. In the first six months of 2018, more than $761 million worth of digital currencies was stolen from exchanges (Ahmed et al 2019). This is compared to $266 million that was stolen in 2017. Several companies are currently working on software to help exchanges and hedge funds that use or trade cryptocurrencies to comply with anti-money laundering laws (Ahmed et al., 2019).

Bitcoin Pricing Models

Bitcoin has gained a lot of attention in recent years and is well known for its large price movements. These large price movements have cast doubts on the use of bitcoin as a medium of exchange and it causes researchers and investors to wonder how to accurately price a bitcoin. Early research suggested there was no true value of a bitcoin because it was merely a speculative asset rather than a proper currency. The argument pertaining to the value of bitcoin still persists today, which has resulted in a lack of consensus regarding the true value of a bitcoin.

The Technology and Economic Determinants of Bitcoin Exchange Rates

Xin Li and Chong Alex Wang (2016) created a model to identify the dynamics of the bitcoin exchange rate. They created an Autoregressive Distributed Lag Model based on the assumption that bitcoin is simultaneously a technology artifact and an economic instrument. They split their data into two time periods known as the early market and the later market. The early market is known as the Mt. Gox period and the later market is the post Mt. Gox period. The technology factors Li and Wang focused their model on were public recognition, mining difficulty, and mining technology. The economic factors they focused on included economic indicators of the foreign country, Bitcoin economy, and market activity.

Li and Wang (2016) found that in the early market the price is dominated by measures of market activity such as trading volume and market volatility. This means the price is heavily influenced by speculative trading, rather than economic fundamentals. However, in the later market, economic factors have a more severe impact on the long-term equilibrium. The exchange rate currently reacts to economic fundamentals such as supply of USD, interest rate, and the number of Bitcoin supported transactions. This shows that Bitcoin has diffused as an alternative medium of exchange and exchange market participants are becoming more rational.

In regards to the technology factors that influence bitcoin’s price, Li and Wang (2016) found thought provoking relationships. Mining difficulty was the predominant driver of the exchange rate in the early market, but as time progressed the impact weakens. Mining difficulty is measured as a proxy for mining costs. As mining becomes more efficient, the hash calculations become faster and require less electricity. The significance of mining costs also decreases over time. This is thought to be because any progression in mining technology reduces the significance of mining costs and weakens the impact of mining difficulty on the exchange rate. The impact of the public recognition variable is more obscure. Shocks in public interest are only significant in the short term. This indicates that investors are becoming more familiar with the Bitcoin system so the market is less sensitive to hype surrounding social media.

The Economics of Bitcoin Price Formation

Paval Ciaian, Miroslava, and d'Artis Kancs (2016) attempt to determine the price of Bitcoin by looking at three factors: market forces of supply and demand, attractiveness indicators, and global macroeconomic and financial development. As a result of their analysis, they concluded the market forces of supply and demand have a strong impact on bitcoin's price. The demand side variables in particular have a larger impact on bitcoin's price than supply side variables. Both an increase in the total stock of bitcoins in circulation puts downward pressure on bitcoin's price, whereas the size of the bitcoin economy leads to upward pressure on its price.

When testing for investor attractiveness Paval Ciaian, Miroslava, and d'Artis Kancs found new posts in online Bitcoin forums had a positive impact on bitcoin's price. These posts are not indicative of good or bad news about Bitcoin, but are rather a way to quantify investor interest. This relationship is likely a result of increasing acceptance and trust in Bitcoin between, and among, users. This relationship could additionally indicate declining transaction costs and uncertainty for investors, which will increase demand, thereby increasing the price. On the other hand, views on Wikipedia had negligible impact on bitcoin's price. This is likely because the type of information provided on Wikipedia is common knowledge for most investors, especially in the long run.

In contrast with multiple other studies, Ciaian et al. (2016) did not find macro-financial developments, such as the Dow Jones Index, to be statistically significant. They conclude this is because other studies did not account for supply and demand, or investor attractiveness variables. However, as Li and Wang (2016) highlight, it may be because these indicators are more important in the later market. Ciaian et al. (2016) did not split their data into two different time periods.

Price Manipulation in Bitcoin

Neil Gandal, JT Hamrick, Tyler Moore, and Tali Oberman (2018) studied the effect of suspicious trading on the BTC—USD exchange rate. Specifically, they focused on the currency exchange between February and November 2013, when there was suspicious trading activity at Mt. Gox.

Gandal et al. (2018) identified two types of suspicious trading activity, which they named Markus and Willy using the naming convention. One trader, Markus, never paid any transaction fees and seemingly paid random prices for bitcoins. There were also duplicate transactions on their account in which the amount paid was changed to a price that was consistent with the other trades made that day. This means Markus likely did not pay for any bitcoins, rather their account was fraudulently credited. The account was active for 225 days where it acquired 335,898 bitcoins worth $76 million. Another set of accounts, Willy, would buy exactly $2.5 million worth of bitcoin before becoming inactive. In total, these accounts bought 268,132 bitcoins worth $112 million. Gandal et al. (2018) believes Willy operated this way in order to delay the inevitable collapse of the exchange, much like the Ponzi scheme run by Bernie Madoff.

Gandal et al. (2018) first looked at how Markus and Willy influenced the exchange rate on the days they were active. They found that even when Markus' activity peaked, there was not a significant change in the price. On the other hand, within the 50 days Willy was active, the BTC—USD increased by an average of $21.85 and fell by an average of $0.88 on the days Willy was not active. This is true across all active exchanges at the time.

There was also a trend between the daily opening price differences between Mt. Gox and other exchanges during the periods of suspicious trading activity. The price difference between Bitstamp, Bitfinex, and Btce grew between 6-12% during periods when Markus and Willy were active. During periods when there was little to no suspicious trading, the price difference was marginal; 0-1.5%.

The authors attribute the rise in the BTC—USD exchange rate from $150 to $1,000 in late 2013 to suspicious trading. Since there is no data available today, it is difficult to discern whether this type of activity remains prevalent in the Bitcoin ecosystem.

Chapter 4 Volatility of Bitcoin

Even with several models for Bitcoin's price, it's extremely volatile prices still persist today. Its immense volatility is often what keeps highly risk averse investors away. Since its creation in 2009, Bitcoin has been trading at a long-term annualized volatility of 86.77%[1]. Figure 2 below illustrates the daily returns for the BTC—USD exchange since February 1, 2012. Bitcoin's volatility is chiefly driven by varying perceptions of its intrinsic value. Its price is also exceedingly sensitive to news and regulations.

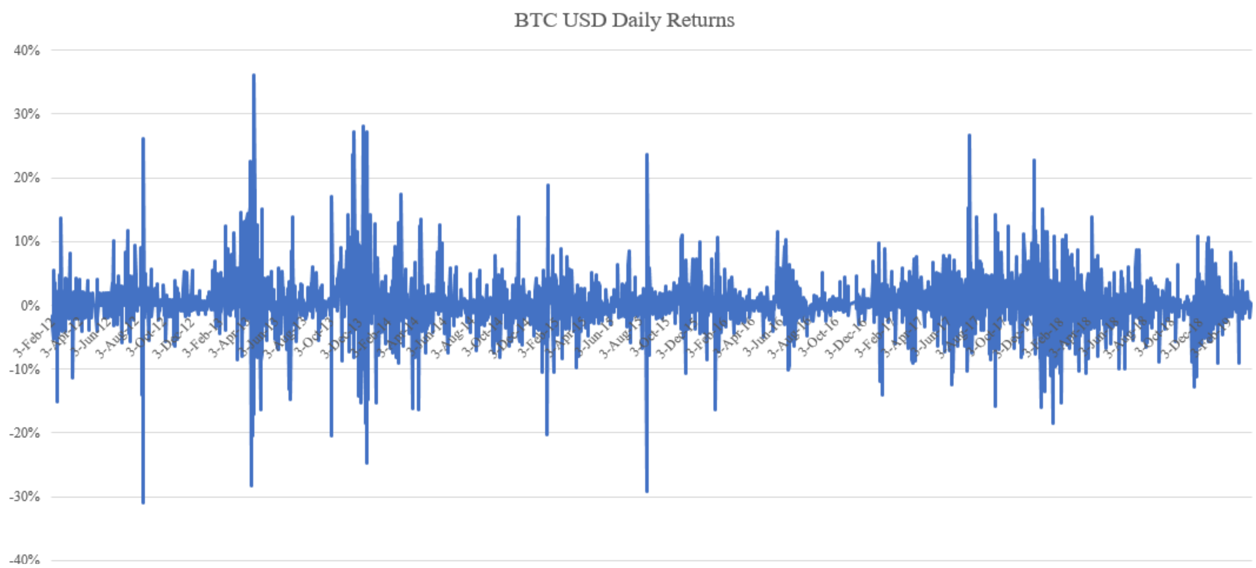

Figure 2. Daily returns for the BTC/USD exchange rate

No investment comes without volatility, but some assets have more volatility than others. Currently, Bitcoin's volatility is much higher than a more traditional currency's volatility. This includes major, minor, and exotic currencies. Major currencies are the most highly traded currencies; since they have such high liquidity, they have the lowest spreads. Minor currency pairs are those that do not include the U.S. dollar. Exotic pairs include both a major currency and the currency of a developing nation. Exotic pairs can more difficult to trade and often have higher spreads. Table 1 below shows the

[1] Bitcoin's annualized volatility was calculated based off of 365 trading days in a year.

annualized volatilities of 19 currency pairs[2]. Please note that the Hong Kong dollar is pegged to the U.S. dollar, which is why the volatility for this currency pair is so low.

Major Currencies						
EUR/USD	GBP/USD	USD/JPY	USD/CAD	AUD/USD	NZD/USD	USD/CHF
9.199%	9.005%	9.512%	8.635%	11.279%	12.035%	11.108%
Minor Currencies						
EUR/GBP	GBP/JPY	EUR/AUD	CHF/JPY	NZD/JPY	GBP/CAD	
8.271%	12.328%	9.872%	12.207%	14.064%	9.273%	
Exotic Currencies						
EUR/TRY	USD/HKD	JPY/NOK	NZD/SGD	GBP/ZAR	AUD/MXN	
13.62%	0.53%	11.80%	8.81%	14.47%	10.62%	

Table 1. Annualized volatilities of major, minor, and exotic currency pairs

Black-Scholes Implied Volatility

Simply having volatility does not mean an asset lacks liquidity. An options contract provides investors with a lot of insight as to how to market perceives the volatility of an asset. An option is a contract which gives an investor the right, but not the obligation, to buy/sell an asset in the future in which the asset price, quantity delivery place and location are specified in the contract (Hull, 2017). A call gives the buyer of the option the right to buy the asset and the buyer of the put has the right to sell the underlying asset. Options have several unique characteristics; its underlying asset, cost, maturity, and strike price. Options can be written on stocks, bonds, currencies, commodities, and futures contracts. In order to enter into an options contract, you have to pay a premium. An option's strike price is the price in which an investor agrees to buy/sell the underlying asset at. If an option's strike price is equal to the spot price, that option is said to be "at the money." If the strike is less than the spot for a call, or greater than the spot for a put, the option is said to be "in the money." If the strike is greater than the spot for a call, or less than the spot for a put, the option is sound to be "out of the money."

[2] All other currency pairs' annualized volatilities were calculated based off of 252 trading days in a year

Volatility can be derived from the Black-Scholes (BS) formula (Black and Scholes, 1973). This implied volatility is an estimation of the future volatility of the asset underlying an option contract. Volatility is the only input in the Black-Scholes model that is not directly observable. Given the current market prices, the equation can be solved to determine the implied volatility. All VBA code used to calculate BS implied volatilities are in the appendix.

Options for bitcoin began trading on LedgerX in October 2017. LedgerX is the first federally regulated exchange to list and clear fully collateralized, physically settled bitcoin swaps and options. Deribit used to trade bitcoin options, but has since been banned in the United States and all U.S. accounts were shut down. For the purpose of this thesis, all option data has been taken from LedgerX's website.

Term Structure of Volatility

The term structure of volatility shows the implied volatilities for at the money options at different maturities. Volatility term structure tends to be upward sloping when short-dated volatilities are at historically low levels and are expected to rise. The term structure tends to be downward sloping when short dated volatilities are at historically high levels and are expected to fall. Figures 3 and 4 below plot the term structure of volatility for at the money options on two days: January 1st, 2018 and January 1st, 2019.

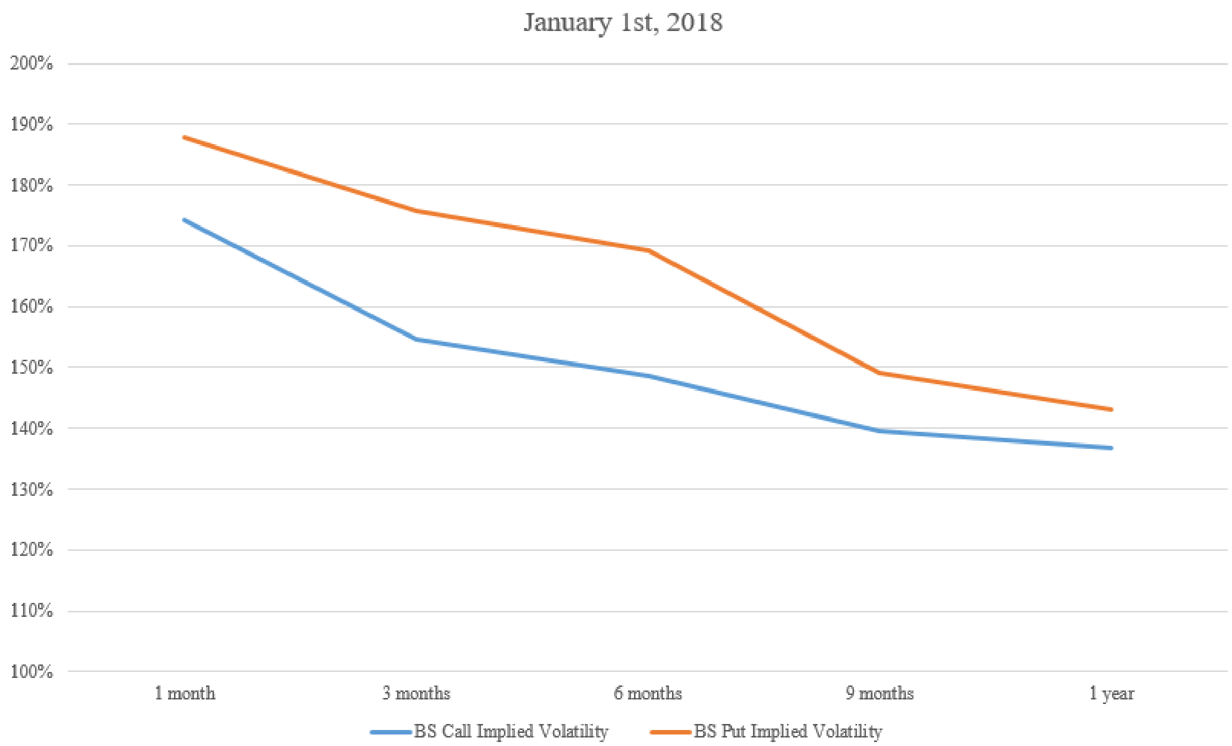

Figure 3. Term Structure of Volatility for bitcoin on January 1st, 2018

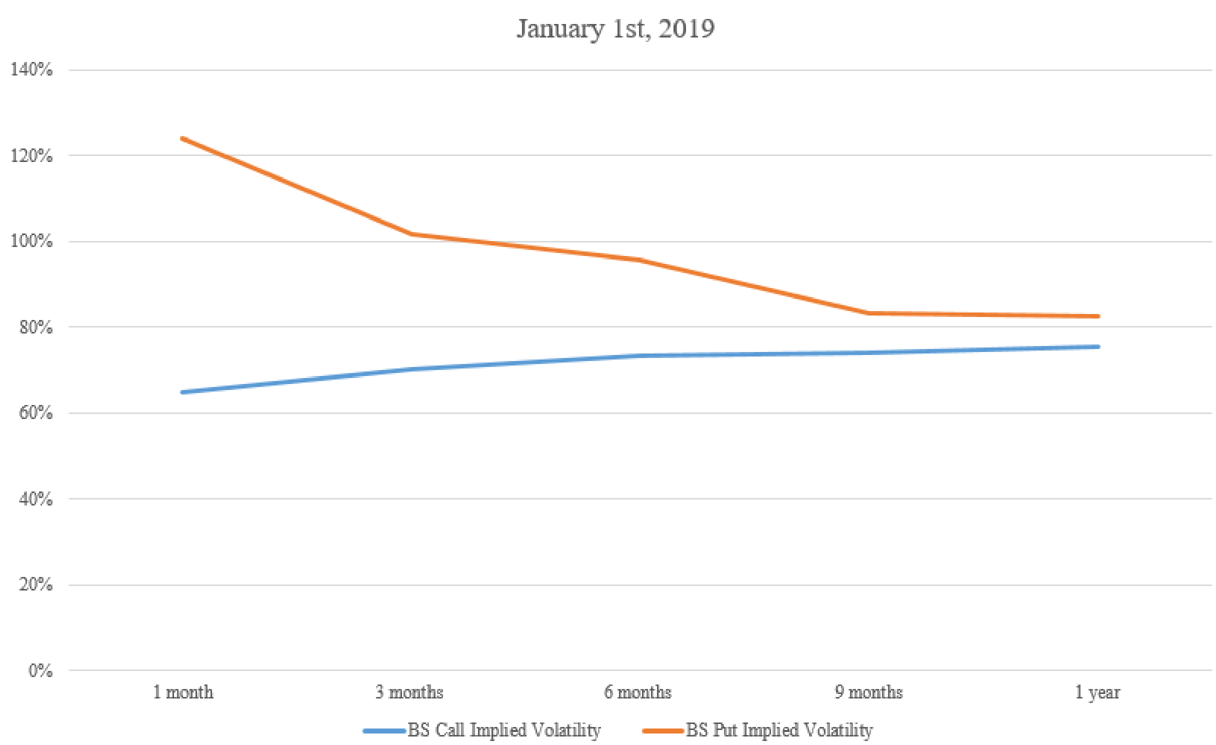

Figure 4. Term Structure of Volatility for bitcoin on January 1st, 2019

January 1st, 2018 was when Bitcoin's short-term volatility was high due to the large price swings in December 2017. The 40-day moving average volatility on January 1st, 2018 was 147.24%, much higher than the 86.77% long-term average. As seen in figure 3 above, short-term options were priced at this high volatility while longer-term options were priced at a lower volatility, but still higher than the long-term average.

On January 1st, 2019 the 40-day moving average volatility was 96.1%. This is still higher than the long-term average, mainly due to uncertainty surrounding regulations. As seen in figure 4 above, the term structure of volatilities is relatively flat, or downward sloping, and moves towards the long term average for longer maturities.

The main takeaway from these graphs is the options do not trade in an efficient market and trade at "bad" prices. Actively traded option contracts trade at similar implied volatilities for calls and puts. Intuitively, this means that one asset (bitcoin in this case) cannot have two different volatilities simultaneously. In an efficient market, there are arbitrage opportunities available if there is a large spread between these implied volatilities. There are not enough traders in the market to take advantage of these arbitrage opportunities.

Volatility Smiles

An important assumption of the Black-Scholes model is that volatility is constant and the distribution of stock returns is normal (Black and Scholes, 1973). Theoretically, a graph of implied volatilities against all strike prices should be a straight line. In practice, this is not the case. Implied volatilities of "out of the money" and "in the money" options is higher than "at the money" options. This creates a smile, or smirk shape instead of a straight line. The smile shape represents a trader's belief that the distribution of stock returns have fatter tails than what the normal distribution implies. Figures 5 and 6 below show the BS implied volatility for each strike price on January 1st, 2019 for an option expiring on January 25th, 2019. The spot price of bitcoin at this time was $3,963.

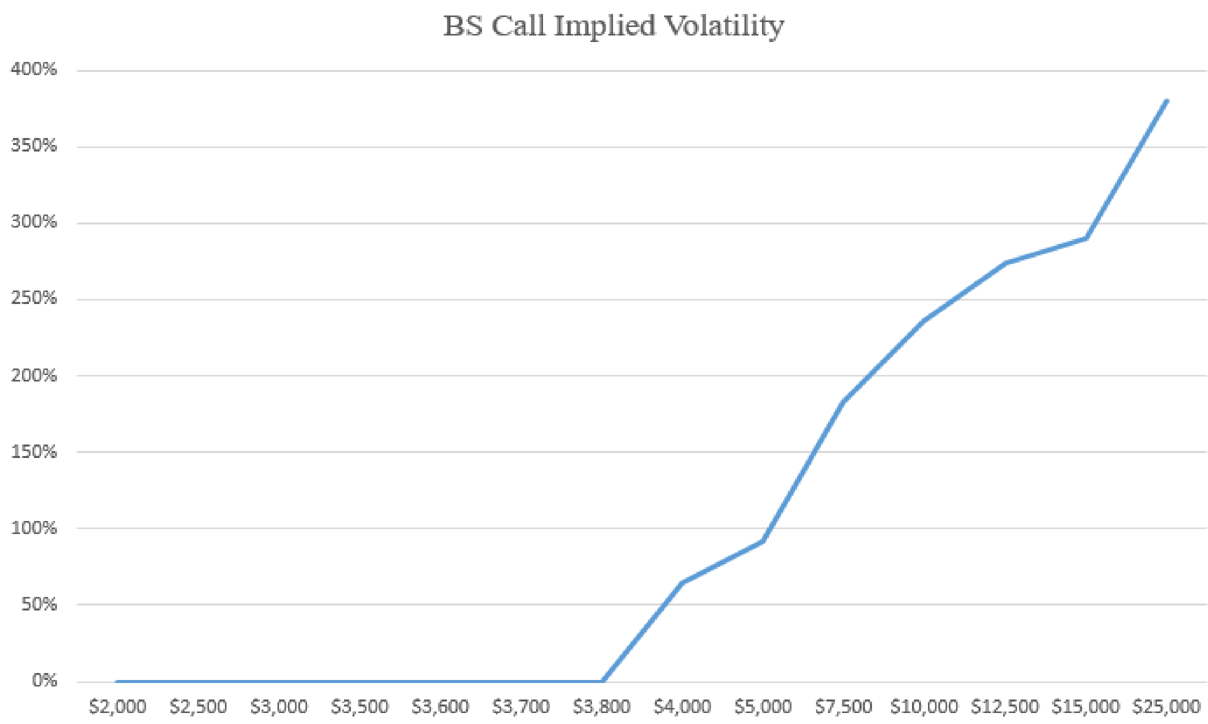

Figure 5. Black-Scholes Call Implied Volatility Smile for January 25, 2019 expiration

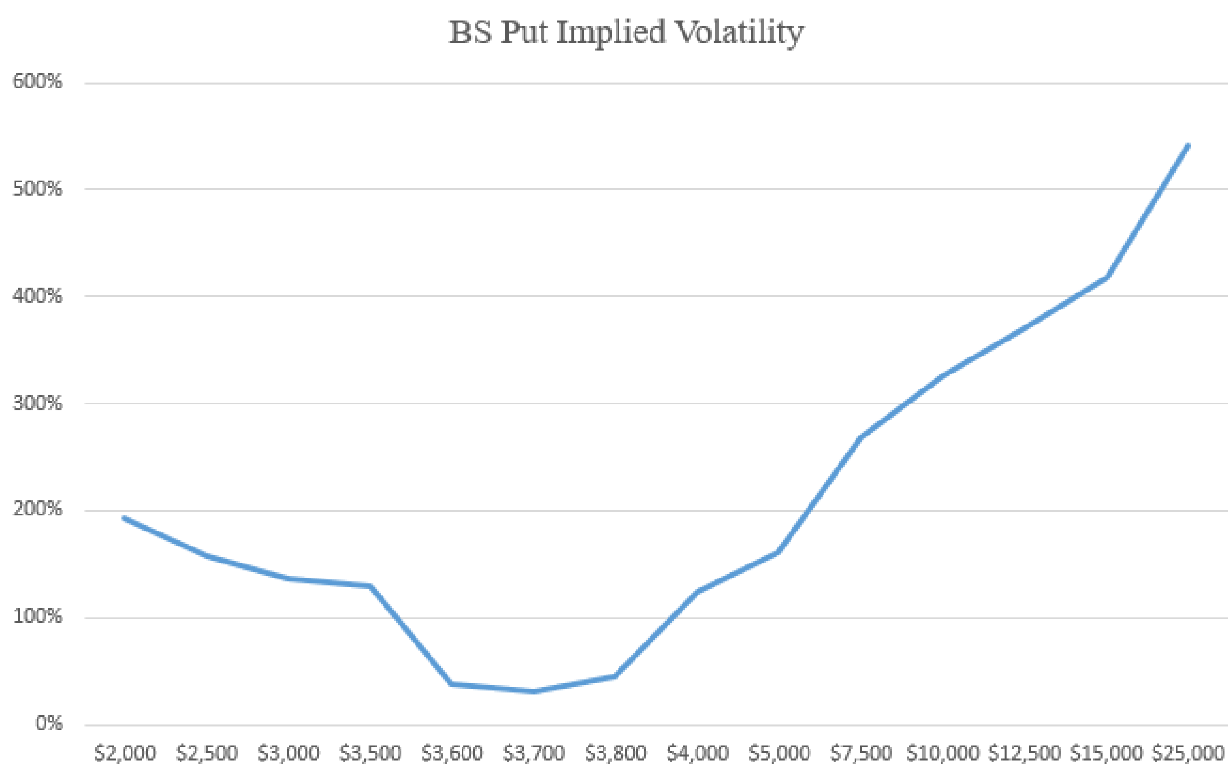

Figure 6. Black-Scholes Put Implied Volatility Smile for January 25, 2019 expiration

The strike skew shows a strong smile shape for the put option, but an unconventional shape for the call option. The 0% implied volatility for "out of the money" call options is likely a result of non-competitive option prices. As previously discussed, an asset with no volatility does not exist. Investors should be buying these out of the money options to bid up the volatility. However, there is very minimal trading at these strike prices. Even if a trader recognizes that the options are not correctly priced, the option may never move to the correct price before expiration when it could become worthless. Again, this is another indicator that the option market for bitcoin lacks liquidity.

Chapter 5 The Futures Market

Bitcoin's liquidity can also be analyzed by looking at the behavior of its futures contracts. Bitcoin futures are often described as innovative digital assets meeting well established financial markets. In order to analyze how the bitcoin contracts behave, it is important to note how a futures contract is supposed to behave.

A futures contract is a financial derivative. A derivative is a financial contract in which the value of the contract is derived or linked to the value of an underlying equity, bond, index, or commodity. (Hull, 2017). The contract is a legally binding agreement between two people to deliver the underlying commodity or financial instrument at a future date with agreed upon payment terms.

Futures contracts are sold on exchanges with a standardized delivery month, quantity, quality, delivery location, and payment terms. In contrast, forward contracts are traded over the counter. The terms of the contract are flexible and the two parties are free to negotiate any mutually beneficial agreement (Hull, 2017). There is a risk that the contract will not be honored in an over the counter agreement, however. There is a market for bitcoin forward contracts, but it is not the focus of this thesis.

Most futures contracts are closed out before maturity. Closing out a futures position involves entering into an offsetting trade. If a futures contract is not closed out before the maturity, it is usually settled by delivering the assets underlying the contract (Hull, 2017).

Margin accounts are required when entering into a futures contract. A margin account is cash deposited by an investor with his/her broker and is adjusted daily to reflect the settlement price. An investor must maintain the maintenance margin level in their account or their position will be liquidated (Hull, 2017). Margins reduce the risk of a loss through default of the contract.

The exchange in which a futures contract is sold will set price limits and position limits. Price limits are set in order to prevent large price movements in the futures prices. Position limits are the maximum number of contracts a trader can hold and are put in place in order to prevent speculative trading from manipulating the markets.

Chicago Mercantile Exchange (CME) Group has listed Bitcoin futures (BTC) since December 2017. The contract specifications are as follows:

Contract Unit	One contract is worth 5 bitcoins and is defined by the exchange's own Bitcoin Reference Rate (BRR). The BRR is determined by a volume weighted average of trading prices across several bitcoin exchanges.
Minimum Price Fluctuations	The minimum price fluctuation for the contract is $5.00 per bitcoin or $25.00 per contract.
Termination of Trading	The last day of trading is the last Friday of the contract month.
Position Limits	Position limits are set at 1,000 contracts.
Price Limits	Price limits are set at 20% above or below the previous settlement price.
Settlement	The contracts are cash settled by reference to the Final Settlement Price
Margin Requirements	The maintenance margin is 37%. For hedgers, the initial margin is 100% of the maintenance margin. For speculators, the initial margin is 110% of the maintenance margin.

Table 2. CME Bitcoin Futures Contract Specifications

The Chicago Board Options Exchange (CBOE) has listed Bitcoin futures (XBT) since December 2017. The contract specifications are as follows:

Contract Unit	One contract is worth 1 bitcoin and is defined by the Gemini Exchange Auction price.
Minimum Price Fluctuations	The minimum price fluctuation for the contract is $10.00 per bitcoin or per contract.
Termination of Trading	The last day of trading is two business days (usually a Wednesday) prior to the third Friday of the contract month.
Position Limits	Position limits are set at 5,000 contracts of all XBT futures contract expirations combined and 1,000 5 business days before a contract expires.
Price Limits	Price limits are set at 10% above or below the previous settlement price.
Settlement	The contracts are cash settled by reference to the Final Settlement Price
Margin Requirements	The maintenance margin is 40%. For hedgers, the initial margin is 100% of the maintenance margin. For speculators, the initial margin is 110% of the maintenance margin.

Table 3. CBOE Bitcoin Futures Contract Specifications

Chapter 6 Behavior of the Futures Contracts in the Market

Futures Curves

A futures curve is a graph that plots prices as a function of the amount of time between now and future delivery. It is also known as the term structure of prices. Contango and backwardation are terms used to describe the shape of the futures curve. A contango market simply describes a case where the futures contract is trading at a premium to the spot price, or the futures curve is upward sloping. A market is in backwardation if the futures contract is trading at a discount to the spot price, or the curve is downward sloping (Hull, 2017).

Contango can occur when the shape of the futures curve is driven by the cost of storing the commodity. Backwardation can occur when producers, rather than consumers, dominate the market for demand for futures contracts.

Commodity markets do not stay in contango or backwardation forever; rather they switch between the two. Below are the normalized futures curves plotted for the CME futures contract. These curves were calculated using the spot price of Bitcoin's price index for the first day of trading for each month. The contracts that expire on quarter end months start trading sooner, therefore they have longer futures curves.

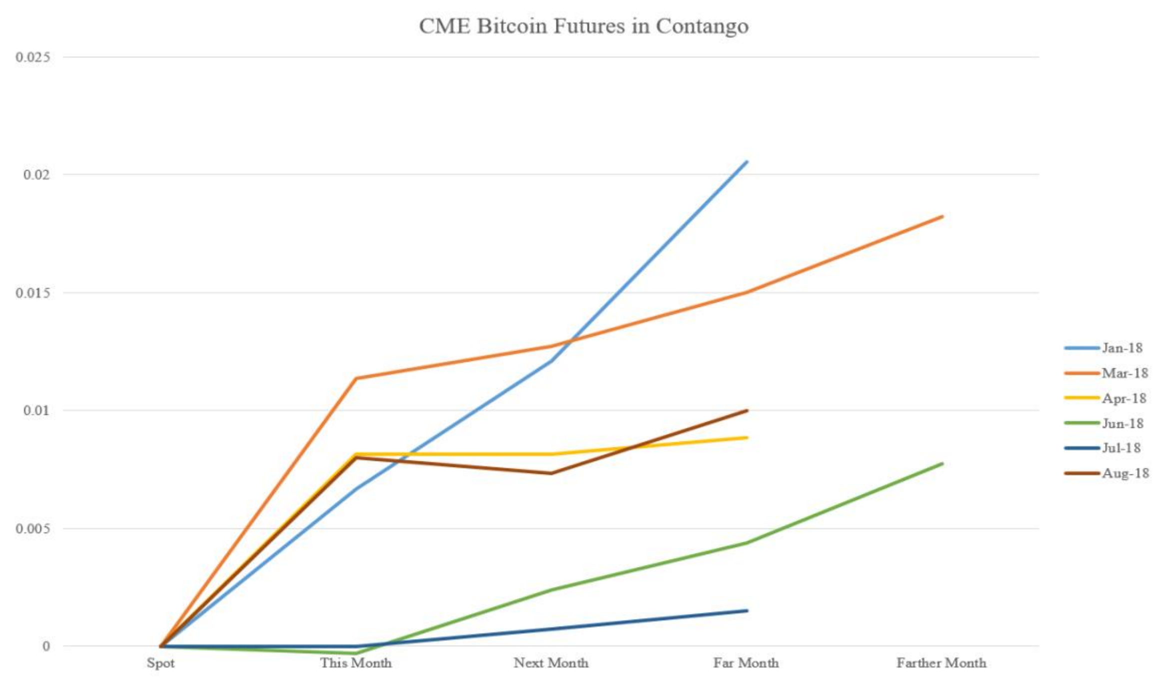

Figure 7. CME Bitcoin Futures in Contango

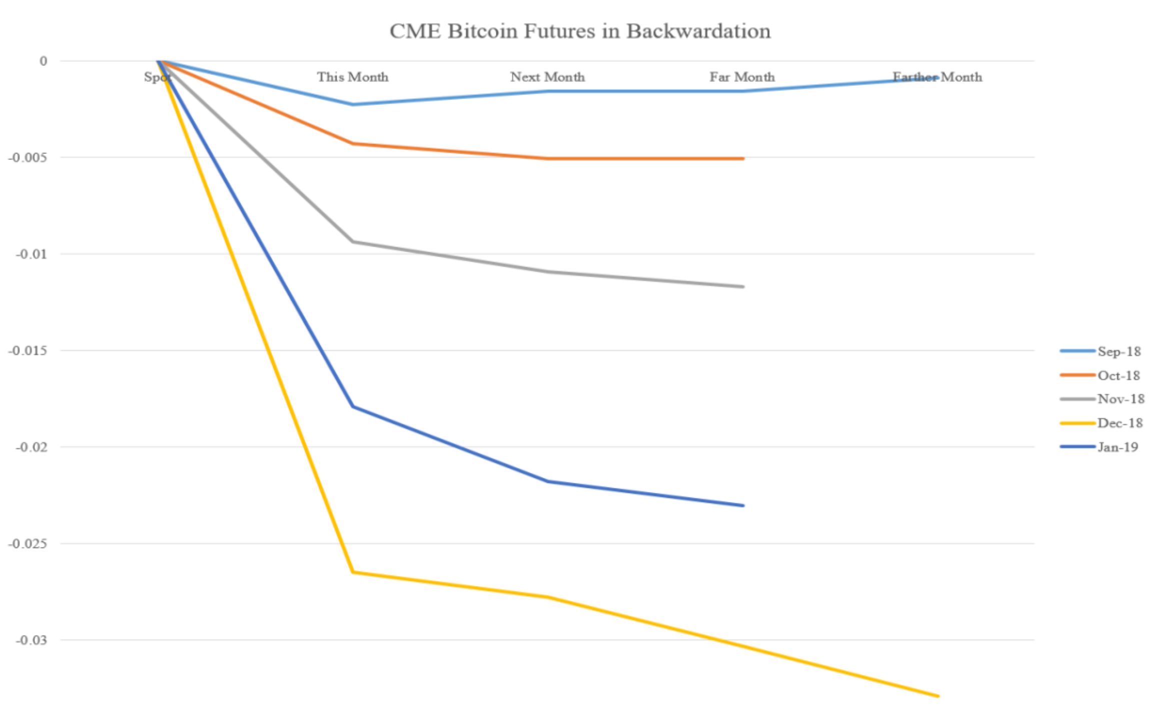

Figure 8. CME Bitcoin Futures in Backwardation

The futures curves show the market was in contango for most of 2018 until September when it switched to backwardation. Where it stayed ever since. This is a sign of a strong bull market in early 2018 when the futures contract was still new. Risk inverse investors may put a premium on Bitcoin but alleviates the cost of storage. Storage costs for Bitcoin are usually defined as the risk of being hacked or misplacing private keys. This creates a contango market.

The switch to backwardation in September could be a result of increased pressure on the SEC to regulate Bitcoin and define it as an asset class. All this uncertainty can put pressure on miners or large institutional investors to protect their downside risk. They are willing to sell contracts below the current spot price in order to protect this downside risk. This is a strong characteristic of a bearish market.

There are a couple months, February and May 2018, in which the market was trading in backwardation for seemingly no fundamental reason. These unusually shaped futures curves represent a lack of trading for these contract expiration months.

Cost of Carry

Another way to analyze bitcoin's liquidity in terms of its futures trading is by calculating its cost of carry. The cost of carry is the costs one would incur by storing a commodity over time. The no arbitrage forward price is $\mathrm{F}_0 = \mathrm{S}_0 * (1 + r + s - l - c)$ where F_0 is the current futures price, S_0 is the current spot price, r is the risk free rate, l is the lease rate, and c is the convenience yield.

In the case of bitcoin, the storage costs and lease rates can be assumed to be 0. This leaves the convenience yield as the only non-observable variable in the equation. Therefore, the theoretical convenience yield be calculated based off current futures and spot prices, and risk free rates. Since bitcoin pays no interest and there is no monetary value to holding bitcoin, the convenience yield should be close to zero. Below are the convenience yields calculated each day the March and June 2018 CME contracts are traded.

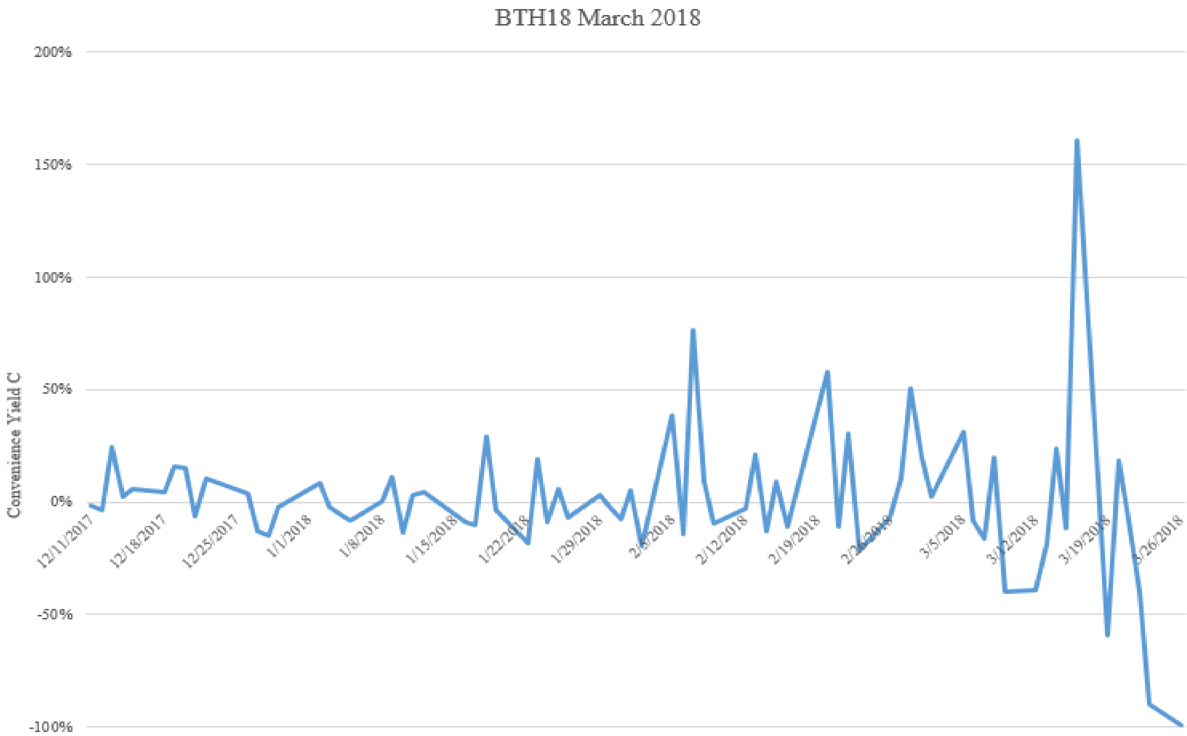

Figure 9. CME March Convenience Yield

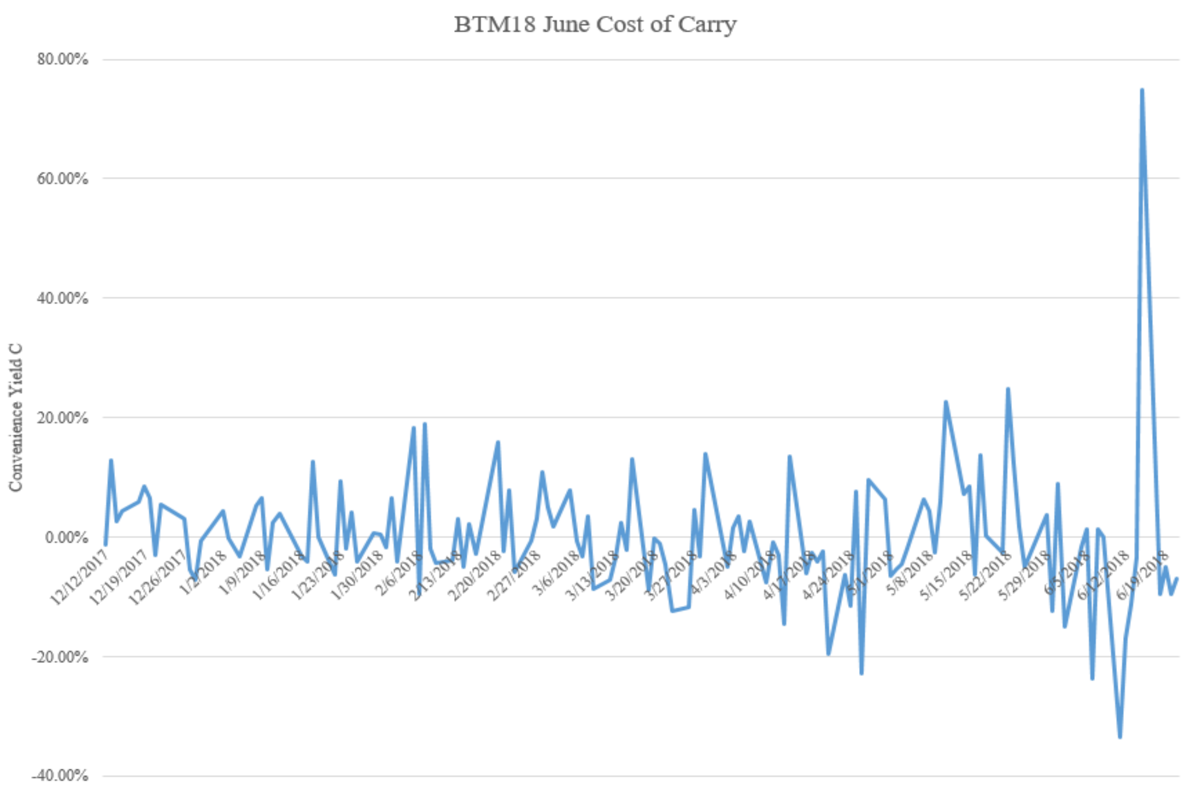

Figure 10. CME June Convenience Yield

As demonstrated in figures 9 and 10 above, the convenience yields are not close to zero. Rather, they move almost daily between positive and negative yields. Intuitively, it does not make sense for the convenience yield to change this quickly. The market seems to slightly favor a positive convenience yield, where the average is very close to 1%. This is a strong indicator that the futures prices are not competitive. In a more mature, liquid market, one would expect to see a steadier convenience yield.

Chapter 7 Uses as a Financial Asset

There are three main reasons why an investor would trade a futures contract: to hedge, use futures to make speculative trades, and to use futures contracts to arbitrage. Hedgers have exposure to the price movement of an asset and they use derivatives to reduce the risk they face from future price movements. They do not bet on the direction of future price movements and their objective is not to make a profit. They simply want to reduce their risk (Hull, 2017).

Another reason to use futures is to make speculative trades. A speculator will use derivatives to bet on the future direction of an asset's price movements (Hull, 2017). They do not have any exposure to the price movements of an asset.

The final reason to use futures contracts is to arbitrage. An arbitrageur will take off-setting positions in two instruments to lock in a profit or they take off-setting positions in the same instrument but in two different markets (Hull, 2017). This is essentially a bet on the mispricing between two instruments or between two markets.

Commitment of Traders (CoT) Report

Every week, the Commodity Futures Trading Commission (CFTC) releases the Commitment of Traders (CoT) report. The report provides a snapshot of large and small commercial hedgers and speculators in each major commodity. The CoT report defines three types of traders: commercial, non-commercial, and non-reporting. Commercial traders are companies that use the futures market in order to offset risk in the spot market. Non-commercial traders are institutional investors or hedge funds that speculate on commodity prices. Non-reporting traders are individual traders that are not required to report their positions. Since these traders are so small and inexperienced, this section is often ignored when reading the report.

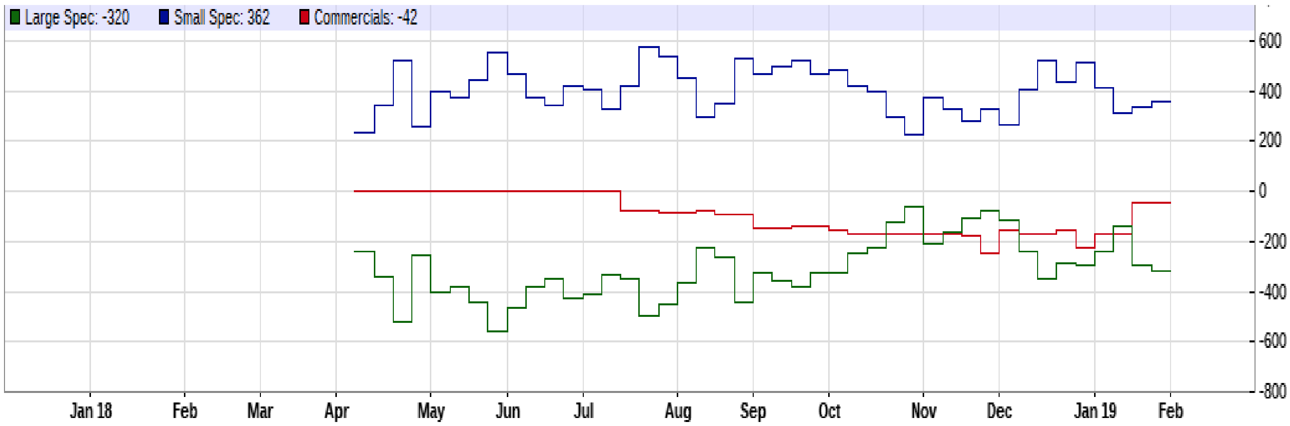

Figure 11. CME CoT Report retrieved from https://www.barchart.com/futures/commitment-of-traders/technical-charts/BT*0

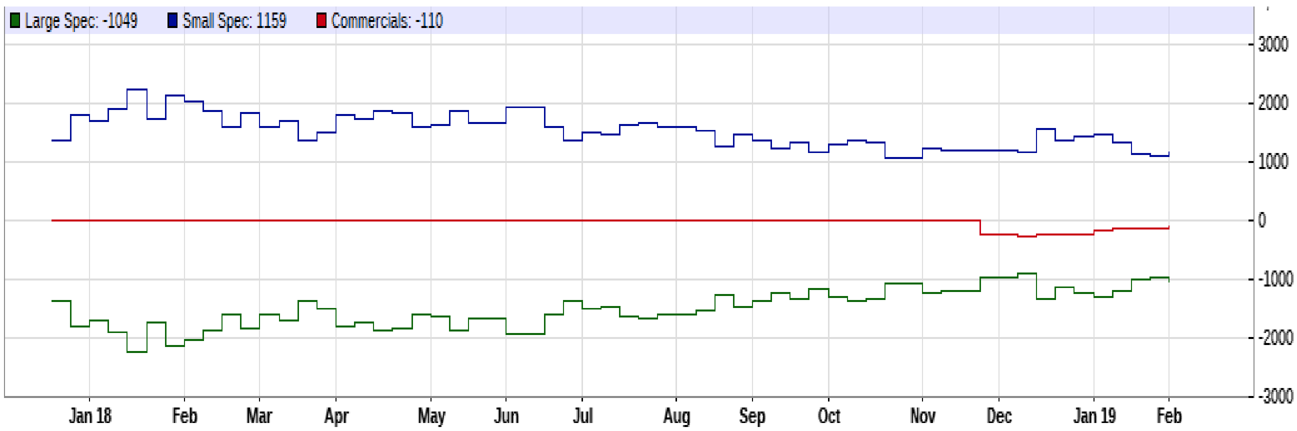

Figure 12. CBOE CoT Report retrieved at https://www.barchart.com/futures/commitment-of-traders/technical-charts/BG*0

The first obvious trend in the data is the lack of trading in the commercial category. This is consistent with the fact not many merchants accept Bitcoin as an acceptable form of payment; therefore not many companies have exposure to bitcoin. Some merchants that do accept bitcoin include Overstock.com, Newegg, Shopify, Dish, Microsoft, and Expedia. However, just because a company has exposure to bitcoin, does not mean it will hedge this risk. Take Overstock.com for example. They are the largest major retailer to accept bitcoin, but the company has made it clear that they do not hold a position in bitcoin, which subsequently eliminates the necessity for them to hedge. Instead, they immediately convert their bitcoins to dollars. The low volume of contracts makes it unlikely that any of the large retailers hedge all their exposure to bitcoin.

The CME contract has more trading in the commercial category than the CBOE contract. This is likely due to the fact a company that wants to hedge their exposure will choose the contract with a bigger contract multiplier. The CME’s contract multiplier is 5 and the CBOE’s is only 1. This means that one contract on the CME will hedge exposure for 5 bitcoins.

Another possible reason there is trading in the commercial category is discussed above as producers/miners hedging their downside risk. This category began trading activity in late July 2018 for the CME contract. One month later the futures curve moved into backwardation. The CBOE contract began showing commercial trading activity in late November when the futures contract was in strong backwardation.

Every week the CFTC also publishes the Traders in Financial Futures (TFF) report. This report separates traders in the financial markets into four categories: Dealer/Intermediary, Asset Manager/Institutional, Leveraged Funds, and Other Reportables. Dealer/Intermediary are typically described as the “sell side” of the market. They design and sell various financial assets to their clients. Asset Manager/Institutional are institutional investors including pension funds, endowments, insurance companies, and mutual funds. Leveraged Funds are typically hedge funds and other types of money managers. These types of investors will typically take speculative and arbitrage positions. Other Reportables are any other trader that does not fit into the first three categories. Traders in this category are mostly using futures to hedge business risk.

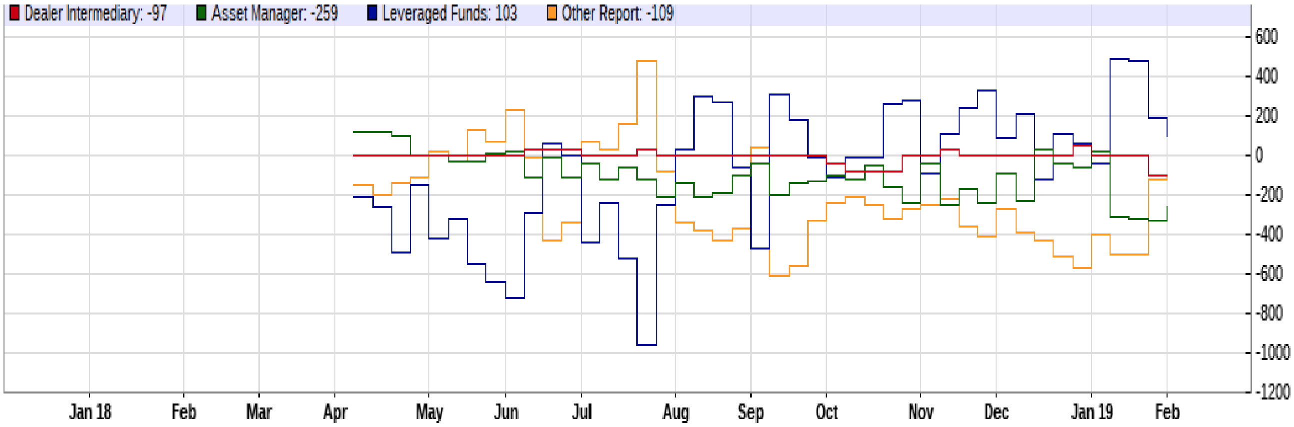

Figure 13. CME TFF Report retrieved from https://www.barchart.com/futures/commitment-of-traders/technical-charts/BT*0

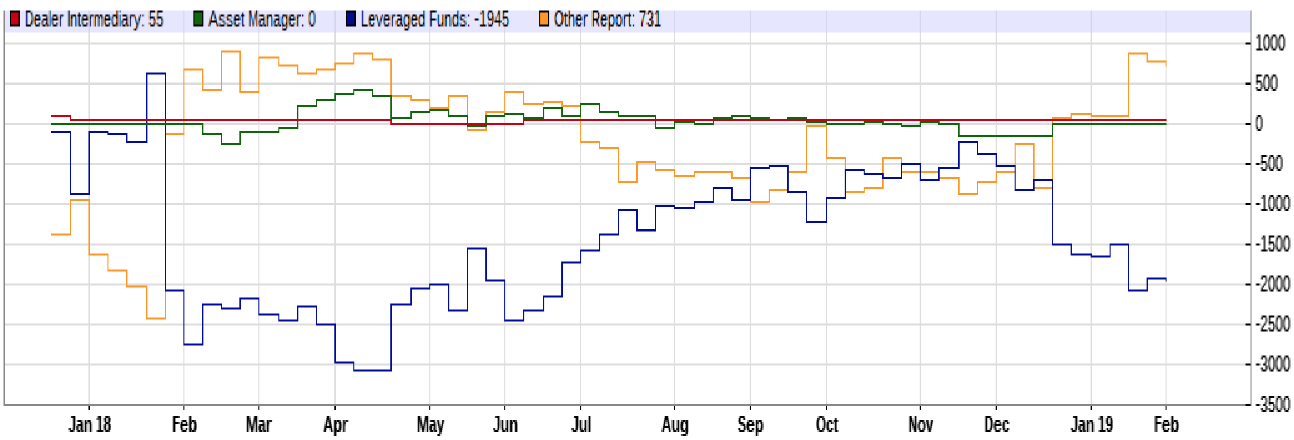

Figure 14. CBOE TFF Report retrieved at https://www.barchart.com/futures/commitment-of-traders/technical-charts/BG*0

In the TFF report, there is again a lack of trading in the dealer/intermediary category. This is likely because they may have a hard time selling financial instruments to other investors that do not support or understand bitcoin.

There is also minimal trading in the asset manager category. Many argue that bitcoin will not become a legitimate asset class until it is backed by global pension and endowment funds. This asset class would hold a lot of risks for these high profile, risk averse, long term investors. Another barrier keeping institutional investors out is the lack of bitcoin ETFs. ETFs have not yet been approved by the SEC. Investors are unsure when or if this will ever happen.

The largest trading category is leveraged funds. These investors are mostly hedge funds and other unregistered funds identified by the CFTC. These investors are likely taking speculative and arbitrage positions. Hedge funds are not restricted on the types of positions they can take nor are they required to disclose their trading strategy.

Arbitrage Opportunities

Arbitrage is an important concept in financial economics. Financial markets typically do not offer a "free lunch," or risk free arbitrage opportunities. This assumption of no arbitrage opportunities holds true in many areas of finance, however there are violations that occur. If arbitrage opportunities did not occur in financial markets, then market participants would have little incentive to watch the markets. Very short-term arbitrage opportunities invite traders to exploit them, therefore, making them disappear quickly.

In foreign exchange markets, arbitrage opportunities exist when the covered interest parity (CIP) assumption is violated. CIP states that it is impossible to earn positive profits by borrowing domestic assets for lending while covering the exchange rate risk through a forward contract with equal maturities, or vice versa. CIP is commonly expressed $(1 + r_d) = \frac{F}{S}(1 + r_f)$ where r_d and r_f denote the domestic and foreign nominal interest rates; S is the spot nominal exchange rate; and F is the foreign nominal exchange rate (Hull, 2017).

There are three main types of arbitrage for Bitcoin: spot/spot arbitrage, futures/futures arbitrage, and spot/futures arbitrage. If trading bitcoin on and across exchanges were free and immediate, then arbitrage opportunities would be plentiful, and markets would possibly be more efficient. In order to understand the feasibility of different arbitrage strategies, we have to consider trading fees. The fee structures for seven popular bitcoin exchanges in the U.S. are in the appendix. They were found on each exchange's website. Most of the exchanges have a maker-taker fee structure in which the maker fee is paid when a trader adds liquidity to the order book by placing a limit order under the ticker price for buy and above the ticker price for sell. The taker fee is paid when a trader removes liquidity when a trade order is matched immediately against an order already on the order book. Any market orders will be executed immediately and charged a taker fee.

Spot/Spot Arbitrage

The first type of arbitrage is spot/spot arbitrage. This arbitrage is possible when there is a price difference in bitcoin across two different exchanges. In theory, an investor could buy bitcoin on the exchange where the price is lower and sell bitcoin on the exchange where the price is higher. They would profit on the difference. Simply having a price discrepancy between exchanges does not necessarily make this arbitrage strategy profitable. There are several fees and waiting time involved in this strategy. It will typically take 1-3 days to move fiat currency onto an exchange, another 1-3 days to transfer it to a different exchange, and another 1-3 days to take it off that exchange. If the price difference does not persist during this time the investor will likely end up with a loss.

The trading fees charged by each exchange also make this strategy less profitable than it may appear. The difference in price needs to be at least as large as the fees the trader will incur. This will mean a difference of .36% - 2.49% depending on the exchange. Exchanges with relatively large fees, Gemini, Coinbase, and Kraken are also the exchanges with the lowest price differences between them. It is unlikely an investor will find a profitable arbitrage opportunity between these exchanges that persists longer than a few minutes.

This does not mean, however, that arbitrage between the other exchanges, where the combined fees are less than 1%, is more profitable. These exchanges have low fees in order to promote higher liquidity. If an arbitrageur placed a large enough order, the arbitrage opportunity could disappear from their order alone. There are also higher risks with holding bitcoins on lesser-known exchanges, as previously discussed.

Spot/spot arbitrage is possible for bitcoin, but it is not exactly a risk free profit. An investor would need to hold money across several exchanges and execute, buy, and sell orders at the same time when a large enough price discrepancy occurs. This is also assuming their order will not influence the price on the exchange.

Futures/Futures Arbitrage

The second type of arbitrage is futures/futures arbitrage. This type of arbitrage is possible when two identical futures contracts have different prices. If the contracts do not have the same specifications, there could be other reasons the prices are different. In the case of the CME and CBOE bitcoin contracts, a price difference does not represent an arbitrage opportunity. The contracts have different contract multipliers, contract expirations, and margin requirements. The contract multiplier is likely the biggest reason the contracts have different prices.

Spot/Futures Arbitrage

The final type of arbitrage is spot/futures arbitrage. This type of arbitrage is possible when there is a mispricing between the spot and futures market. As a futures contract gets closer to expiration, the price differences should converge to zero. If this convergence has not happened on the day the contract expires, arbitrage opportunity exists. Since the introduction of both the CME and CBOE contracts, there have been many arbitrage opportunities available to investors. In some cases, there was up to a $300 price difference on expiration. The price difference for the CME contract was prevalent in the early stages of the contract, but has significantly lessened since September 2018. The CBOE contract has also had small price differences since September 2018, but it also had small differences in April, June, and July.

The reason the expiration of the futures contracts are not more correlated with spot price is a story of liquidity and market size. When the exchanges experience a surge in trading volume, the correlation between the futures price and the spot price increases. Currently, the futures market is not big enough to affect the spot price of Bitcoin. Additionally, since the contracts are cash settled, the futures market is restricted on how much it can affect the spot price. Bitcoin settled futures contracts are expected to launch later this year and are expected to have a bigger impact on the price of bitcoin. Once the SEC approves Bitcoin exchange traded funds, the spot price will likely follow the trend of other crypto assets including those in the futures market and over the counter. The SEC has rejected all proposed ETFs because “the exchange has offered no record evidence to demonstrate that bitcoin futures are markets of significant size,” (Young 2019).

Chapter 8 Conclusion

Currently, there is significant evidence to indicate that Bitcoin's current financial instruments trade in an illiquid, inefficient market. This thesis specifically analyzed options traded at LedgerX and futures traded at CME and CBOE.

LedgerX options provided insight into the perceived volatility of Bitcoin. There are options trading at implied volatilities of over 200%, when realized volatilities have rarely surpassed 100%. In an efficient market, investors would be writing these option contracts to bring the implied volatilities down. Likewise, there are call options trading at 0% implied volatility. These options should be bought to push that volatility closer to its true value. However, there is not enough trading in the market for this to happen. Even close to expiration, the options trade at implied volatilities that are higher than realized volatilities in the market.

Futures contracts provide insight into investor sentiment surrounding Bitcoin. The futures curves show the market has been a strong bear market since September 2018. It is not clear, though, if these curves represent true investor sentiment or are a product of bad prices and inefficient markets. It is evident that the futures prices are not competitive when you explore the market's view of Bitcoin's convenience yield. Currently, the market doesn't seem to favor a positive or negative cost of carry. This is confirmation that the market does not know how to accurately price a futures contract.

In an interview, Gabor Gurbacs, the head of digital assets at VanEck, argued institutional investors are not concerned about the spot price of bitcoin. Rather they prioritize the structure of the market and want a selection of investment vehicles in which they can safely invest in the cryptocurrency market (Young 2019). The current behavior of derivatives in the market is indicative of investors being unsatisfied with the selection of bitcoin investments available. Other financial products are set to launch later this year at Fidelity, NASDAQ, and Bakkt.

Further analysis could be done on this topic to reveal if certain events trigger an increase in liquidity for these markets. These events could include: increased regulations, the SEC defining cryptocurrencies as an asset class, or the SEC approving Bitcoin ETFs. This paper's final recommendation is for investors to consider the liquidity of the derivative markets for Bitcoin before deciding to invest in them.

Appendix

	Gemini		Coinbase			Kraken		Bitstamp	
	Maker	**Taker**	**The Greater of:**			**Maker**	**Taker**	**0**	0.25%
0	1.00%	1.00%	**≥ $10**	$ 0.99	**0**	0.16%	0.26%	**≥ 20,000**	0.24%
≥ 25,000	0.75%	0.75%	**≥ $25**	$ 1.49	**≥ 50,000**	0.14%	0.24%	**≥ 100,000**	0.22%
≥ 50,000	0.50%	0.25%	**≥ $50**	$ 1.99	**≥ 100,000**	0.12%	0.22%	**≥ 200,000**	0.20%
≥ 500,000	0.25%	0.15%	**≥ $200**	$ 2.99	**≥ 250,000**	0.10%	0.20%	**≥ 400,000**	0.15%
≥ 5,000,000	0.15%	0.10%	**Flat Fee**	1.49%	**≥ 500,000**	0.08%	0.18%	**≥ 600,000**	0.14%
≥ 15,000,000	0.10%	0.00%			**≥ 1,000,000**	0.06%	0.16%	**≥ 1,000,000**	0.13%

	CEX IO			Bitfinex			Itbit	
	Maker	**Taker**		**Maker**	**Taker**		**Maker**	**Taker**
≤ 5 BTC	0.25%	0.16%	**0**	0.10%	0.20%	**0**	0.00%	0.25%
≥ 30 BTC	0.23%	0.15%	**≥ 500,000**	0.08%	0.20%	**≥ 600,000**	0.00%	0.175%
≥ 50 BTC	0.21%	0.13%	**≥ 1,000,000**	0.06%	0.20%	**≥ 3,000,000**	0.00%	0.10%
≥ 100 BTC	0.20%	0.12%	**≥ 2,500,000**	0.04%	0.20%	**≥ 15,000,000**	0.00%	0.075%
≥ 200 BTC	0.18%	0.10%	**≥ 5,000,000**	0.02%	0.20%	**≥ 60,000,000**	0.00%	0.50%
≥ 1,000 BTC	0.15%	0.08%	**≥ 7,500,000**	0.00%	0.20%			

	Gemini	Coinbase *	Kraken	Bitstamp		CEX IO	Bitfinex **	Itbit
	≥ 10 BTC			**% Fee**	**Minimum Fee**			
Deposit	$ -	$ -	$ 5.00	0.05%	$ 7.50	$ -	$ -	$ 10.00
Withdrawal	.002 BTC	$ -	$ 5.00	0.09%	$ 15.00	$ -	.0004 BTC	$ -

***** Coinbase deposits are only available for amounts greater than $5,000 and withdrawals greater than $25,000

****** Bitfinex deposits are only free for deposits greater than $1,000, otherwise they cost .0004 BTC

```
Function BSCall(s, k, v, r, t, d)
  d_1 = (Application.Ln(s / k) + (r - d + (v ^ 2) / 2) * t) / (v * t ^ 0.5)
    nd1 = Application.NormSDist(d_1)
  d_2 = d_1 - v * t ^ 0.5
    nd2 = Application.NormSDist(d_2)
BSCall = s * Exp(-d * t) * nd1 - k * Exp(-r * t) * nd2
End Function


Function BSPut(s, k, v, r, t, d)
  d_1 = (Application.Ln(s / k) + (r - d + (v ^ 2) / 2) * t) / (v * t ^ 0.5)
    minus_nd1 = Application.NormSDist(-d_1)
  d_2 = d_1 - v * t ^ 0.5
    minus_nd2 = Application.NormSDist(-d_2)
BSPut = -s * Exp(-d * t) * minus_nd1 + k * Exp(-r * t) * minus_nd2
End Function


Function putvol(s, k, r, t, d, mkt)
hivol = 6
```

```
lovol = 0
   Do While (hivol - lovol) > 0.0001
      If BSPut(s, k, (hivol + lovol) / 2, r, t, d) > mkt Then 'if bsput > Mkt price
      hivol = (hivol + lovol) / 2 'lower vol
      Else: lovol = (hivol + lovol) / 2 'raise vol
      End If
   Loop
putvol = (hivol + lovol) / 2
End Function


Function callvol(s, k, r, t, d, mkt)
hivol = 4
lovol = 0
   Do While (hivol - lovol) > 0.0001
      If BSCall(s, k, (hivol + lovol) / 2, r, t, d) > mkt Then 'if bscall value is too high
      hivol = (hivol + lovol) / 2 'lower vol
      Else: lovol = (hivol + lovol) / 2 'raise vol
      End If
   Loop
callvol = (hivol + lovol) / 2
End Function
```

BIBLIOGRAPHY

Ahmed, Mansoor & Shumailov, Ilia & Anderson, Ross. (2019). Tendrils of Crime: Visualizing the Diffusion of Stolen Bitcoins.

Andreessen, Marc. "Why Bitcoin Matters." *The New York Times*, The New York Times, 21 Jan. 2014

"Bitcoin Exchanges." *Bitcoin*, bitcoin.org/en/exchanges#international

Black, Fischer, and Myron Scholes. "The Pricing of Options and Corporate Liabilities." *Journal of Political Economy*, vol. 81, no. 3, 1973, pp. 637–654., doi:10.1086/260062.

B¨ohme, Rainer, Breuker, Dominic and Mo¨ser, Malte. An inquiry into money laundering tools in the Bitcoin ecosystem. In Proceedings of the Seventh APWG eCrime Researcher's Summit, pages 1–14. IEEE, 2013.

Edelman, Benjamin. 2014. "Consumers Pay More When They Pay with Bitcoin." PYMNTS.com, May 20

Gandal, N., Hamrick, J.T., Moore, T. and Oberman, T., 2018. Price manipulation in the Bitcoin ecosystem. Journal of Monetary Economics.

Hull, J. C. (2017). *Fundamentals of futures and options markets*.

Miroslava Rajcaniova Pavel Ciaian and dArtis Kancs. The economics of bitcoin price formation. Applied Economics, 48:1799–1815, May 2016.

Moore, Tyler, and Nicolas Christin. 2013. "Beware the Middleman: Empirical Analysis of Bitcoin-Exchange Risk." In Financial Cryptography and Data Security, vol. 7859 of Lecture Notes in Computer Science, pp. 25–33. Springer.

Nilsson, Kim, 2015, The missing MtGox bitcoins, *WizSec*, April 19.

Rainer B¨ohme, Nicolas Christin, Benjamin Edelman, and Tyler Moore. Bitcoin: Economics, technology, and governance. Journal of Economic Perspectives, 29(2):213–38, 2015.

Satoshi Nakamoto. Bitcoin: A Peer-to-Peer Electronic Cash System

Sauer, Beate, (2016), Virtual Currencies, the Money Market, and Monetary Policy, *International Advances in Economic Research*, 22, issue 2, p. 117-130,

Xin Li and Chong Alex Wang. The technology and economic determinants of cryptocurrency exchange rates: The case of bitcoin. Decision Support Systems, December 2016.

Young, Joseph. “Bitcoin Futures Expired Last Week, Did It Affect $10 Billion Plunge of Crypto Markets?” Cointelegraph, Cointelegraph, 14 Feb. 2019, cointelegraph.com/news/bitcoin-futures-expired-last-week-did-it-affect-10-billion-plunge-of-crypto-markets.

ACADEMIC VITA

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EDUCATION

The Pennsylvania State University — **University Park, PA**
Schreyer Honors College — *May 2019*
Thesis: Liquidity and Market Efficiency: The Case of Bitcoin Derivatives
Outline: Market Conditions | Price Determinants | Futures Curves | Price Convergence and Arbitrage

Smeal College of Business, Bachelor of Science in Finance
Minor in International Business
College of the Liberal Arts, Bachelor of Science in Economics with Honors

Beta Gamma Sigma Honors Society Member

Maastricht University — **Maastricht, The Netherlands**
Course Title: *Doing Business in Emerging Markets in Central and Eastern Europe* — *July 2016-Aug 2016*

WORK EXPERIENCE

Eaton — **Beaver, PA**
Financial Analyst Intern — *May 2018-Aug 2018*

- Managed a fixed asset inventory to locate 2,148 assets in a 555,000 square foot plant
- Collaborated with 15 supervisors to get further clarification on intangible assets and new asset additions
- Prepared for a physical count of $10 million of inventory completed by 100 people in 2 days

Visionese — **State College, PA**
Project Procurement Intern — *May 2017-Aug 2017*

- Communicated with 45 universities to gain awareness for Project Virtual Reality Campus (VRC)
- Secured funding for Project VRC through the Mozilla Gigafund
- Researched 20 new leads per week and worked to build relationships with prospect customers

RELEVANT EXPERIENCE

Penn State Asset Management Group — **University Park, PA**
Fixed Income Sector Lead Analyst — *Sept 2018- Present*

- Researched the healthcare sector and worked with 3 other members to create a debt research report for Merck

Students Consulting for Non-Profit Organizations — **University Park, PA**
Project Manager for Global Connections — *Sept 2017-May 2018*

- Managed a team of 3 consultants throughout a year-long project engagement
- Delegated deliverables to each team member and ensured they are meeting the project's quality standards
- Communicated weekly with Global Connections executive director regarding project advancement

Consultant for ACRES — *Sept 2016-May 2017*

- Studied hydroponics to assist in the development of ACRE's business plan
- Analyzed the vegetable market in State College using Porter's five forces to determine profitability and payback period

Rules and Regulations THON Committee — **University Park, PA**
Will Call Specialist — *Sept 2015-Present*

- Trained 32 committee members on the proper procedures to use when assigned to will call
- Delegated responsibilities to 5 committee members on each of the 3 will call shifts THON weekend