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The regulated tail that wags the honey badger

Researching price discovery in bitcoin, identifying the leading instruments, and examining the impact of the regulated futures market.

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Abstract

In this thesis, we examine the process of how new information is impounded into the market, more commonly known as the price discovery process. We used GIS by Lien & Shrestha (2014) and identified the most relevant and important markets in bitcoin's price discovery process. We analyzed the GIS within various markets using minute-by-minute market close data from 21 different bitcoin pairs from June 1, 2020, until April 30, 2021.

First, we analyzed the GIS in the spot market. The results suggest that Binance's stablecoin denominated pair leads the spot market, with Coinbase in a close second. Second, we analyzed the GIS in the unregulated futures market. Our results indicate that Huobi and OKEx futures lead the unregulated futures market. Third, we analyzed the GIS in the perpetual swaps market. We found indications that Binance's linear perpetual swap is the leading instrument in the perpetual swap market.

We then analyzed the leaders from each group, in addition to CME bitcoin futures. The results from this analysis suggest that the unregulated futures on Huobi and OKEx tend to lead the market. However, we observed trends of substantial price discovery taking place on both the CME futures and the Binance perpetual swap contract. We identified a more pronounced leading role of the CME bitcoin futures than found in previous literature following the same methodology, suggesting that the regulated futures market has become an important part of bitcoin's price discovery.

Keywords – Bitcoin, Price discovery, Generalized Information Share

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1 Introduction

In 2008, the pseudonymous creator Satoshi Nakamoto published a white paper establishing Bitcoin as the first digital currency to operate through a peer-to-peer network without a central authority (Nakamoto, 2008). Since the Bitcoin genesis block of January 3rd, 2009, the bitcoin trading ecosystem has evolved organically through the emergence of spot markets, decentralized exchanges, and unregulated and regulated derivatives markets.

However, bitcoin's value, necessity, and underlying technology have been heavily debated topics in the last 12 years. Despite its critics, bitcoin has seen a sharp appreciation in value, reaching a market capitalization above $1 trillion (coinmarketcap.com, n.d.). Thus, bitcoin is an asset that should be studied rigorously by economists seeking to understand this emerging asset from technical, financial, philosophical, and theoretical perspectives.

This thesis aims to provide a better understanding of the bitcoin market. This investigation identifies the most important exchanges and investigates whether the involvement of regulated markets has impacted the price discovery of bitcoin.

1.1 Motivation

In December of 2017, bitcoin's value soared after a yearlong bull market. It reached a peak of over $19,000 per coin, a value that long held the record of being the all-time high, until December of 2020.

Around the time of bitcoin's 2017 peak, the Chicago Mercantile Exchange (CME) and the Chicago Board Options Exchange (CBOE) introduced financially settled futures contracts on bitcoin. Previous price discovery research papers have credited the launch of the futures contracts by CME and CBOE as a key factor in the massive price decline of bitcoin in the following months. More specifically, the inception of an organized, transparent derivatives market for institutional investors enabled traders to more easily short bitcoin (Baur & Dimpfl, 2019; Sebastião & Godinho, 2020; Fassas et al., 2020).

However, the daily volumes from CME and CBOE were substantially lower than those of other unregulated exchanges, and CBOE eventually announced its withdrawal in March 2019 (Hill, 2019).

Although the regulated exchanges entered the market in 2017, the unregulated exchanges had been operating since 2011 (Bragin, 2015). Thus, it may seem odd that so few have researched the role of unregulated derivatives exchanges in bitcoin despite their significant trading volume.

Furthermore, unregulated derivatives exchanges such as Binance, BitMEX, Bybit, Deribit, FTX, Kraken, OKEx, and Huobi all have substantial trading volumes and open interest in bitcoin futures, perpetual swaps (perpetuals), and options. In this paper, the term "unregulated" is used because many of these exchanges are based in countries with little or no regulation of derivatives trading. Additionally, unregulated exchanges' possible price discovery role has been overlooked in many of the previous price discovery articles on bitcoin. In fact, it has been researched only by Alexander et al. (2020) and Alexander & Heck (2020). These articles revealed significant price discoveries at the unregulated exchanges, where both the perpetuals and futures contracts have important roles.

Based on the findings in these papers, the authors concluded that bitcoin was not ready for mainstream trading products such as exchange-traded funds (ETF). That is, the risk of market manipulation was too high. However, since the release of these two research papers, there have been momentous developments within the bitcoin market.

From the beginning of April 2019 until January 2020, the time period of the data used by Alexander & Heck (2020), BitMEX was the largest exchange for futures and perpetuals by average daily volume (ADV). In 2020, CME's bitcoin futures substantially increased their trading volume. By the end of November 2020, CME's bitcoin futures had a larger open interest than any unregulated exchange (Arcane Research, 2020).

Furthermore, in 2020, BitMEX faced legal issues due to a lack of proper know-your-customer (KYC) implementation on the platform. Thus, the Commodity Futures Trading Commission (CFTC) charged BitMEX for illegally operating a cryptocurrency derivatives trading platform and anti-money laundering violations. Additionally, the U.S. Department of Justice (DOJ) charged the founders of BitMEX with violations of the Bank Secrecy Act (Department of Justice, U.S. Attorney's Office, 2020). BitMEX's open interest declined following these charges, while other unregulated platforms such as Binance and Bybit grew in size, changing the market structure.

Given the changes in the futures market over the last year, it would be valuable to re-examine the previous studies on price discovery, with unregulated exchanges included, to better understand the current state of the market. Furthermore, understanding the roles of and the relationship between the regulated and unregulated derivatives markets in bitcoin is also important for regulatory authorities.

In recent years, there have been several attempts to create bitcoin ETFs in the United States. However, the U.S. Securities and Exchange Commission (SEC) has declined all ETF applications thus far, mainly because of the underlying bitcoin market and the risks of market manipulation (Bambrough, 2020a).

The lack of a proper bitcoin ETF in the U.S. has created unfortunate market inefficiencies, impacting retail investors. As of this writing, there exist certain instruments through which U.S. investors can gain bitcoin exposure through their 401-Ks. The most notable instrument is the Grayscale Bitcoin Trust, in which accredited investors may invest directly in Grayscale either in cash or in-kind using bitcoin. This fund currently holds more than 600,000 bitcoin (Stevens & Copeland, 2021). Retail investors are eligible to invest in the Grayscale Bitcoin Trust only through shares in the secondary market. Due to the lack of an active redemption program and a six-month lock-up period, the shares in the secondary market frequently trade at a significant premium or discount from the net asset value. Thus, this fund is suboptimal for investors seeking bitcoin exposure (Lunde, 2020).

With bitcoin's strong performance in 2020 and 2021, many new ETF applications have been issued. Currently, there are ten active bitcoin ETF applications issued by entities such as VanEck, Fidelity, Skybridge, NYDIG, and Galaxy Digital (Napach, 2021; De, 2021). This thesis aims to shed light on the current role of the regulated futures market in bitcoin, helping the SEC assess the current risk of market manipulation.

Therefore, this paper proposes the following research question:

How relevant is the regulated market in the price discovery process?

This question will be answered with data gathered from coinAPI and Bloomberg for 21 different price pairs, consisting of spot pairs and various derivative instruments between May 2020 and April 2021.

2 Background and theory

This section encompasses relevant theories and background information for this thesis. It presents Bitcoin and how its trading ecosystem evolved to its current state. The section further introduce stablecoins, the derivatives used in the analysis, and the markets in which they trade.

2.1 Bitcoin

Bitcoin is an invention based on decades of research developed to build a digital, decentralized currency. The Bitcoin whitepaper itself is heavily influenced by the ideas presented in Wei Dai's B-Money (1998) and Adam Back's Hashcash (2002). Behind the innovation of Bitcoin was the fundamental idea of allowing value to be transacted from one entity to another without the need for a trusted intermediary. This feature of Bitcoin was enabled by the use of cryptographic proof of work instead of trust (Nakamoto, 2008). When transactions in Bitcoin are conducted, they are timestamped and compiled into a new block every 10 minutes. Each block is then transferred to the network for confirmations and secured by the proof of work which is completed by miners solving hashing algorithms related to the block. Additionally, each block carries a cryptographic hash from the previous block, meaning that each new block contains information from the previous block. In turn, this process creates a chain of blocks filled with transactions, creating a tamper-proof distributed ledger, popularly called a blockchain. This thesis will refer to the blockchain as "Bitcoin" using a capital letter "B", and the cryptocurrency as "bitcoin", with a lowercase "b".

The miner solving the hash for the upcoming block is rewarded with bitcoin. In addition to transaction fees, this reward is the mechanism that incentivizes miners to commit computational power to the Bitcoin network. The block reward (or miner subsidy) is fixed, but it halves every 210,000 blocks, approximately every fourth-year (Nakamoto, 2008). The current block reward sits at 6.25 bitcoin per block, with a current inflation rate per annum at 1.77%. Bitcoin has an absolute scarcity because there will only ever be 21 million bitcoins in existence. As of now, more than 18.7 million bitcoins are in circulation, meaning that 89.15% of the supply has already been issued (bitcoinblockhalf.com, n.d.).

Bitcoin is transferable at any time, 365 days a year, with no need for an intermediary. It is completely permissionless, meaning that anyone can transfer value on the Bitcoin network whenever and to whomever they desire, with full finality (Arcane Research, 2021a). These features enable bitcoin to function well as a collateral asset, enable financial innovation, and continuous trading on exchanges. That is, bitcoin can be traded globally at any time, on both the spot markets and in the bitcoin-collateralized futures market.

2.1.1 Bitcoin trading ecosystem

The bitcoin market is complicated, with many entities serving various roles within the market. This environment involves many spot exchanges, a large unregulated derivatives market, and a growing regulated derivatives market. From an outside perspective, the bitcoin trading ecosystem may be difficult to understand.

Therefore, the following pages provide a brief recap of bitcoin's history, giving the reader sufficient background information to understand how the bitcoin trading ecosystem reached its current state. The paper details this enlightenment process by describing Bitcoin's 12-year old history. In the process, this study defines four major cycles that have shaped the market into its current state.

During Bitcoin's **first market cycle** from 2010 to 2011, Bitcoin gained attention due to its permissionless transfers. The first known purchase of a physical good paid with bitcoin was conducted on May 22 2010 when Laszlo Hanyecz purchased two pizzas for 10,000 BTC (laszlo, 2010).

In 2010, Wikileaks transfers were blocked by Visa, MasterCard (Greenberg, 2010), and PayPal (WikiLeaks, 2010). Early Bitcoin activists reached out to Wikileaks to convince them to accept bitcoin payments (Matonis, 2012). However, Satoshi Nakamoto was unhappy with Bitcoin being involved in Wikileaks and commented as follows:

> "It would have been nice to get this attention in any other context. WikiLeaks has kicked the hornet's nest, and the swarm is headed towards us." (Nakamoto, 2010)

Satoshi could not stop the activists, despite being the creator of Bitcoin. Wikileaks started accepting bitcoin payments, and Bitcoin's properties saw its first major real-world use case with activists donating funds to the organization, utilizing the permissionless nature of the asset. In addition to the Wikileaks donations, Bitcoin's permissionless transfers created a thriving black market, most notably on The Silk Road (U.S. Attorney's Office, 2013).

During this cycle, the majority of the bitcoin trades were conducted from peer-to-peer markets, but the cycle also involved the first order book exchanges (Sedgwick, 2018).

The second market cycle occurred in 2013. During this second cycle, Bitcoin received its first major round of public attention. As the attention grew, more advanced infrastructures were built around trading bitcoin and purchasing goods for bitcoin, with The Silk Road and Mt. Gox as the dominating platforms. The Silk Road was removed by the FBI in October 2013 because, among other things, it facilitated the buying and selling of drugs (U.S. Attorney's Office, 2013). A couple of months later, Mt. Gox, the largest crypto exchange at the time, which at that time purported to handle 80% of all bitcoin trade volume (Spaven, 2013), filed for bankruptcy (Takemoto & Knight, 2014).

Additionally, in December 2013, China banned banks from handling bitcoin trade (BBC tech, 2013). These events occurred during the most volatile period of bitcoin's rally towards and beyond $1000 of late 2013 (coinmarketcap.com, n.d.) and were followed by a protracted bear market. The Chinese ban led early bitcoin activist Roger Ver to launch the successful marketing campaign titled ***Bitcoin: The honey badger of money***. The campaign was a reference to a popular meme at the time depicting how the honey badger ignores all of the dangers and challenges it meets. This illustration projected that Bitcoin would thrive even if Chinese or American politicians wanted to ban it (McMillan, 2013).

During the second cycle, new spot exchanges such as Bitstamp, Kraken, Coinbase, and Gemini emerged. These exchanges have since cooperated with regulators by implementing KYC and anti-money laundering (AML) procedures while also improving the custody of user funds on their platforms.

The third market cycle occurred in 2017. At its peak, Bitcoin frequently made headlines in mainstream news outlets, and public awareness of Bitcoin increased. As the spot markets matured during the bear market of 2014-2015, market places for bitcoin derivatives gradually arose. The permissionless nature of Bitcoin made building unregulated derivative exchanges possible.

Initially, the unregulated derivative exchanges offered inverse futures for bitcoin (Bragin, 2015). This was a convenient solution for miners seeking to hedge their operations and also enabled opportunists to gain leveraged exposure to the upside.

On May 13, 2016, the derivative exchange BitMEX launched an innovative derivative product, the inverse perpetual contract (Hayes, 2016). This derivative product is discussed in greater detail in section 2.5. Once Bitcoin entered its bull market in 2017, trading in the perpetuals grew, and during the peak of the bull market, the trade volumes of the perpetuals overtook those of the spot market (interdax, 2019).

During the third cycle, allocating assets into cryptocurrencies was a simple process for retail investors, but the trading ecosystem was not optimized for sophisticated, well-capitalized institutional players. That is, trusted and regulated derivative instruments did not exist until the peak of the 2017 bull market (Damiani, 2017; CME Group, 2017). Additionally, the market-making across exchanges was relatively poor, as spreads often occurred across exchanges and fiat currency pairs (Pongratz, 2021). Thus, the market was not ready for large-scale institutional adoption.

At the peak of the third cycle, an important step was taken towards a more mature derivative market in bitcoin. The Chicago Mercantile Exchange (CME) launched cash-settled bitcoin futures (CME Group, 2017), giving institutional investors access to bitcoin through a regulated marketplace with a trusted intermediary in a familiar system. Bitcoin soared in value towards the launch of the CME futures, as market participants anticipated that the entrance of a regulated futures market would lead institutional buyers to the market. However, on the day of the launch, bitcoin reached its price peak of the cycle. The expectations were too high, and institutional investors were careful with allocating funds in bitcoin. Then followed yet another protracted bear market in bitcoin.

Bitcoin is currently in its **fourth market cycle**. More robust institutional offerings have emerged, and institutional investors have begun investing in bitcoin utilizing brokers (Genesis, 2021), institutionally oriented spot markets through LMAX Digital (Abdel-Qader, 2021), OTC desks (Kaul et al., 2021), futures on CME (Godbole, 2021), and bitcoin investment vehicles (Grayscale, 2021).

The institutional adoption of bitcoin accelerated in the aftermath of the COVID-19 crisis. This was a reaction to the monetary and fiscal policies initiated globally in response to the financial instability caused by the virus. In May 2020, Paul Tudor Jones publicly stated that he had invested in bitcoin as an inflation hedge, comparing it to investing in gold in the 1970s.

> "I also made the case for owning Bitcoin, the quintessence of scarcity premium. It is literally the only large tradeable asset in the world that has a known fixed maximum supply.[...] This brilliant feature of Bitcoin was designed by the anonymous creator of Bitcoin to protect its integrity by making it increasingly near and dear, a concept alien to the current thinking of central banks and governments." (Jones & Giorgianni, 2020)

When Tudor Jones entered this investment space, his action had a snowballing effect. Stan Druckenmiller (Bambrough, 2020b) later invested in bitcoin, along with major funds such as RenTech's Medallion Fund (Wigglesworth & Aliaj, 2020); BlackRock (Stankiewicz, 2021); StoneRidge (del Castillo, 2020); Skybridge (La Monica, 2021); Guggenheim (Greifeld & Hajric, 2020); Ruffer Investments (Voell, 2020); and college endowments (Allison, 2021). Additionally, corporations began adding bitcoin to their balance sheet. This occurred with MicroStrategy first (Reuters, 2021); Square later (Lee, 2021); and then Tesla (Kovach, 2021) in the United States. In Norway, Aker allocated capital to bitcoin through its newly established daughter company Seetee (AKER, 2021).

The four cycles described above have all contributed to shaping the bitcoin trading ecosystem as we know it today. First, a gradually maturing spot market evolved with various large platforms. Next, the unregulated derivative platforms emerged, adding a new and important layer to bitcoin's price discovery. After this, the regulated market matured through both spot markets and derivatives market infrastructure enabling large investors from traditional financial markets to gain access to the bitcoin markets. Thus, this ecosystem has evolved organically to its current state.

2.2 Stablecoins

Stablecoins are bearer monetary assets designed to mimic the price of fiat currencies by utilizing a stabilization mechanism. They are essentially a digital representation of fiat currency that lives on blockchains (The Block Research, 2021). These assets combine the low volatility of sovereign currencies with the settlement assurances of public blockchains, allowing fiat currency to be transferred and settled anywhere over the internet with less interference than the traditional banking system would cause (The Block Research, 2021). The most common stablecoins are USD-collateralized stablecoins with a 1:1 backing. That is, one unit of these USD collateralized stablecoins is redeemable for one USD. From January 1, 2020, to January 1, 2021, the number of stablecoins in circulation grew by 400%, from $6 to $30 billion, with Tether (USDT) being the largest of these stablecoins (The Block Research, 2021). As of May 16, 2021, there are $58.6 billion USDT in circulation (Tether, n.d.).

Therefore, stablecoins have become an integral part of the trading ecosystem of cryptocurrencies. They are now frequently used in all markets, from spot markets to the unregulated futures market. In the futures market, stablecoins enable unregulated futures exchanges to create linear futures, in contrast with the inverse futures and quanto futures. The latter structure was common in futures contracts before stablecoin-settled futures began to gain traction in 2020 (Arcane Research, 2021b).

2.3 Unregulated derivatives exchanges

Unregulated markets have played a significant role in Bitcoin's history. In many ways, this history is unlike the histories of most of the available investment vehicles in recent history. That is, this trading ecosystem has grown organically through adoption and innovation in the unregulated markets to reach its current state. Crypto native derivative exchanges utilizing the permissionless nature of bitcoin arose before bitcoin gained the attention of regulators and institutions. The subsequent evolution and adoption were first based on specialized infrastructure, so there is still considerable bitcoin trade volume occurring on unregulated exchanges (coinmarketcap.com, n.d.).

The inverse perpetual by BitMEX (Hayes, 2016) became a popular derivative instrument to trade during the 2017 bull market. However, it was not until the bear market of 2018-19 that the adoption of the derivatives markets accelerated to absorb most of the trading volume in bitcoin (interdax, 2019). As the market became less volatile, speculators sought to partake in leveraged positions with hopes of achieving greater returns, and the derivative space evolved. Exchanges such as OKEx and Huobi underwent sharp rises in trade volume on their futures contracts, while new exchanges such as Bybit, Binance, and FTX first entered the scene. As of May 16, 2021 the unregulated derivatives exchanges held $16.4 billion worth of open interest (Skew.com, n.d.).

Some countries, most notably the United States, forbid their citizens to partake in trades on these platforms (Chernin et al., 2020). Nevertheless, such derivative exchanges had done little to prevent U.S. citizens from trading on these platforms until 2020. Now, however, geo-restrictions have been implemented, and most platforms operate with KYC and AML procedures in place. This transition towards KYC and AML erupted as the CFTC and DOJ took action against what was then the largest unregulated bitcoin futures exchange, BitMEX (Department of Justice, U.S. Attorney's Office, 2020).

In January 2020, BitMEX accounted for 36% of the total open interest in the bitcoin futures market, but there was a fallout with the regulators and a fiery liquidation loop in March 2020 (Le Calvez & Coin Metrics, 2020). Thus, the exchange experienced a sharp decline in its active user base, and it currently holds only about 10% of the total open interest in the market (Arcane Research, 2020).

The increased focus from U.S. regulators on the unregulated derivatives exchanges led, BitMEX, Deribit, and FTX, among other entities, to implement KYC procedures. This was an important step forward for the bitcoin derivative market. Overall, the trend in the bitcoin derivatives markets seems to involve a growing focus on KYC-procedures from unregulated exchanges.

2.4 Regulated derivatives exchanges

Another important step towards a more mature derivative market in bitcoin occurred on December 18, 2017, when CME launched cash-settled bitcoin futures. The boundaries to trade on CME compared with the unregulated platforms are far higher. That is, the minimum contract size sits at five bitcoin, whereas the margin requirements are far more conservative because traders are subject to a margin requirement of 37% (CME Group, n.d.). The stiff requirements to trade on CME likely led CME's bitcoin futures to hold a relatively low share of the total open interest in the bitcoin futures market. In January of 2020, this figure was approximately 4%. However, because bitcoin has gained traction among institutional investors in 2020, the open interest has grown in the CME bitcoin futures. As of May 27, 2021, the open interest accounts for about 15% of the total open interest in the bitcoin futures market (Skew.com, n.d.).

2.5 Perpetual swap contracts: inverse and linear

The perpetual swap contract in bitcoin is a fixed floating swap between two different currencies, bitcoin, and either USD or a stablecoin. In this arrangement, the nominal amount of one currency is rebalanced against the other currency, according to market changes throughout the holding period. One side pays an interest rate, called the funding rate, according to the price difference between the contract and the underlying spot index.

The funding rate is a tool to prevent divergence between the perpetual and the bitcoin spot index. The funding rate equations and funding periods vary across the exchanges. Some instruments use hourly funding periods, whereas most of the perpetuals have eight-hour funding intervals. However, all of the perpetuals share the unique attribute of having no fixed maturity. For bitcoin, this is highly beneficial, as it eliminates the need for rolling over trades, something that could be risky due to the high volatility of bitcoin (Alexander & Heck, 2020).

Although the first perpetual used bitcoin as the underlying collateral, some perpetuals have used stablecoin collateral in recent years. Thus, traders have the option to speculate on either inverse or linear perpetuals if they so desire.

2.6 Futures

A futures contract represents a legal agreement to buy or sell a particular asset or security at a given point in time in the future. The price of the contract is determined at the time of which the contract is agreed upon (Alexander & Heck, 2020).

In the early years of the unregulated bitcoin futures market, the most common futures instruments were the inverse bitcoin futures. The inverse contract in bitcoin is quoted in USD, while its margin and profit and loss (PnL) is denominated in bitcoin (Hayes, 2017). Inverse contracts involve a negative gamma for long positions because the value of the underlying margin declines when the bitcoin prices decline. However, inverse futures are convenient instruments in short positions due to their opposite dynamics, with the collateral increasing in value when the bitcoin price appreciates, leading to a positive gamma.

In recent years, linear futures contracts have become more common in bitcoin. That is, USD denominated linear futures, with margin and PnL in USD offered on CME. Additionally, stablecoin denominated linear futures with margin and PnL in stablecoins, most often USDT, is available on several unregulated bitcoin futures exchanges.

3 Literature review

This section aims to provide an overview of relevant literature on the subject of the price discovery process and highlight the existing literature on price discovery processes in Bitcoin.

The work of this thesis relates to previous research conducted on the relationship between the spot and derivative markets of bitcoin. This paper is a partial replica of a paper published by Alexander & Heck (2020), but this study has further built on that one by adding new and relevant price pairs. Compared with the data used in this previous paper by Alexander and Heck, there has been a revolt in the futures market over the last year, including a large shift in average daily volumes across the different exchanges (Skew.com, n.d.). Additionally, this paper involves derivatives not included by Alexander and Heck, with the introduction of linear futures and perpetuals settled in stablecoins. Therefore, this should be an informative addition to existing literature.

Price discovery has been a topic for extensive research across a range of assets and products. According to Garbade & Silber (1983), Flemming et al. (1996), and Silvapulle & Moosa (1999) an array of reasons explain why futures should lead in established asset classes. These include lower transaction costs, the absence of short-sale restrictions, built-in leverage, and greater transparency.

Numerous researchers have studied price discovery over the years, and the prevailing view in the literature is that future contracts dominate in price discovery processes. Kawaller et al. (1987) demonstrated the leading role of futures contracts on the S&P 500 index. Many years later, Chakravarty et al. (2004) used a modified version of the information share (IS) approach to establish that the options market was leading the spot market for 60 stocks listed on the NYSE and options listed on CBOE. Furthermore, Figuerola-Ferretti & Gonzalo (2010), Jin et al. (2018), and Bohmann et al. (2019) found similar results with futures and options leading spot markets for commodities and other precious metals.

In contrast to the prevailing view in literature, some researchers have found that futures do not lead in the price discovery process for all instances. In some cases, the spot markets are the leading vehicle. This has been demonstrated by Cabrera et al. (2009) for Euro and Japanese Yen exchange rates and by Shrestha (2014) for crude oil.

Regarding the previously conducted research on price discovery processes in bitcoin, the results have been inconclusive, both between spot and futures as well as within the spot market. Schei & Rix-Nielsen (2019), Pagnottoni & Dimpfl (2019), and Dimpfl & Peter (2020) all found different spot exchanges leading in the price discovery within the spot market. Moreover, all of these papers used different models to analyze their data.

Beyond this, Corbet et al. (2018) investigated the spot market volatility of bitcoin after the introduction of futures on CME and CBOE and further analyzed both price discovery and whether the contracts were effective hedging instruments. These researchers used minute-by-minute data for futures contracts on both exchanges and the spot market. In their analysis, they found that the spot market volatility increased after the introduction of futures contracts. They also tested different price discovery metrics such as IS (Hasbrouck, 1995), component share (CS) (Gonzalo & Granger, 1995), information leadership (Yan & Zivot, 2010), and information leadership share (ILS) (Putniņš, 2013). In all of these cases, this team found that the spot market was leading in price discovery and claimed that the traders using futures were uninformed noise traders.

Baur et al. (2018) further tested the results presented by Corbet et al. (2018), with similar results. They used five-minute data from CME and CBOE for their future contracts' prices. However, to align their work with the spot data from Binance, they manipulated the data to obtain 15-minute intervals. In the analysis, they used IS (Hasbrouck, 1995) and CS (Gonzalo & Granger, 1995), and both methods provided clear dominance of the spot market over the futures market. Additionally, these researchers noted that some key advantages of the spot market over the futures market are longer opening hours and higher trading volumes.

In contrast to both Corbet et al. (2018) and Baur et al. (2018), Kapar & Olmo (2019) tested the relationship between CME futures contracts and Coindesk's spot index. Much like the previous research papers, their team used IS by Hasbrouck (1995) and CS by Gonzalo & Granger (1995). Unlike Corbet et al. (2018) and Baur et al. (2018), they used daily data. They attributed these changes as a possible reason for why their results differed from those of previous research, as both IS and CS find a clear dominance of futures over the spot market. However, these results are in line with the prevailing view in the literature of other assets.

Adding to this body of work, Entrop et al. (2020) analyzed the price discovery by using IS (Hasbrouck, 1995) and CS (Gonzalo & Granger, 1995). They also analyzed the impact of trading volume, the bid-ask spread, relative numbers of quotes, spot market volatility, and testing the market quality based on sentiment, attention, and macroeconomic news. Their findings included effects of trading volume and trade size on price discovery metrics while also finding a more important role of futures in high news-based sentiment periods.

Alexander et al. (2020) used BitMEX, the largest unregulated exchange at the time, to check for price discovery. This team incorporated the largest derivative product available at that time, the inverse perpetual. They used MIS (Lien & Shrestha, 2009) and CS (Gonzalo & Granger, 1995) for price discovery through a four-dimensional VECM. This was the first research that was conducted on an unregulated exchange, finding that the product led the prices of the major spot exchanges.

Next, Fassas et al. (2020) conducted a price discovery analysis, along with an analysis of volatility transmission between futures and spot. This team emphasized that volatility is a proxy for information flow. They also expanded a traditional price discovery analysis with a cointegration analysis to examine the length of time before a new futures market would perform well in a price discovery function. As consensus in the literature, these researchers found that the price discovery occurred in the futures market, while also finding that the volatility of the markets was closely related to price discovery metrics.

Further developing the findings showing futures lead spot in bitcoin, Akyildirim et al. (2020) tested whether CBOE or CME led the other, as well as their relationships to the spot market. These findings are summarized as showing that futures led spot, and that CBOE led CME, tested with IS (Hasbrouck, 1995), CS (Gonzalo & Granger, 1995), information leadership (Yan & Zivot, 2010) and ILS (Putniņš, 2013).

Alexander & Heck (2020) performed a price discovery analysis including 21 instruments on bitcoin, many of them being from unregulated exchanges. By using GIS (Lien & Shrestha, 2014) and CS (Gonzalo & Granger, 1995), they found that unregulated exchanges led the CME futures and spot market and that both CME and spot market reacted rather slowly in some instances. They also concluded that the SEC's decision not to approve any ETFs at the time being was correct due to the leading role of the unregulated derivatives market in bitcoin.

4 Hypothesis development

A key theoretical principle for an efficient market is that the price of a security or an asset should reflect its true or fundamental value (Lien & Shrestha, 2014). How the information regarding the true or fundamental value is impounded into the market is called to be the price discovery process (Hasbrouck, 1995). This thesis explores the price discovery process of bitcoin by analyzing the minute-level data from the most relevant markets, including both regulated and unregulated exchanges. The analysis will focus on price discovery both within and across different exchanges and instruments. In the following paragraphs are the justification for the hypotheses, and the concrete hypotheses for this master thesis. The hypotheses are formulated as alternative hypotheses.

In the data, there are too many and too different instruments for it to be appropriate to compare all at once for the entire period of our data. As of this, the different instruments have been grouped within the market they trade, these groups are the spot market, the perpetuals market, and the futures market. Within each group, the daily contributed market innovation is tested and aggregated into a monthly information share. This thesis is following the methodology of Alexander & Heck (2020) in this process. Within each group, the analysis will likely uncover that some instruments contribute more in bitcoin's price discovery process, and lead the the bitcoin price discovery within the group. This is measured by Generalized Information Share (GIS) (Lien & Shrestha, 2014). This will align with previous research conducted on the topic.

H1: There will be indications of some exchanges leading the price discovery process in each group.

Furthermore, in comparison between the different instruments on unregulated and regulated exchanges, this study expects the futures contracts on CME to have a more pronounced leadership role in the price discovery process in bitcoin, compared to the results of Alexander & Heck (2020).

H2: The regulated futures contract on CME is one of the leading instruments in bitcoin's price discovery.

5 Data

This section presents the data used in the analysis for the thesis. The bitcoin spot market involves well above 100 spot exchanges. Likewise, the futures market is highly diverse and competitive, with more than 10 vibrant offshore unregulated derivatives exchanges offering various kinds of bitcoin futures, options, and perpetuals, in addition to the cash-settled bitcoin futures on CME.

The thesis was based on minute-by-minute open-high-low-close-volume (OHLCV) data from June 1, 2020 till April 30, 2021, from the relevant exchanges and price pairs for the analysis. Within this period, bitcoin was in a strong bull market and grew from $9000 to a peak of $64,000 on April 14 with a large inflow of institutional investors amid a period of unprecedented fiscal and monetary stimulus globally.

The sample period is filled with volatile events, with futures both trading in a high contango and also periods with futures trading in sharp backwardation. The research was conducted on a total of 8.6 million observations from 21 different bitcoin instruments.

The price data was gathered through two different main sources. Price data on the CME futures was obtained through the Bloomberg Terminal. All other prices were obtained through HTML requests from CoinAPI. This was a formidable endeavor. CoinAPI has request limitations of 100,000 lines of data per API-key per day. OHLCV data was obtained from 20 instruments, each with approximately 435,000 observations per pair. This required 87 different API requests. To avoid spending 87 days obtaining the data, 87 separate API-keys were created using VPNs and various email addresses to obtain the data required for the thesis and avoid The Norwegian School of Economics being banned by the CoinAPI servers.

Furthermore, open interest data from Skew.com was used to select the most relevant instruments in the bitcoin futures market.

5.1 Price pairs and markets

5.1.1 Spot market

From the spot market, data from Coinbase, Bitfinex, Bitstamp, Kraken, and Binance was obtained. These spot markets are considered the largest spot markets measured by real and legitimate trading volume. This is based on research conducted by Bitwise Asset Management (2019) on the issue of wash trading and fake volumes in the bitcoin markets. Coinbase, Bitfinex, Bitstamp, and Kraken have most of their trading volume in fiat currencies, whereas a majority of the trading volume on Binance's bitcoin spot market is based on the stablecoin Tether.

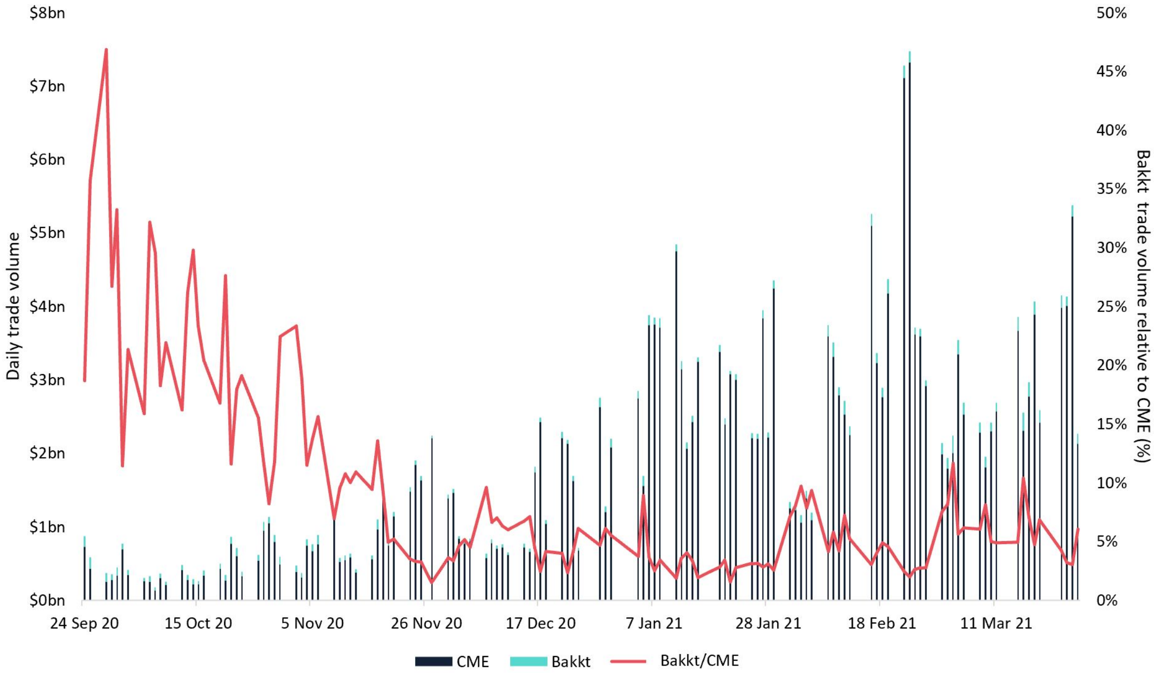
5.1.2 The futures market

To adjust trading data on the futures market into a continuous time series, futures were rolled over from the prompt to the next contract at midnight the day before expiration. This was inspired by the methodology used by Alexander & Heck (2020) in their price discovery analysis.

5.1.2.1 The regulated futures market

During the time period, there were only two regulated futures exchanges. CME offered one future instrument, a linear futures contract settled in USD with a contract size of five bitcoin, while the Intercontinental Exchange subsidiary Bakkt offered both inverse and linear futures with a smaller contract size of 1 bitcoin. During the entire sample period, CME dwarfed Bakkt in terms of both trading volume and open interest. As of April 18, 2021, the open interest on CME's bitcoin futures was 3887% the size of Bakkt. Bakkt accounted for 0.3% of the open interest in the bitcoin futures market and was by all accounts an insignificant player in the market. Thus, the thesis focused on the far more popular futures market on CME and did not include Bakkt's futures.

Figure 5.1: Trading volume, Bakkt and CME



Note: This figure shows the trading volume on Bakkt and CME. The data is collected from Skew.com (n.d.). The left axis shows the daily trade volume denoted in $ billions, and the right axis shows the trading volume on Bakkt compared to the trading volume on CME.

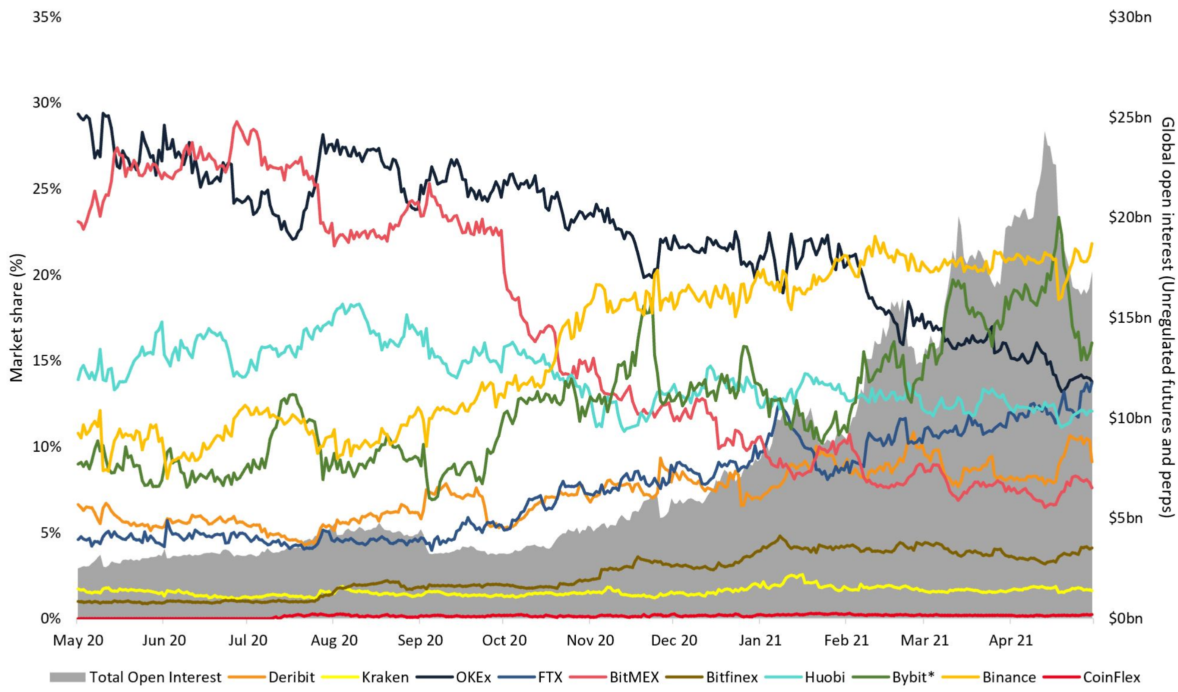
CME offers monthly futures contracts, settled at 4 pm London time, on the last Friday of each month. The contract settles at the simple unweighted average of the price of the underlying Bitcoin Reference Rate index between 3 pm and 4 pm London time. The Bitcoin Reference Rate index is based on the volume-weighted average price of BTCUSD fetched from constituent exchanges Coinbase, Bitstamp, Kraken, Gemini, and itBit (CME Group, n.d.).

The bitcoin futures on CME trades from Sunday to Friday 6 pm to 5 pm ET and are also closed on holidays (CME Group, n.d.). In that regard, the CME futures is unique in bitcoin. All other markets examined in this thesis are trading 24/7, 365 days a year without interruption, which is a considerable disadvantage for the CME contracts in contrast to the other investment tools available.

5.1.2.2 The unregulated offshore futures market

In addition to the regulated futures market, the bitcoin trading ecosystem also has a large and diverse unregulated futures market, with instruments available for trading 24/7, 365 days a year. In this thesis, the most relevant futures instruments were selected based on open interest data fetched from Skew.com. This thesis, therefore, included data from Binance, BitMEX, Deribit, FTX, Huobi, and OKEx.

Figure 5.2: Global open interest unregulated futures and perpetuals, May 1 2020 - April 30 2021



Note: The figure shows the daily global open interest for bitcoin's unregulated futures and perpetuals. The data is collected from Skew.com (n.d.). The left axis shows the market share, and the right shows the open interest in billion USD.

Table 5.1: Average share of global open interest, May 1 2020 - April 30 2021

Exchange	Deribit	Kraken	OKEx	FTX	BitMEX
Open interest	7.19%	1.56 %	22.36 %	7.50 %	16.49 %

Exchange	Bitfinex	Huobi	Bybit*	Binance	CoinFlex
Open interest	2.55 %	14.12 %	12.34 %	15.74 %	0.14 %

Note: The table shows the average share of global open interest for bitcoin's unregulated futures and perpetuals. The data is collected from Skew.com (n.d.).

There are some key differences between the futures instruments available on the unregulated exchanges. Data from linear futures settled in stablecoins were obtained from Binance, FTX, and OKEx. Further, data from inverse futures was gathered from BitMEX, Deribit, Huobi, and OKEx. The research was based on the quarterly futures available in these markets, as they were the most frequently traded instruments and the futures instruments with the highest open interest.

There are also minor differences in terms of contract specifications, margin requirements, and underlying settlement indexes in these futures, summarized in table 5.2. In general, the unregulated exchanges have far smaller unit sizes for contracts and enable far higher leverage than the CME futures. This makes the unregulated market more accessible for retail traders.

Table 5.2: Futures specifications

Exchange	CME	Binance	FTX	OKEx
Contract size	5 BTC	100 USD	0.0001 BTC	100 USD
Margin requirement	37%	0.8%	1%	0.8%
Settlement	Cash in USD	Cash in USDT	Cash in stablecoins	Cash in USDT
Trading days	Weekdays	24/7	24/7	24/7
Delivery date	Last friday	Last friday	Last friday	Last friday
Constituent markets	Coinbase, Bitstamp, Kraken, Gemini, itBit	Binance, Bitfinex, Bittrex, HitBTC, Huobi, OKEx	Binance, Bitstamp, Bittrex, Coinbase, FTX, Kraken, OKEx	OKEx, Binance, Huobi, Poloniex

Exchange	BitMEX	Deribit	Huobi	OKEx
Contract size	1 USD	1 USD	100 USD	100 USD
Margin requirement	1%	1%	0.8%	0.8%
Settlement	Cash in BTC	Cash in BTC	Cash in BTC	Cash in BTC
Trading days	24/7	24/7	24/7	24/7
Delivery date	Last friday	Last friday	Last friday	Last friday
Constituent markets	Bitstamp, Bittrex, Coinbase, Gemini, Kraken	Bitstamp, Bittrex, Coinbase, Gemini, itBit, Kraken, LMAX Digital	Bitstamp, Coinbase, Gemini, Kraken	OKEx, Binance, Huobi, Poloniex

Note: This table describes the main specifications of the futures contracts used in this thesis. CME is the only contract in this thesis with trading breaks. The settlement currency varies, depending on whether the contract is linear or inverse. FTX's settlement currency differs from the other linear futures, as the settlement currency on FTX is a basket of various stablecoins consisting of USDC, TUSD, BUSD, PAX, and HUSD.

5.1.3 The perpetual swaps

The largest futures exchanges in the unregulated market offer perpetuals in addition to the futures instruments mentioned previously. Perpetuals is a popular derivative in the bitcoin markets, a thorough explanation of these instruments is presented in section 2.5. Data on perpetuals are obtained from Bybit, Binance, BitMEX, Deribit, FTX, Huobi, and OKEx.

The perpetuals instruments available through the various markets also have different specifications depending on the exchange and instrument. Linear perpetuals offered by Binance, FTX, and OKEx, and inverse perpetuals from BitMEX, Deribit, Huobi, Bybit, and OKEx, was used in this thesis.

The perpetuals on these exchanges also differ in other aspects. Margin requirements vary, in addition to some noteworthy differences in the funding rate mechanism across the instruments summarized in table 5.3.

Table 5.3: Perpetuals specifications

Exchange	Binance	BitMEX	Bybit	Deribit
Margin	0.8%	1%	0.8%	1%
Funding rate	8 hrs	8 hrs	8 hrs	Continous
Settlement currency	USDT	BTC	BTC	BTC

Exchange	FTX	Huobi	OKEx Inverse	OKEx
Margin	1%	0.8%	0.8%	0.8%
Funding rate	1 hr	8 hrs	8 hrs	8 hrs
Settlement currency	Stablecoins	BTC	BTC	USDT

Note: This table describes the main specifications of the perpetual swap contracts used in this thesis. The settlement currency varies, depending on whether the contract is linear or inverse. FTX's settlement currency differs from the linear perpetual on Binance, as the settlement currency on FTX is a basket of various stablecoins consisting of USDC, TUSD, BUSD, PAX, and HUSD.

5.2 Data statistics

This section presents the summary statistics on the data obtained for the thesis. The ADV illustrates the average daily trading volume for the full sample period measured in $ millions. The no-trade ratio (NTR) depicts the ratio of minutes where no trade occurred. The no-trade ratio is calculated based on CME's trading times, ignoring 5 pm to 6 pm Chicago time and holidays.

Table 5.4: Data Statistics

Type	Instrument	Data start	ADV	NTR
Spot	Binance	June 1, 2020	1791.60	7.54%
	Bitfinex	June 1, 2020	173.19	21.94%
	Bitstamp	June 1, 2020	192.39	1.43%
	Coinbase	June 1, 2020	523.63	0.16%
	Kraken	June 1, 2020	163.09	4.83%
Reg. Futures	CME	June 1, 2020	997.88	31.65%
Unreg. Futures	Binance	August 5, 2020	632.36	4.31%
	BitMEX	June 1, 2020	64.06	12.48%
	Deribit	June 1, 2020	59.05	25.09%
	FTX	June 1, 2020	43.99	49.62%
	Huobi	June 1, 2020	3276.42	13.37%
	OKEx USDT	June 1, 2020	226.83	2.19%
	OKEx inverse	June 1, 2020	1270.91	28.47%
Perpetuals	Binance	June 1, 2020	7710.48	0.25%
	BitMEX	June 1, 2020	2141.79	0.06%
	Bybit	June 1, 2020	3522.98	2.29%
	Deribit	June 1, 2020	491.54	8.81%
	FTX	June 1, 2020	1413.23	23.83%
	Huobi	June 1, 2020	4250.71	14.53%
	OKEx USDT	June 1, 2020	375.05	1.28%
	OKEx inverse	June 1, 2020	897.65	1.14%

Note: The table shows the date for which transaction data are available for each spot pair and derivative instrument. The ADV is the average daily volume in million USD and the NTR is the ratio of minutes without recorded transactions. The calculations of both ADV and NTR follows the opening hours on each exchange, as presented in table 5.2 and 5.3.

The perpetual from BitMEX had the best NTR ratio of 0.06%, while the worst NTR was found in the FTX futures due to low-quality data. Coinbase has the best NTR within the spot market of 0.16%. Within the unregulated futures market, the linear OKEx contract has the best NTR of 2.19%. The regulated CME futures has a NTR of 31.65%, in Alexander & Heck (2020) CME had a NTR of 43.18%. This suggests that the bitcoin futures on CME has experienced more frequent trading from June 2020 till April 2021 than it saw from April 2019 until January 2020.

Table 5.5: Monthly ADV Spot Market

Month	Coinbase	Bitfinex*	Kraken	Bitstamp	Binance**
June 20	106.91	46.70	50.40	66.46	475.90
July 20	100.53	38.61	38.07	63.38	475.94
August 20	159.11	54.72	49.93	72.81	706.50
September 20	121.68	45.39	41.66	74.68	611.66
October 20	133.11	51.29	49.83	71.32	615.11
November 20	316.25	164.50	122.08	157.96	1491.11
December 20	449.96	209.97	159.98	185.57	1783.62
January 21	1266.34	532.79	398.90	506.70	3810.85
February 21	1232.82	487.36	333.37	394.78	4116.50
March 21	1067.66	-	301.84	277.58	3672.86
April 21	851.63	-	258.57	257.75	3079.25

Note: This table shows the monthly ADV for the five spot exchanges from June 1, 2020, to April 30, 2021. *Bitfinex data was missing from February 23 towards the end of the sample. The February ADV on Bitfinex is adjusted to only account for the first 23 days of the month. A hyphen is inserted to illustrate the missing data on Bitfinex in the last months. **Data was missing from the Binance spot pair from April 7. The April ADV on Binance is adjusted to only account for the first seven days of the month.

Table 5.6: Monthly ADV Futures

Month	Binance*	BitMEX	CME	Deribit	FTX**	Huobi***	Okex linear	OKEx inverse****
June 20	-	32.31	223.23	1.80	14.96	1461.55	177.30	356.00
July 20	-	34.74	264.44	1.69	15.35	2391.19	266.55	-
August 20	133.20	43.57	434.83	35.68	13.45	3112.04	257.24	-
September 20	85.76	32.19	403.23	30.43	17.80	1582.80	170.87	79.29
October 20	111.74	45.81	328.84	32.12	10.43	3308.63	294.84	563.16
November 20	453.49	63.04	655.45	62.77	21.87	3780.44	212.53	932.87
December 20	436.93	48.44	945.53	68.29	31.26	2547.48	185.07	781.54
January 21	1135.24	139.13	1867.53	91.28	86.38	7339.58	393.60	2712.36
February 21	1105.89	101.32	1849.23	122.30	50.26	6253.07	231.44	2033.16
March 21	910.43	58.16	2027.88	103.16	-	3224.43	148.22	1150.74
April 21	1260.31	112.31	1749.69	105.91	141.50	4355.46	180.10	1600.53

Note: This table shows the monthly ADV for the seven unregulated futures contracts from June 1, 2020, to April 30, 2021. *The Binance futures was launched on August 5, 2020, and thus have no trading data for the first two months of the period, up until August 5, 2020. **FTX data was missing from February 18 to April 9. The ADV in February and April is adjusted to only account for the days when the contract traded. ***Huobi is missing data from October 1, 2020, to October 28, 2020; thus Huobi's ADV in October is adjusted to only account for the trading days with available data. ****The inverse Q3 2020 futures contract from OKEx's was missing, leading to lacking data from June 26, 2020, to September 24, 2020. A hyphen is inserted to illustrate the missing data from the aforementioned contracts.

In the spot market, see table 5.5, Binance's BTCUSDT pair had the highest ADV at $1791.6 million. In the futures market, the Huobi futures had the highest ADV at $3276.42 million, while Binance's perpetual had the highest ADV of all instruments used in this research with an ADV at $7710.48 million. Within the spot market, Binance had the highest ADV in each month analyzed. Coinbase followed with the second-largest ADV each month, while Bitfinex data was missing in the last two months of the time period.

Within the futures market, see table 5.6, Huobi had the highest ADV in each month analyzed, except October, due to missing data. OKEx's inverse futures was the instrument with the second-highest ADV for most of the months in this sample, but also within the inverse OKEx futures, data was missing. The entire Q3 contract of OKEx's inverse futures was missing in the data set.

Binance's futures was launched on August 5, 2020. Therefore, a hyphen was added on the first two months of the sample on Binance's ADV. The ADV of Binance's futures has grown month over month, and in April, the Binance futures hit an ADV of $1260 million.

CME was the third-largest futures market in terms of trading volume and saw its ADV surpass $2 billion in March.

Table 5.7: Monthly ADV Perpetuals

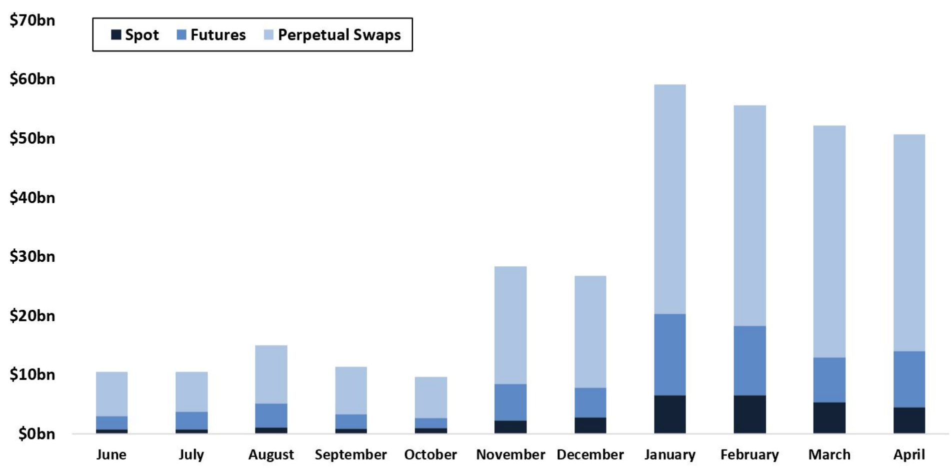
Month	BitMEX	Bybit	Deribit	Huobi*	OKEx linear	OKEx inverse	Binance	FTX**
June 20	1364.09	704.94	9.51	2231.51	400.70	387.03	2109.55	218.31
July 20	1227.66	686.73	8.36	2137.44	370.86	398.26	1825.53	177.16
August 20	1764.13	1128.98	256.04	3069.91	390.91	526.78	2530.94	242.47
September 20	1388.97	740.70	182.74	2265.20	357.21	491.37	2280.20	274.14
October 20	1283.54	953.94	241.78	4746.51	319.01	426.12	2900.29	403.71
November 20	2164.79	2556.48	410.86	5688.31	455.79	805.88	6829.44	1017.38
December 20	2176.84	2365.21	447.15	4272.55	374.82	995.05	7074.38	1203.69
January 21	3665.34	6485.83	875.82	9165.89	512.02	1635.63	13807.06	2735.82
February 21	3108.55	7142.99	1111.22	6627.68	351.63	1449.29	14532.02	2980.82
March 21	2607.98	8453.72	953.37	5599.57	319.55	1461.49	16635.68	-
April 21	2876.40	7810.02	956.94	5425.55	270.28	1332.13	14794.60	3211.23

Note: This table shows the monthly ADV for the eight perpetual swaps contracts from June 1, 2020, to April 30, 2021. *Huobi is missing data from October 1, 2020, to October 28, 2020, thus Huobi's ADV in October is adjusted to only account for the trading days with available data. **FTX data was missing from February 18 to April 9. A hyphen is inserted to illustrate the missing data from these contracts, while the ADV in February and April is adjusted to only account for the days when the contract traded.

Binance's stablecoin settled perpetual had the highest ADV of all instruments used in this research, see table 5.7. Throughout 2021, the Binance perpetual had an ADV above $10 billion as the only instrument examined in this thesis. Bybit had the second-largest ADV of all the perpetuals, and also had the second-largest ADV of all instruments analyzed in this thesis in 2021.

BitMEX's perpetual used to be the most heavily traded instrument in bitcoin, but it got surpassed by Binance, Bybit, Huobi and FTX in terms of trading volume after a rough 2020 for the exchange and its founders, who originally launched the first perpetual instrument back in 2016.

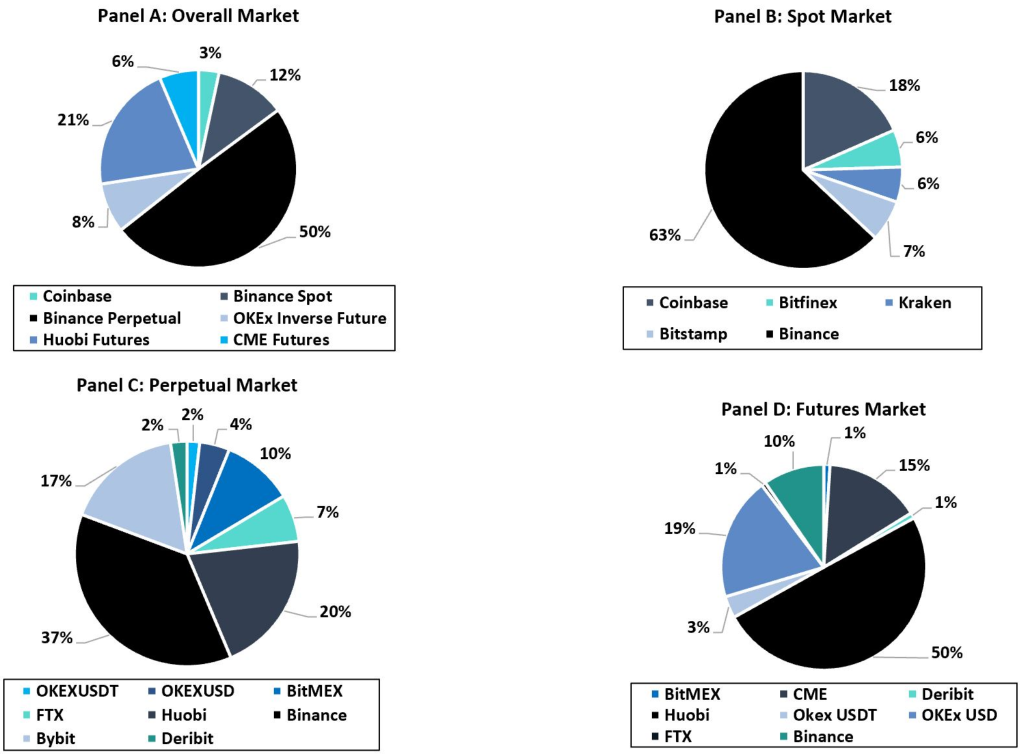
Figure 5.3: Monthly ADV by instrument type



Note: This figure illustrates the sum of the monthly ADV from June 1, 2020, to April 30, 2021, for all instruments used in this thesis. The trading volume has been grouped into three groups, the spot market, the futures market, and the perpetual swaps market.

The derivatives market was clearly dominating the trading volume in bitcoin during our sample. Within the derivatives, the bitcoin perpetuals saw a larger trading volume than the bitcoin futures. The aggregated ADV across all markets peaked in January at $60 billion and since remained above $50 billion, far higher than the ADV in H2, 2020. This could be explained by bitcoin surpassing its 2017 peak (the former all-time high) on December 16, 2020, with bitcoin for the first time surpassing $20,000.

Figure 5.4: Relative trading volume



Note: This figure shows the relative trading volume from June 2020 till April 2021. Panel A represents the overall for the main instruments, panel B is for the spot market, panel C for the perpetual market, and panel D for the futures market (regulated and unregulated combined).

6 Methodology

The methodology section first introduces the vector error correction model and IS. These components form the foundation for the method used in this paper, the GIS (Lien & Shrestha, 2014). This study follows the methodology of Alexander & Heck (2020), where they used both GIS (Lien & Shrestha, 2014) and CS (Gonzalo & Granger, 1995), and found similar results for both methods. Yan & Zivot (2010) investigated IS and CS to determine their effectiveness and discovered that CS does not provide details of the informativeness of individual markets. CS also has a possible outcome of negative results in some markets (Alexander & Heck, 2020). We have thus chosen not to include CS in this paper and thus only use GIS.

Other considered methods for the price discovery method besides GIS and CS, was IS (Hasbrouck, 1995), MIS (Lien & Shrestha, 2009), information leadership (Yan & Zivot, 2010), and ILS (Putniņš, 2013). However, as IS, MIS, information leadership and ILS are specified for bivariate models, they are excluded from this study looking into multi-dimensional information flows.

The desired outcome by using GIS as the method for this thesis is to find indications of which market and which derivative instrument or spot pair are leading in the price discovery process. Based on the researched methods for this thesis, this method appears to be the most optimal alternative to answer the hypotheses due to its ability to handle multivariate data and instruments that are not on the exact same but cointegrated and exist in interrelated markets (Lien & Shrestha, 2014).

6.1 Vector error correction model

The vector error correction model forms the basis for the methodology of IS, and GIS, relying on equations and methodology presented by Engle & Granger (1987). An individual variable, viewed by itself might wander extensively. However, considering several variables that have the same underlying asset, such as bitcoin, the variables will probably not wander too far apart from each other. Large fluctuations in the short-run might occur, but the prices will converge towards equilibrium of one common implied efficient price in the long-run. The time series moving towards an equilibrium is a prerequisite for the

VECM and a part of the theory for price discovery. When this happens, the prices are said to be cointegrated and have an underlying stochastic trend (Lien & Shrestha, 2014).

To test and confirm the existence of cointegration relationship between the different spot and derivative instruments, this thesis relies on cointegration testing following the Johansen procedure (Johansen, 1988). One benefit of this procedure is that it applies to multivariate time series.

The procedure begins with a null hypothesis stating that the number of cointegrated relationships of the time series is zero. The alternative hypothesis is that there are more than zero cointegrated relationships. If the null hypothesis is rejected, a new test with the null hypothesis of one cointegrated relationship and the alternative hypothesis being more than one cointegrated relationship ensues. This process is repeated until the null hypothesis can no longer be rejected at a 1% or 5% critical value (Johansen, 1988).

This thesis tested the cointegration relationships, in contrast to previous literature on bitcoin price discovery, as previous literature has assumed the cointegration relationship exist. This assumptions is based on arbitrage dynamics as the instruments track the same underlying asset, and should therefore be cointegrated (Alexander & Heck, 2020). Thus, the prices should not diverge in the long-run. As a result of the cointegrated relationships, a linear combination of non-stationary variables might be stationary (Enders, 2008).

When the Johansen procedure confirms the existence of a cointegrated relationship between all of the time series used in the data set, a VECM is formed. This confirmation of cointegrated time series and the formation of a VECM will allow the analysis to respond to the hypothesis in this thesis. If the prices were not cointegrated, the data would not comply with the requirements of GIS (Lien & Shrestha, 2014), and the analysis would not be performed.

To present the equation framework of the VECM and price discovery processes, one can let p_t be a $N \times 1$ vector of the (log) prices of N instruments at the time t. There is also an assumed $(N-1)$ cointegrating vectors. Thus, this study present the equation with its basis from Engle & Granger (1987) for the VECM:

$$\Delta p_t = \alpha + \sum_{i=1}^{q-1} \Gamma_i \Delta p_{t-i} + \delta z_{t-1} + e_t \tag{6.1}$$

Equation 6.1 assumes that α is a constant, δ is a $N \times (N-1)$ error correction matrix and Γ_i represents some $N \times N$ parameter matrices. Additionally, δ represents the prices' reactions to temporary deviations from the long-run equilibrium. Lastly, e_t is a vector of serially uncorrelated innovations of zero mean with covariance matrix Ω.

Further development of this equation is used to transform it into a vector moving average (VMA) model. The form used is then written as follows:

$$\Delta p_t = \Psi(L)e_t \tag{6.2}$$

The Ψ denotes a matrix polynomial in the lag operator L. When integrated, this equation becomes the following expression.

$$p_t = p_0 + \Psi(1)\sum_{j=1}^{t} e_j + \Psi^*(L)e_t \tag{6.3}$$

In this equation, p_0 is a constant vector. The sum of the moving average is represented by $\Psi(1)$ and $\Psi^*(L)$ is a matrix polynomial in the lag operator. As was previously assumed, the cointegration relationship for this time series coincides with the Engle-Granger representation theorem (Engle & Granger, 1987). This implies that the following conditions hold (De Jong, 2002; Lehmann, 2002):

$$\beta^T\Psi(1) = 0 \quad \text{and} \quad \Psi(1)\alpha = 0 \tag{6.4}$$

Because both of these expressions are identical, one can assume that all pairwise cointegration relationships are of the form $(1, -1)^T$. Thus, the common row vector is denoted by ψ.

6.2 Information share

The equations used above were used by Hasbrouck (1995) in the development of the method of IS. The IS of each market is its relative contribution to the innovations of the common implicit efficient price for every market. As it is only a bivariate model, due to the requirement of the time series being integrated in a one-to-one order, the value of the two different variables is equal to one, finding the upper and lower boundaries for each analyzed time series contribution to the price discovery. The method starts by using the VECM developed above and transforming it as illustrated to a VMA. First, by the inclusion of the VMA, the equation formulated by Hasbrouck (1995) is:

$$\Delta p_t = \psi(L)e_t \tag{6.5}$$

Using the equation above, Hasbrouck (1995) further formulate the equation for the IS:

$$IS_i = \frac{([\psi F]_i)^2}{\psi \Omega \psi^T} \quad \text{for} \quad i = 1, ..., N. \tag{6.6}$$

Where ψF represents the ith element of the row vector ψF, and F is the lower triangular matrix of the Cholesky decomposition of Ω. The IS_i of each market denotes how much of a contribution to the innovation in the long-run equilibrium is done by the i-time series, also known as the ith market.

6.3 Generalized information share

GIS was introduced as a further development of the IS by Hasbrouck (1995) and MIS (Lien & Shrestha, 2009) where IS and MIS was generalized. The method was introduced by Lien & Shrestha (2014). One benefit of the GIS compared with the IS is that the former does not require a one-to-one cointegration relationship between the time series used in the equations. Thus, this method can be used on interrelated markets and not only identical markets, as it requires only that all n unit-root series are driven by a single stochastic trend. This can be validated by checking if there exists a $n - 1$ cointegrating vectors among n series, tested with the Johansen procedure. In the analysis conducted in this thesis, GIS is a fitting method because the study used N similar or homogeneous instruments. Thus, the structure of the GIS method deviates from the IS by changing the requirement for the β matrix of the cointegrated vectors. Making this alternation changes the equation for the long-run impact of the different series, producing the following equation:

$$S_j^G = \frac{(\psi_j^G)^2}{\psi_1^r \Omega \psi_1^{rT}} \tag{6.7}$$

Where $\psi^G = \psi_1^r F^M$, $F^M = [G \wedge^{-1/2} G^T V^{-1}]^{-1}$. Beyond this, $\wedge$ is the diagonal matrix containing the characteristic root of the correlation matrix on the diagonal, and the corresponding eigenvectors are given by Matrix G. Finally, V is a diagonal matrix containing the innovation standard deviations on the diagonal.

The result of all markets analyzed for each group using GIS will similarly to the IS (Hasbrouck, 1995) also sum to 1. The result per derivative instrument or spot pair will then be the percentage of contribution to the innovation in the price discovery, leading to one common implied efficient price (Lien & Shrestha, 2014).

7 Analysis

This part of the thesis presents the results of the analysis and a discussion regarding the results obtained. The analysis is based on a grouping of the different instruments by category. The grouping constitutes three markets, the spot market, unregulated futures, and perpetuals. Within each group, the GIS method is applied. A fourth group consisting of the main derivative instruments and spot pairs, hereby shortened to main instruments, is then created. The main instruments are selected based on the results within the analysis of the three sectors. Additionally, CME data has been added to the main instrument analysis. The GIS methodology is applied to the fourth group in order to identify the most relevant leading instruments in the price discovery of bitcoin.

The results of the analysis in this study are made using the minute-by-minute OHLCV data from June 1, 2020 till April 30, 2021. The analysis is based on daily calculations of the GIS for each of the instruments. The daily GIS is then converted to a monthly GIS based on a non-weighted average of the daily observations. As the analysis is using transaction prices for actual trades and not mid-quotes data, there are occasions of infrequent trading. Illiquidity in the market might affect the results of the price discovery process. To avoid this issue, instruments seeing 4,5 hours or more between two subsequent trades are excluded from the daily GIS analysis, as in Alexander & Heck (2020). We have used the last traded price for shorter periods with no trading as a substitute for no recorded transaction price.

Regarding the selection of lags in the model, the analysis follows the method proposed by Alexander & Heck (2020) and uses 1 lag for all models. By applying the same methodology as Alexander and Heck, the results from this thesis are directly comparable and analogous to the previous research, while being based on a different time period.

7.1 Cointegration

Before applying the VECM method, cointegration relationships in the instruments must be identified. Therefore, a cointegration test following the Johansen procedure is performed on the time series, identifying that they are cointegrated. In table 7.1, we show the results from the Johansen procedure on the instruments used in this thesis.

It is worth dwelling on the results from the spot market. The analysis is based on spot data for bitcoin traded against both USDT and USD. The Johansen procedure shows that the USDT pair is, in fact, cointegrated with the USD denominated spot pairs.

Table 7.1: Results of Johansen cointegration test for all groups

Null hypothesis	Johansen test r=0 vs. r≥ 1	r=1 vs. r≥ 2	r=2 vs. r≥ 3	r=3 vs. r≥ 4	r=4 vs. r≥ 5	r=5 vs. r≥ 6	r=6 vs. r≥ 7	r=7 vs. r≥ 8
Spot								
Test statistic	72899.07	54943.52	6210.08	3867.59	4.81			
1 pct	42.36	36.65	30.34	23.65	16.26			
Unreg. futures								
Test statistic	1700.79	978.00	768.24	436.52	280.08	47.22	4.58	
1 pct	54.71	49.51	42.36	36.65	30.34	23.65	16.26	
Perpetuals								
Test statistic	41510.62	29720.79	16928.18	12992.95	8983.42	566.36	1624.80	5.48
1 pct	62.46	54.71	49.51	42.36	36.65	30.34	23.65	16.26
Final group								
Test statistic	40628.57	21157.86	3816.38	180.24	76.84	6.98		
p value	49.51	42.36	36.65	30.34	23.65	16.26		

Note: The table shows the results of the Johansen procedure for testing cointegrated relationships in each group. For spot, the null hypothesis of 4 cointegrated relationships is not rejected. For unregulated futures, the null hypothesis of 6 cointegrated relationships is not rejected. For perpetuals, the null hypothesis of 7 cointegrated relationships is not rejected. For the main instruments, the null hypothesis of 5 cointegrated relationships is not rejected. All rejections are based on 0,01 significance levels.

7.2 The spot market

The analysis begins by analyzing the day-by-day price discovery within the spot market. All spot markets analyzed trade 24/7, so the analysis is based on UTC days. On days when the exchanges lack trading data, the exchange is removed from the analysis, and its market share equals 0% that day.

The spot market data was consistent and of high quality up until February. Data was missing from Bitfinex following February 23, and the data was also missing from the Binance spot market from April 7. This was not caused by no occurring trades, but rather missing data, so for further analysis, the values post February 23 might be slightly distorted.

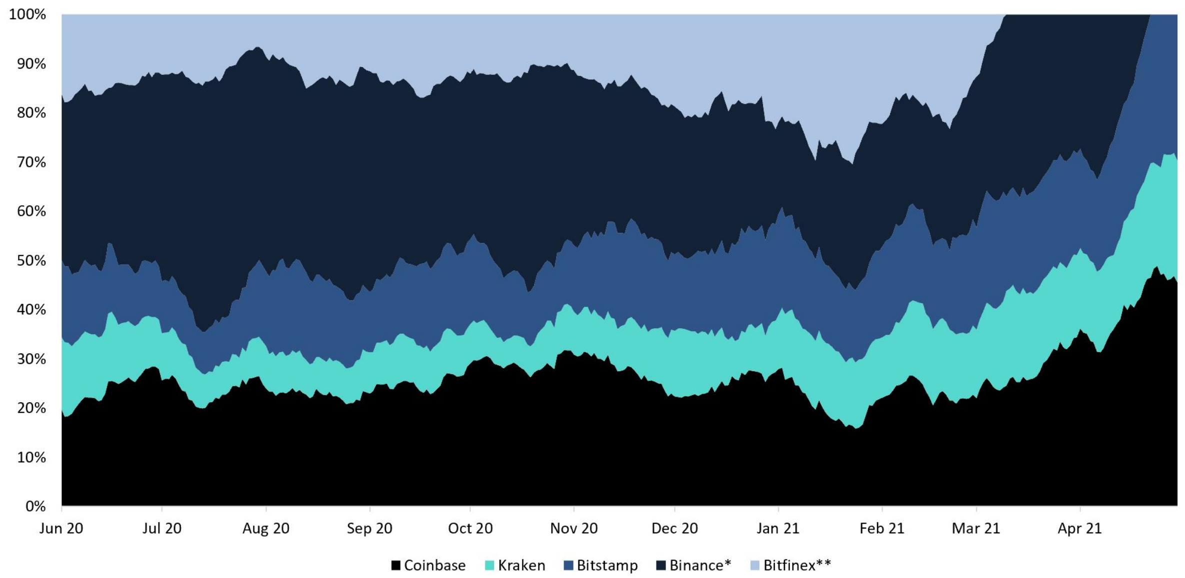
Table 7.2 shows the monthly GIS for the different exchanges, while figure 7.1 shows the 14-day moving average of the daily GIS time series.

Table 7.2: Monthly shares of GIS for the spot market

Month	Coinbase	Kraken	Bitstamp	Binance*	Bitfinex**
Jun-20	25.88 %	11.87 %	12.22 %	36.32 %	13.70 %
Jul-20	22.80 %	7.38 %	12.30 %	47.03 %	10.48 %
Aug-20	22.86 %	7.36 %	14.64 %	42.34 %	12.80 %
Sep-20	26.15 %	8.60 %	17.00 %	34.47 %	13.78 %
Oct-20	29.83 %	7.61 %	12.93 %	37.67 %	11.97 %
Nov-20	25.31 %	11.04 %	17.50 %	29.68 %	16.46 %
Dec-20	26.22 %	10.41 %	18.65 %	25.11 %	19.61 %
Jan-21	20.16 %	13.37 %	16.93 %	25.01 %	24.53 %
Feb-21	22.70 %	15.21 %	20.02 %	26.51 %	15.56 %
Mar-21	30.26 %	17.09 %	20.18 %	32.46 %	-
Apr-21	43.26 %	21.35 %	27.28 %	8.12 %	-
Full sample	26.86 %	11.94 %	17.24 %	31.34 %	12.63 %

Note: This table shows the monthly GIS for the five spot exchanges from June 1, 2020, to April 30, 2021.
*Data was missing from the Binance spot pair from April 7, reducing the GIS of Binance in April.
**Bitfinex data was missing from February 23 towards the end of the sample. A hyphen is inserted to illustrate the missing data on Bitfinex in these months.

Figure 7.1: GIS spot market: 14 day moving average



Note: This figure shows the time series of the daily GIS of the five spot pairs from June 1, 2020, to April 30, 2021. The daily GIS is smoothed with a 14-day moving average. *Data was missing from the Binance spot pair from April 7, reducing the GIS of Binance in April. **Bitfinex data was missing from February 23 towards the end of the sample.

The two leading exchanges in terms of trading volume in the spot market also led in terms of bitcoin's price discovery. This aligns with the findings of Chen & Tsai (2017), finding that speculation is often beneficial for price discovery. For the entire sample period, Coinbase has an average GIS of 27%, whereas Binance has an average GIS of 31%, despite lacking observations for the final 23 days. Based on the results, it is clear that Binance and Coinbase have led the price discovery within the spot market.

In 9 out of the 10 months with complete datasets available from Binance, the Binance BTCUSDT spot pair led the price discovery within the spot market. However, the share of Binance's GIS saw a declining trend from sitting above 40% during the beginning of the time series, and down towards 25-30% for the latter part of the time series.

Coinbase's share of the GIS has been more stable throughout the observation period and trended upwards, particularly going into Q4, 2020. Large investors are said to have used Coinbase's brokerage solution to conduct large trades throughout this period. This could explain Coinbase's strength in this period. In December, Coinbase was the largest contributor to the GIS in the spot market, reaching 26%.

Kraken and Bitstamp have played a minor role in the price discovery within the spot market, with the monthly GIS fluctuating between 7% to 21% on Kraken, and 12% and 27% on Bitstamp. Both Kraken and Bitstamp peaked towards the end of the time series when Bitfinex and Binance data were missing. The low GIS of Kraken and Bitstamp indicates that these spot pairs mainly follows the other spot pairs.

Bitfinex saw a spike in their GIS in January and had the second-largest GIS of 24.53%. Unfortunately, Bitfinex data was unavailable following February 23, so it is unclear whether this trend persisted.

Coinbase and Binance's dominating role in the price discovery within the spot market is worth examining further, both due to their substantial GIS and also due to the fact that they reflect different underlying currencies. Binance is based on USDT denominated trades, and Coinbase is based on USD denominated trades. Our results indicate that both instruments have an important role in bitcoin's price discovery. Thus, we elected both instruments in the final GIS-model scoping the most pronounced leading instruments within each group.

7.3 The unregulated futures market

The analysis further examines the unregulated bitcoin futures market using the day-by-day price discovery of the dominating instruments in the market. Similar to the bitcoin spot market, unregulated futures also trade 24/7.

In the dataset, there were some unfortunate issues. In particular, the data from FTX saw missing values from February 18 to April 9. This reduced the GIS of FTX for the full sample period, in addition to the latter months. Throughout the sample, FTX has only held minor shares of the GIS in the futures market. While it is unfortunate that the FTX futures data is incomplete, it does not impact our conclusion of the price discovery leadership within the unregulated futures market.

There are also occasional days where the data was blank for long periods or the entire day for certain instruments. These instruments have been excluded from the analysis for that particular day. For most of these instruments, the missing data was a short-term problem, and the instruments were included in the GIS model the following day. We do not believe this to have a large enough impact on the results to distort the results in a substantial manner.

However, one large missing piece of data is worth mentioning. The dataset miss data from the Q3, 2020 inverse contract on OKEx. This reduces the full sample period GIS of the instrument considerably. OKEx's futures have a high GIS in the remainder of the sample period. Additionally, Binance launched its bitcoin futures on August 5, 2020, so there is no data recorded before this.

Therefore, we analyze two different periods. One period for the full sample and another for a sample period from October until April. We did this to improve the conclusions of the information leadership within the unregulated futures market.

Table 7.3 shows the monthly GIS across each instrument, while figure 7.2 illustrates the time series of the GIS in the futures market with a 14-day moving average.

Table 7.3: Monthly shares of GIS for the unregulated futures market

Month	Binance*	BitMEX	Deribit	FTX**	Huobi***	OKEx linear	OKEx inverse****
Jun-20	-	12.09 %	13.94 %	8.15 %	20.57 %	20.71 %	24.54 %
Jul-20	-	20.30 %	8.22 %	11.93 %	38.42 %	21.13 %	-
Aug-20	19.32 %	20.64 %	10.61 %	3.65 %	27.43 %	18.35 %	-
Sep-20	13.38 %	14.08 %	10.53 %	7.47 %	15.71 %	32.57 %	6.26 %
Oct-20	13.85 %	30.78 %	16.21 %	5.45 %	3.65 %	10.12 %	19.95 %
Nov-20	11.32 %	15.41 %	12.13 %	4.96 %	17.19 %	17.26 %	21.72 %
Dec-20	10.13 %	9.84 %	17.02 %	6.55 %	17.47 %	23.03 %	15.94 %
Jan-21	17.04 %	10.98 %	6.67 %	9.28 %	22.66 %	20.60 %	12.78 %
Feb-21	18.58 %	7.61 %	16.18 %	2.18 %	21.66 %	15.25 %	18.53 %
Mar-21	20.93 %	8.77 %	8.57 %	-	17.69 %	19.28 %	24.72 %
Apr-21	13.78 %	16.48 %	17.95 %	6.67 %	15.00 %	12.44 %	17.67 %
Full sample	12.58 %	15.18 %	12.55 %	6.03 %	19.77 %	19.16 %	14.74 %
Oct-Apr	15.09 %	14.27 %	13.53 %	5.01 %	16.48 %	16.85 %	18.76 %

Note: This table shows the monthly GIS for the seven unregulated futures contracts from June 1, 2020, to April 30, 2021. *The Binance futures was launched on August 5, 2020, and thus have no trading data for the first two months of the period, up until August 5, 2020. **FTX data was missing from February 18 to April 9. ***The October data on Huobi is distorted due to missing data from October 1, 2020, to October 28, 2020. ****The inverse Q3 2020 futures contract from OKEx's was missing, leading to lacking data from June 26, 2020, to September 24, 2020. A hyphen is inserted to illustrate the missing data from the aforementioned contracts. Additionally, an aggregated GIS from October 2020 to April 2021 is added to illustrate the GIS in the unregulated futures market when the data quality is better.

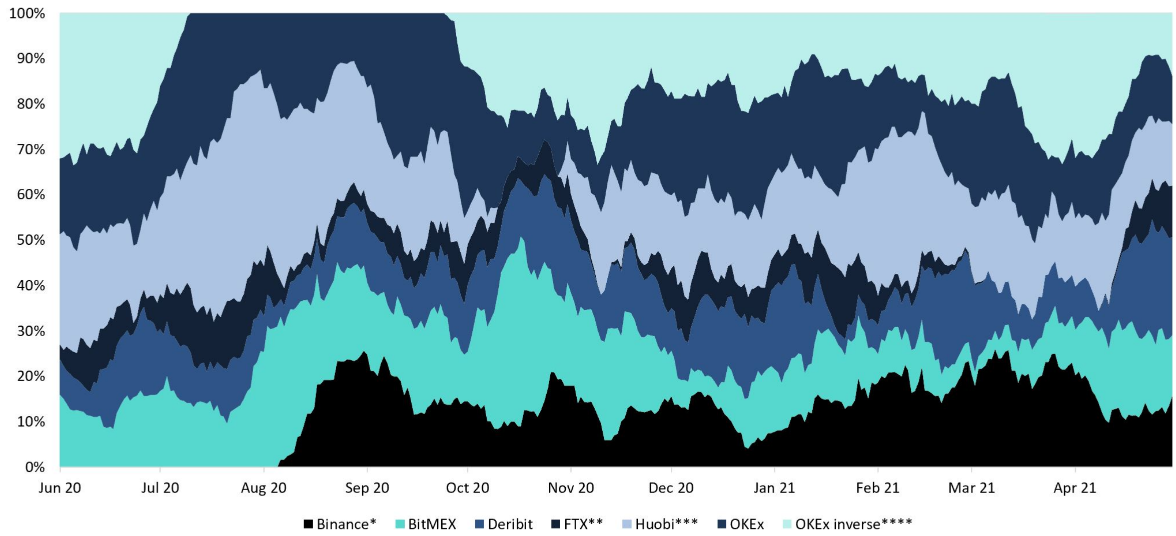
The results suggests that Huobi and OKEx are the leading instruments within the unregulated bitcoin futures.

With its large trading volume, it is not a surprise that Huobi's futures instruments tend to lead in terms of price discovery. Huobi held the largest share of the GIS in 3 of the 10 months analyzed, whereas the OKEx inverse contract also led in 3 instances. OKEx's 2 instruments and Huobi's instrument combined accounts for 52% of the GIS for the entire duration of the sample.

Since launching, Binance has also had a substantial GIS, but it has to this day never been the major monthly contributor to the price discovery within the unregulated futures market.

The most surprising observation within the price discovery of the unregulated bitcoin futures is the significant contributions from Deribit. The results suggest that Deribit has an important role in the price discovery within the unregulated futures market, despite the low trading volume on the Deribit futures compared to its peers.

Figure 7.2: GIS unregulated futures market: 14 day moving average



Note: This figure shows the time series of the daily GIS of the seven unregulated futures contracts from June 1, 2020, to April 30, 2021. The daily GIS is smoothed with a 14-day moving average. *The Binance futures was launched on August 5, 2020, and thus have no trading data for the first two months of the period, up until August 5, 2020. **FTX data was missing from February 18 to April 9. ***The October data on Huobi is distorted due to missing from October 1, 2020, to October 28, 2020. ****The inverse Q3 2020 futures contract from OKEx was missing, leading to missing data from June 26, 2020, to September 24, 2020.

In April, Deribit's futures had the largest GIS of all instruments at 17.95%, while the instrument saw an ADV of $105 million in the month compared to Huobi's $4356 million. The traders on Deribit's futures are seemingly more informed, contributing significantly to the price discovery within the futures market.

An explanation for Deribit's considerable contribution in the unregulated futures market despite the low trading volumes could be Deribit's market-leading role within options trading. Deribit offers plain vanilla European-styled bitcoin options and is by far the leading exchange in terms of open interest in the bitcoin options market, accounting for near 90% of all the open interest in the market (Arcane Research, 2021a). The options use Deribit's futures as the underlying settlement. Activity on Deribit options could affect the information flow to the underlying futures on Deribit.

Due to the dominance of Huobi and OKEx's instruments throughout the observation period, we include their instruments when measuring the GIS for the main instruments in section 7.4.

7.4 The perpetual swaps market

In the third group, we analyze the bitcoin perpetuals using the day-by-day price discovery of the dominating instruments in the market. Like the spot market and the unregulated futures market, the perpetuals trade 24/7, 365 days a year.

Data on FTX perpetual was unavailable from February 18 to April 9, and we also missed data on the Huobi perpetual for the majority of October. This affects the GIS observations. As we highlight later, FTX's GIS on the perpetual has been trending upwards, suggesting that FTX's perpetual is an important instrument in the price discovery within the perpetuals instruments. Therefore, we will be careful with making any firm conclusions surrounding the leadership role of FTX in the perpetuals market in our analysis based on the full sample GIS.

In the data of the perpetuals, we also experienced some occurrences of data missing from random dates in the dataset. This was similar to the observations of the data for the unregulated futures contracts. Again, the effect of some eliminations of single dates is not something that we believe has a large impact on the results.

In table 7.4 we report the monthly average price discovery shares of the eight perpetuals analyzed in this thesis, and in figure 7.3 we show the 14-day moving average time series of the GIS between perpetuals.

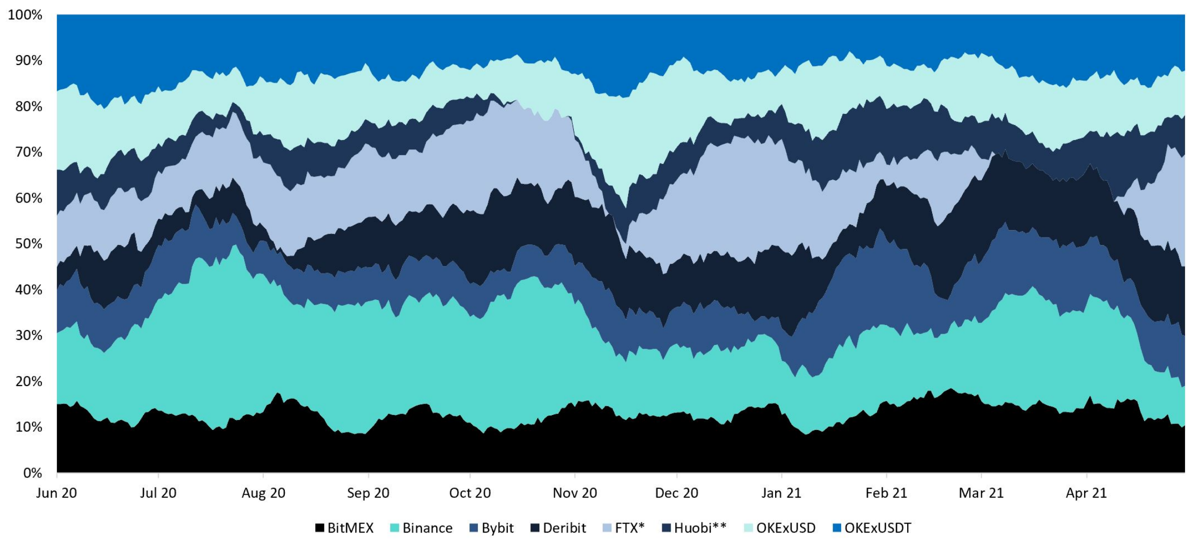
Table 7.4: Monthly shares of GIS for the perpetuals market

Month	BitMEX	Binance	Bybit	Deribit	FTX*	Huobi**	OKExUSD	OKExUSDT
June, 2020	12.99 %	19.11 %	10.55 %	8.61 %	10.40 %	7.01 %	12.98 %	18.35 %
July, 2020	11.88 %	32.88 %	7.72 %	5.01 %	13.75 %	4.97 %	10.36 %	13.43 %
August, 2020	11.21 %	25.98 %	7.47 %	8.60 %	14.95 %	6.44 %	12.64 %	12.71 %
September, 2020	13.08 %	23.11 %	8.03 %	12.63 %	16.31 %	6.08 %	7.86 %	12.90 %
October, 2020	12.98 %	27.67 %	7.97 %	14.85 %	15.22 %	0.45 %	9.85 %	11.02 %
November, 2020	12.16 %	13.36 %	9.05 %	11.85 %	9.92 %	7.66 %	21.58 %	14.42 %
December, 2020	12.51 %	14.16 %	7.79 %	13.95 %	23.91 %	5.95 %	8.59 %	13.15 %
January, 2021	13.09 %	16.08 %	17.94 %	9.44 %	9.53 %	11.60 %	12.88 %	9.44 %
February, 2021	15.30 %	15.25 %	12.20 %	17.26 %	8.79 %	9.16 %	11.45 %	10.59 %
March, 2021	14.34 %	23.76 %	13.47 %	14.73 %	-	7.45 %	12.36 %	13.89 %
April, 2021	13.23 %	12.20 %	9.72 %	14.90 %	15.53 %	10.42 %	10.54 %	13.46 %
Full period	12.98 %	20.32 %	10.17 %	11.98 %	12.57 %	7.02 %	11.92 %	13.03 %

Note: This table shows the monthly GIS for the eight perpetual contracts from June 1, 2020, to April 30, 2021. *FTX data was missing from February 18 to April 9. A hyphen is inserted to illustrate the missing data from these contracts. **The October data on Huobi is distorted due to missing from October 1, 2020, to October 28, 2020.

For the entire observation period, Binance's stablecoin margined perpetual has been the leading instrument among the perpetuals, accounting for 20.32% of the GIS for the entire duration of the sample. Binance had a particularly strong leading role among the perpetuals in the first five months analyzed. In the last months, the Binance leadership became less pronounced, as Binance has only led once in 2021, in March. This is surprising given how Binance has seen the largest trading volume by far among perpetuals, particularly in 2021, with the ADV being above $10 billion for the first four months of 2021.

Figure 7.3: GIS perpetuals market: 14 day moving average

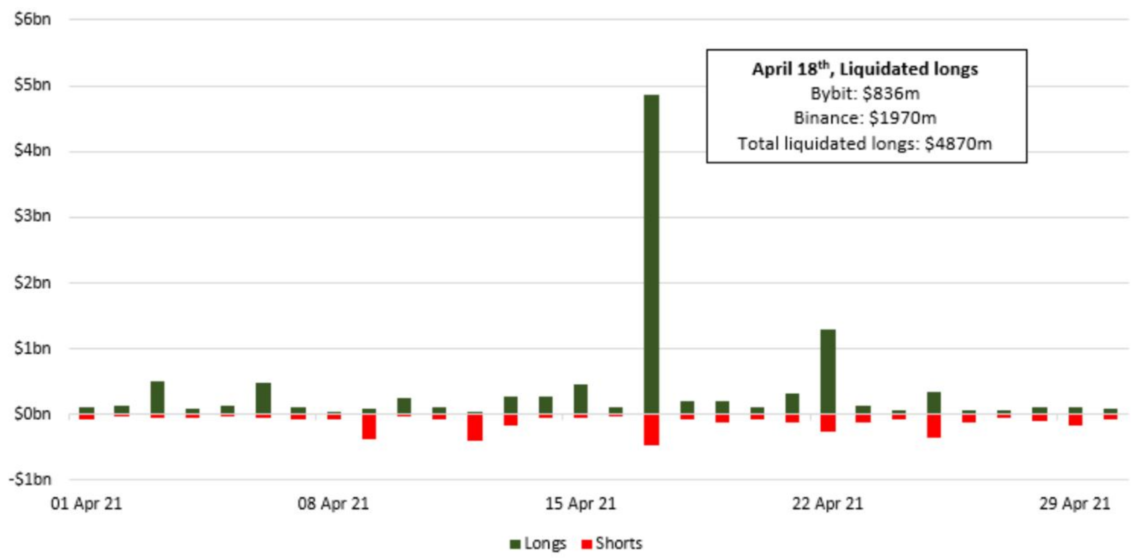


Note: This figure shows the time series of the daily GIS of the eight perpetual swaps contracts from June 1, 2020, to April 30, 2021. The daily GIS is smoothed with a 14-day moving average. *FTX data was missing from February 18 to April 9. A hyphen is inserted to illustrate the missing data from these contracts. **The October data on Huobi is distorted due to missing from October 1, 2020, to October 28, 2020.

Similarly, the low GIS of Bybit is also surprising. Bybit is the second largest in terms of ADV among the perpetuals for the full duration of the sample but only leads in January. Bybit has the second-lowest GIS for the full sample period of all perpetuals analyzed. Thus, despite Bybit's large trading volume, the Bybit perpetual in general contribute little to bitcoin's price discovery. Bybit mostly reacts to price movements in the other perpetuals.

The less pronounced dominance on Binance and Bybit despite their large trading volumes could be a result of less informed and less sophisticated traders. Both exchanges focus heavily on retail customers, and the available leverage on the platforms is frequently advertised. On Binance, 20x leverage is the preset input on trades, alebit, it is possible to conduct trades with lower leverage. The preset input leverage could possibly be nudging traders to deploy high leverage in their trades, leading to many liquidations during volatile events. This might lead to an increased basis in these perpetual instruments, over-emphasizing the direction of the price movement in the general market.

Figure 7.4: Bybt.com: Liquidated longs and shorts - April 2021

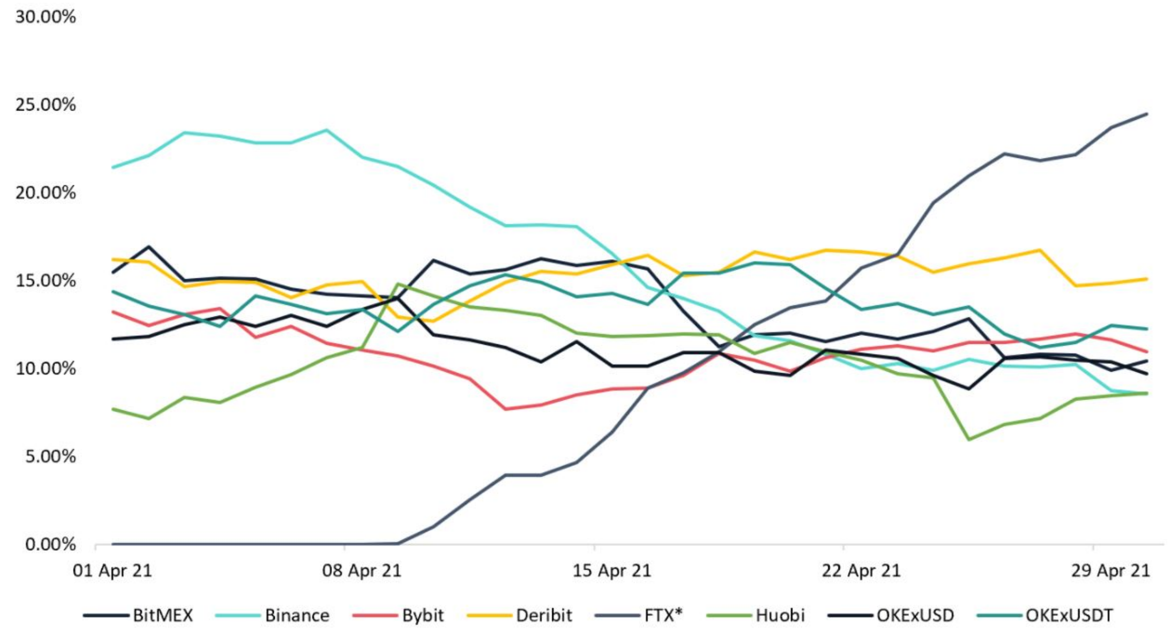


Note: This figure shows the volume of liquidated long and short positions in the perpetuals from April 1, 2020, to April 30, 2021. Notice the spike on April 18, 2020, with a total of $4.87 billion liquidated long positions. Of the liquidated longs, $836 million originated from Bybit, and $1970 million from Binance. On April 18, bitcoin saw large intraday volatility, with bitcoin seeing an intraday high of $60,400 and an intraday low of $51,500 before ending the day trading at $56,300. This figure serves the purpose of illustrating the impact of the volatility spike, in addition to highlighting the high leverage used on Bybit and Binance. The data is gathered from bybt.com (n.d.).

The Binance futures market is also pushing the narrative of easy on-boarding and extreme leverage. The first message looming over the screen for new visitors on Binance futures highlights this, "Trade Crypto Futures with up to 125x Leverage. Open an account in under 30 seconds." clearly focusing on retail speculators. Amid high volatility, traders on Binance and Bybit have frequently been "victims" of large squeezes, in particular for long positions. This leads the spreads between the spot indexes and the Bybit and Binance perpetuals to widen, and with the low GIS, particularly on Bybit, this seems to be an isolated price shock, not impacting the broad markets. During downside volatility, the impact on these perpetuals tends to be particularly exaggerated. Overextended longs get liquidated, exemplified by the crash of April 18, 2021, leading $4.87 billion worth of long positions to be automatically liquidated, with $836 million and $1970 million worth of longs being liquidated on Bybit and Binance's perpetuals alone.

Surprisingly, both Deribit and FTX have seen months with the instruments leading in terms of price discovery, despite seeing ADVs far below Binance and Bybit. Deribit led in February, while the ADV of Binance was 12 times as large as Deribit's, suggesting that Deribit traders are more informed and sophisticated. Similarly, FTX led both in December and April. FTX leading in April is quite remarkable, given that we miss data from April 1 till April 9 in our data set. By the end of April, FTX was clearly leading in terms of GIS, while all other perpetuals analyzed saw relatively similar price discovery contributions, suggesting that FTX's perpetual is becoming a more important instrument in the perpetuals market.

Figure 7.5: GIS perpetuals: April, 2021 (14d MA)



Note: This figure shows the linear time series of the daily GIS of the eight perpetual swaps contracts from April 1, 2021, to April 30, 2021, smoothed with a 14-day moving average. It illustrates the growing GIS of FTX in April. FTX data from April 1 to April 9 was missing, and the 14-day moving average GIS of FTX on April 30, 2021, ended at 24%, substantially higher than the runner-up Deribit at 15%. This implies a growing leadership role of the FTX perpetual.

Due to missing data observations, and Binance's leading role in terms of GIS for the entire duration of the sample, we only append the Binance perpetual in the final GIS test.

7.5 Main instruments

Lastly, we examine the leading instruments within each category, in addition to the CME futures, in a final GIS model. The purpose is to uncover the most important instruments in bitcoin's price discovery during the bull market of June 2020 till April 2021. We analyze the GIS of the stablecoin spot pair from Binance, Coinbase's BTCUSD spot pair, Binance's stablecoin margined perpetual, the Huobi futures, OKEx futures, and CME futures.

In order to adjust for CME's trading breaks, we exclude holidays, weekends, and the daily hourly trading break on the CME futures from 5 pm to 6 pm Chicago time. We thus analyze the instruments once they are available to trade on all exchanges. This could overemphasize the role of CME's bitcoin futures in bitcoin's price discovery due to weekend volatility.

As trading data on the Q3 futures of OKEx's inverse futures was missing, we use the stablecoin margined futures on OKEx in the first four months. We then implement the inverse futures from October. We justify this choice with our previous results suggesting the importance of the inverse OKEx instrument within the price discovery in the unregulated futures market when all instruments have data.

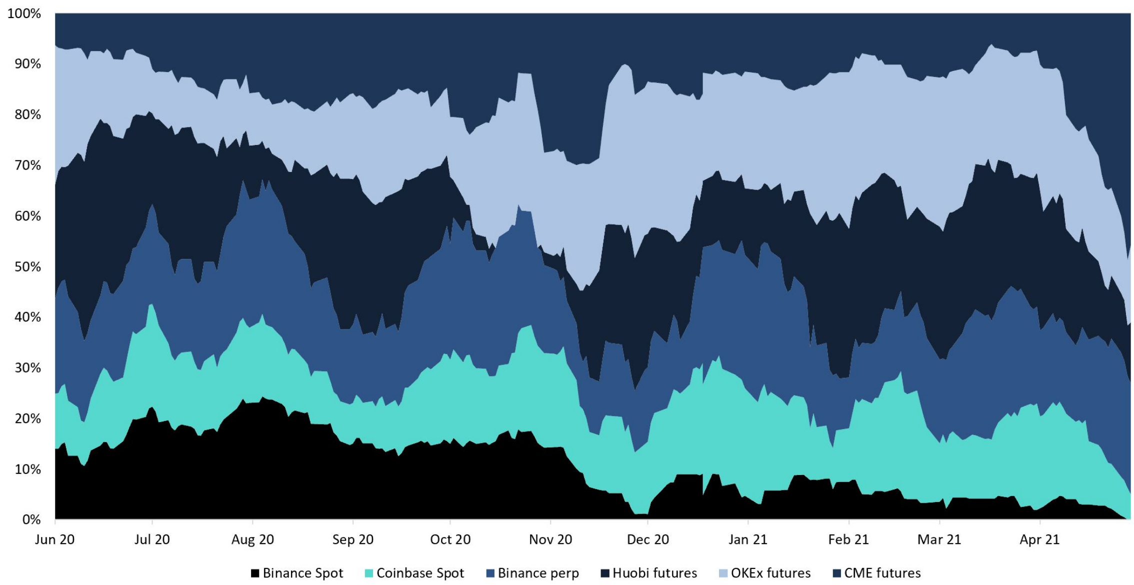
Table 7.5 shows the monthly average GIS for the six main instruments, while figure 7.6 shows the 14-day moving average time series of the daily GIS of the instruments.

Table 7.5: Monthly shares of GIS for the main instruments

Month	Spot		Perpetual	Futures		
	Binance	Coinbase	Binance	Huobi	OKEx*	CME
Jun-20	16.62 %	16.16 %	18.46 %	28.28 %	12.44 %	8.05 %
Jul-20	20.62 %	12.07 %	22.17 %	17.13 %	11.29 %	16.72 %
Aug-20	16.64 %	10.40 %	18.04 %	23.74 %	14.56 %	16.62 %
Sep-20	15.91 %	14.73 %	20.57 %	15.82 %	16.22 %	16.75 %
Oct-20	13.60 %	15.44 %	19.57 %	1.74 %	22.57 %	27.08 %
Nov-20	4.19 %	14.02 %	13.44 %	22.63 %	31.19 %	14.52 %
Dec-20	8.42 %	22.22 %	23.42 %	12.79 %	21.83 %	11.32 %
Jan-21	7.66 %	12.05 %	14.59 %	28.89 %	24.22 %	12.58 %
Feb-21	3.31 %	18.31 %	16.60 %	22.21 %	27.60 %	11.97 %
Mar-21	3.97 %	17.17 %	22.22 %	26.98 %	21.87 %	7.80 %
Apr-21	1.98 %	7.04 %	19.76 %	13.84 %	18.72 %	38.66 %
Full sample	10.27 %	14.51 %	18.99 %	19.46 %	20.23 %	16.55 %

Note: This table shows the monthly GIS for the six main instruments from June 1, 2020, to April 30, 2021, adjusted for CME's trading breaks. *The Q3 2020 contract on OKEx's inverse bitcoin futures was missing in the sample. In table 7.3 we found a high GIS on the linear OKEx futures during the first four months of the sample. Thus, we have included OKEx's linear futures from June 2020 to the end of September 2020 before switching over to the inverse OKEx futures from October 2020 and onwards. This might lead to a slight distortion of the GIS of OKEx, visible by the growing GIS of OKEx from October 2020 and onwards within the main instruments group.

Figure 7.6: GIS perpetuals: April, 2021 (14d MA)



Note: This figure shows the time series of the daily GIS of the six main instruments from June 1, 2020, to April 30, 2021. The daily GIS is smoothed with a 14-day moving average. *The Q3 2020 contract on OKEx's inverse bitcoin futures was missing in the sample. In table 7.3 we found a high GIS on the linear OKEx futures during the first four months of the sample. We have thus included OKEx's linear futures from June 2020 to the end of September 2020 before switching over to the inverse OKEx futures from October 2020 and onwards.

In contrast to the minor role of CME from April 2019 to January 2020, identified in Alexander & Heck (2020), we find a more pronounced leadership role of CME in bitcoin's price discovery following the same methodology from June 2020 to April 2021.

Similar to the findings of Alexander & Heck (2020), we find that OKEx's bitcoin futures lead bitcoin's price discovery, with Huobi's futures following closely.

The GIS of the Huobi futures fluctuates between 14% and 28% with an outlier in October of 2% due to low-quality data. In total, the Huobi futures leads in 4 out of the 11 months analyzed.

The inverse bitcoin futures of OKEx account for between 18% to 31% of the monthly GIS across all the main instruments. In contrast, the stablecoin-margined futures from the first 4 months have a lower impact on the price discovery of bitcoin ranging between 11% to 16%. In total OKEx lead in 2 of the 11 months analyzed in this sample.

The Binance perpetual also have an important role in bitcoin's price discovery, leading the market in 3 out of 11 months analyzed. Binance's GIS is fairly stable month over month, with the monthly GIS fluctuating between 13% and 23%.

While Binance stablecoin denominated spot pair dominated most months within the spot market, the impact of Binance's spot market is far less pronounced when extending our price discovery model to account for additional instruments. In the first months of the time series, Binance's stablecoin spot pair had a pronounced role, contributing with 15-20% of the GIS month by month in the first four months of the sample. Then, the Binance stablecoin spot pairs fade into obscurity. Binance's spot pair was the least important contributor to the GIS in the full instrument sample from November and onwards, with a GIS ranging between 8% to 2%.

On the other hand, the spot market on Coinbase seems to have a more important role in the price discovery of bitcoin during the entire sample period, with its monthly GIS ranging from 7% to 22%. Based on this, we believe that while Coinbase never led in terms of price discovery, the spot market on Coinbase each month had a substantial contribution to bitcoin's price discovery.

Intuitively these results makes sense. Activity in the Coinbase spot pair is in part driven by new dollars entering the system, whereas the Binance USDT pair is based on stablecoins. New buyers seeking to convert fiat currencies to bitcoin will go through one of the "fiat gateways", such as Coinbase. Likewise, a large seller seeking to realize profits will sell on fiat gateways. Investors buying or selling through stablecoins could be motivated by other factors, such as collateralizing leveraged derivative trades or investing in other cryptocurrencies. Investments coming from the outside of the system are intuitively more likely to lead to price movements impacting the broad market than investments coming from within.

The most significant observation from the full sample period is the growing importance of CME's regulated futures market. In Alexander and Heck's article (2020), CME never saw a monthly GIS surpassing 9% in the period from April 2019 till January 2020. However, from June 2020 till April 2021, CME seems to have a far more substantial importance in the market, with a GIS ranging from 7% at its lowest months to 39% at most. CME's GIS in April 2021 is the highest GIS measured in any of the instruments for the entire time series within the main instrument analysis. This indicates that CME's role in bitcoin's price discovery is growing. In the latter parts of April, the 14-day moving average GIS of CME's bitcoin futures reached 48%, indicating that the regulated bitcoin futures on CME has become an important contributor to the price discovery of bitcoin. It is worth noting that April 2021 was the first month since September 2020 where bitcoin saw negative monthly returns. The high GIS of CME might suggest that trading activity on CME was leading the trend shift in bitcoin, suggesting a possible declining interest from institutional investors in bitcoin.

8 Limitations and Further Research

In this section, we will briefly comment on the limitations of our thesis and recommend further research on the topic of price discovery in bitcoin.

8.1 Limiations

The major limitation of our thesis is the quality of the datasets used. Several of the instruments have large gaps of information. The most unfortunate gaps are found in the FTX data. From Q1, 2021, and onwards, our findings suggest a growing leadership from the FTX perpetual. However, we cannot firmly confirm whether this is a persisting trend or if the high GIS from January and April were outlier events due to missing data. We also had issues with rendering the full datasets from Binance's spot market, Bitfinex, OKEx's inverse Q3 contract and temporal outages from Huobi. Albeit the research, in general, is based on rich data, and we are comfortable with the validity of our results.

8.2 Further research

The bitcoin options market has blossomed the last year. On April 14, the options market peaked with $15 billion worth of open interest in the options market, and the trading volume of the options market has reached an ADV of $1 billion according to Skew.com. With the growth of the bitcoin options market, it would be valuable to understand its current influence on bitcoin's price discovery.

We would also recommend involving LMAX Digital's spot prices to further analyze the price discovery in bitcoin. The exchange is a part of the LMAX Global cooperation and is used by large accredited investors trading in the FX markets, and in 2021 has an ADV above $1 billion. By adding LMAX Digital in the price discovery analysis, one may gain a more nuanced understanding of the impact of institutional trading in bitcoin.

Further, as we are wrapping up this thesis, CME has launched a new futures contract in bitcoin with a smaller contract size of 0.1 bitcoin. Over time, more investors might move towards these smaller contracts as they allow for more flexible trades. Analyzing the impact of the entrance of the new contracts within CME could be interesting.

9 Conclusion

In this thesis, we examined the process of how new information is impounded into the market, more commonly known as the price discovery process. We used GIS by Lien & Shrestha (2014) and identified the most relevant and important markets in bitcoin's price discovery process. We analyzed the GIS within various markets using minute-by-minute market close data from 21 different bitcoin pairs from June 1, 2020, until April 30, 2021.

First, we analyzed the GIS in the spot market by analyzing five spot pairs. The results derived from this thesis suggest that Binance's stablecoin denominated pair is leading the spot market, with an average GIS of 31% throughout the sample period. Coinbase also contributed substantially to the price discovery in the spot market with an average GIS of 27% for the full sample period.

Second, we analyzed the GIS in the unregulated futures market by analyzing seven futures instruments. Our results indicate that Huobi and OKEx futures are leading the unregulated futures market with their instruments combined accounting for 52% of the GIS for the full duration of the sample. In terms of GIS, OKEx's inverse bitcoin futures was on average the leading instrument from October to April, when this period was analyzed separately due to missing data. Huobi and OKEx's leading role was also discovered by Alexander & Heck (2020) in their analysis. This indicates that these instruments have maintained their position despite the massive developments in the bitcoin market structure over the last year.

Third, we analyzed the GIS in the perpetuals market by analyzing eight perpetual instruments. We found indications that Binance's linear perpetual is the leading instrument in the perpetuals market, with a GIS of 20%. Binance's leadership was on par with what one would expect, given their dominance in trading volume with an ADV of $7 billion for the entire duration of the sample.

We then analyzed the main instruments in bitcoin's price discovery process based on GIS. They were selected based on their contribution within the aforementioned groups. We also included the regulated bitcoin futures on CME in this last group, to identify the role of the regulated markets in bitcoin's price discovery. The results from this analysis suggest that the unregulated futures on Huobi and OKEx tend to lead the market. Additionally, we observed trends of substantial price discovery taking place on both the CME futures and the Binance perpetual, with CME seeing the largest monthly GIS recorded in any instruments for the entire duration of the sample in April of 39%.

Through analyzing the main instruments, we identify that contrary to within the spot market group, Binance's stablecoin denominated spot pair primarily reacts to price movements when compared to all the main instruments. Coinbase, on the other hand, maintains a relatively high GIS when analyzed in the main instruments group. Intuitively these results make sense. Coinbase's spot pair is driven by new dollars entering the system, whereas the Binance USDT pair is based on stablecoins. Investments coming from the outside of the system are intuitively more likely to lead to price movements impacting the broad market than investments coming from within.

This thesis further backs up the narrative of increased institutional adoption of bitcoin in 2020 due to the more pronounced leading role of CME's bitcoin futures. Our observations of the growing importance of CME could contribute to making a case for an ETF approval from the SEC more likely. This would give retail investors a fair investment product in bitcoin without fluctuating premiums and discounts. In our view, it would serve the retail investors justice to approve an ETF in light of the growing presence of regulated instruments in this trillion-dollar asset.

We also conclude that CME's importance in the price discovery of bitcoin is more pronounced now than it was from April 2019 till January 2020, when it was analyzed by Alexander & Heck (2020).

The regulated futures market on CME is wagging bitcoin, "the honey badger of money".

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Appendix

A1 Johansen procedure for cointegration testing

Following are the full results for Johansen procedure for cointegration testing.

Table A1.1: Johansen-Procedure for cointegration testing of the spot market

		10pct	5pct	1pct
r <= 4	4.80	10.49	12.25	16.26
r <= 3	3867.58	16.85	18.96	23.65
r <= 2	6210.08	23.11	25.54	30.34
r <= 1	54943.52	29.12	31.46	36.65
r <= 0	72899.06	34.74	37.52	42.39

Table A1.2: Johansen-Procedure for cointegration testing of the unregulated futures market

		10pct	5pct	1pct
r <= 6	4.58	10.49	12.25	16.26
r <= 5	47.22	16.85	18.96	23.65
r <= 4	280.08	23.11	25.54	30.34
r <= 3	436.52	29.12	31.46	36.65
r <= 2	768.24	34.75	37.52	42.36
r <= 1	978.00	40.91	43.97	49.51
r <= 0	1700.79	46.32	49.42	54.71

Table A1.3: Johansen-Procedure for cointegration testing of the unregulated perpetuals market

		10pct	5pct	1pct
r <= 7	5.48	10.49	12.25	16.26
r <= 6	1624.80	16.85	18.96	23.65
r <= 5	5666.36	23.11	25.54	30.34
r <= 4	8983.42	29.12	31.46	36.65
r <= 3	12992.95	34.75	37.52	42.36
r <= 2	16928.18	40.91	43.97	49.51
r <= 1	29720.79	46.32	49.42	54.71
r <= 0	41510.62	52.16	55.50	62.46

Table A1.4: Johansen-Procedure for cointegration testing of leaders from different groups and CME

		10pct	5pct	1pct
r <= 5	6.70	10.49	12.25	16.26
r <= 4	178.29	16.85	18.96	23.65
r <= 3	330.06	23.11	25.54	30.34
r <= 2	1075.96	29.12	31.46	36.65
r <= 1	3530.74	34.75	37.52	42.36
r <= 0	20839.41	40.91	43.97	49.51