Wilshire Phoenix

Efficient Price Discovery in the Bitcoin Markets

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Introduction

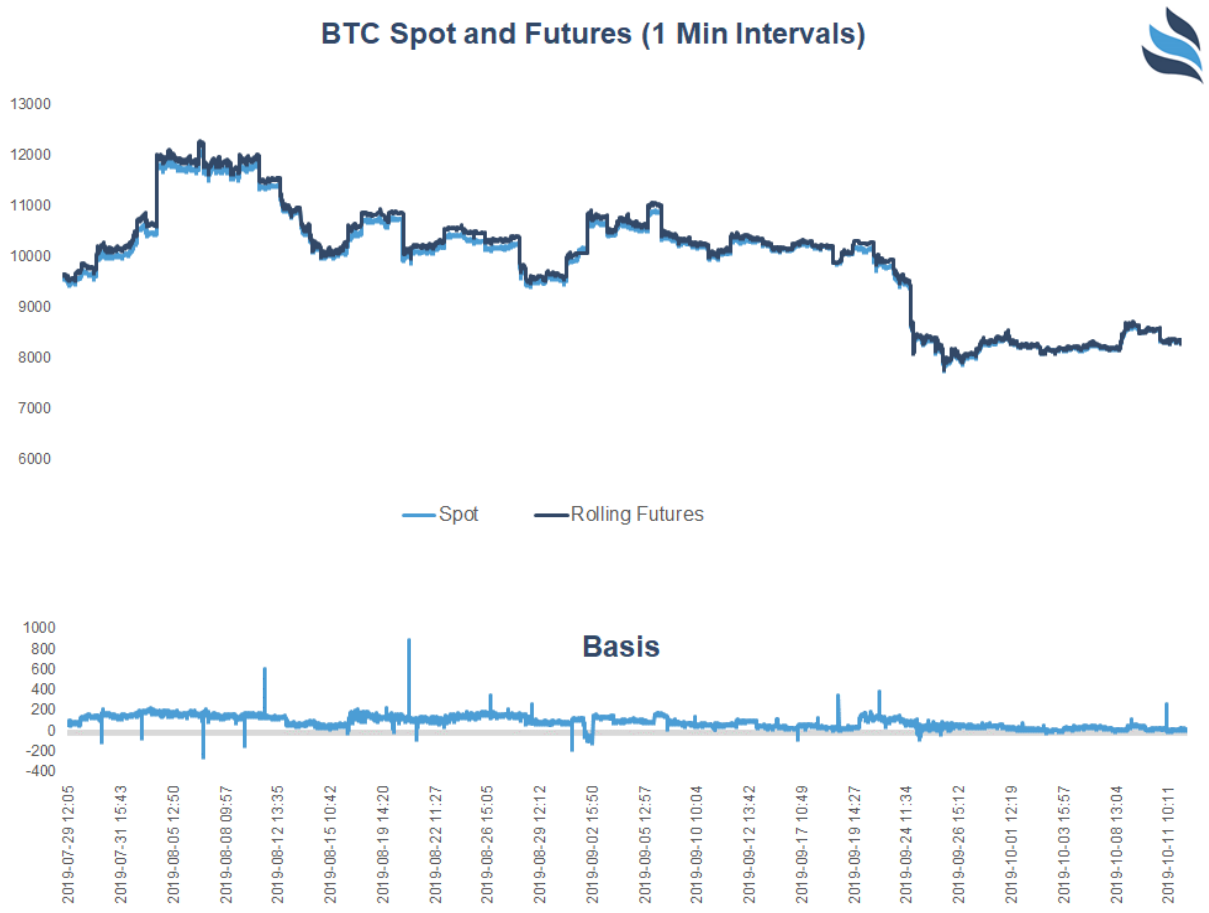
- The findings of Wilshire Phoenix (hereinafter, "we" or "our") indicate that CME Bitcoin Futures contribute more to price discovery than its related spot markets
- Our analysis was performed using similar methodology previously employed by the SEC's Division of Economic and Risk Analysis to evaluate price formation
- CME Bitcoin Futures have grown to become significant, this is not only demonstrated through trading volume and open interest, but also by influence on spot price formation
- A leading futures market suggests the existence of a robust base of traders who may trade on such market for many reasons such as trust in the exchange venue and lower latency
- Studies on price formation between the spot and futures markets in other asset classes often find that the futures markets lead

Price discovery is a hotly contested topic amongst trading venues and participants on multiple sides of primary markets as well as policy makers and regulators. The concept even merits explanation on the CFTC agency website where it states that price discovery is "the process of determining the price level for a commodity through the interaction of buyers and sellers and based on supply and demand conditions."[1] Effective price discovery facilitates best execution, the fulfillment of fiduciary responsibilities and the practicalities of pricing IPOs and secondary offerings.[2]

Efficient prices also form the bedrock underpinning the $448.97 trillion interest-rate derivatives and $6.87 trillion equity-linked derivatives industry (which includes exchange-traded products).[3] Obstacles to price discovery can increase trading costs, lead to sudden volatility, and diminish the efficient functioning of the global capital markets.

Given that price discovery in the traditional markets remains a contested topic, it is no surprise that the debate regarding the same in the bitcoin markets is that much more unsettled.[4] Therefore, this paper seeks to evaluate the bitcoin price discovery process using proven, respected, and recognized academic methods that have been utilized for many other tradeable commodities and financial instruments over the past several decades. Another way our analysis differs is our usage of data at a higher frequency than previous papers, with ticks, grouped into one-minute intervals, as compared to 10 or 15 minutes. This allows a more precise estimation of the contribution of the spot and the futures markets to the process of price discovery.

FIGURE 1



Source: Kaiko, Chicago Mercantile Exchange (CME)

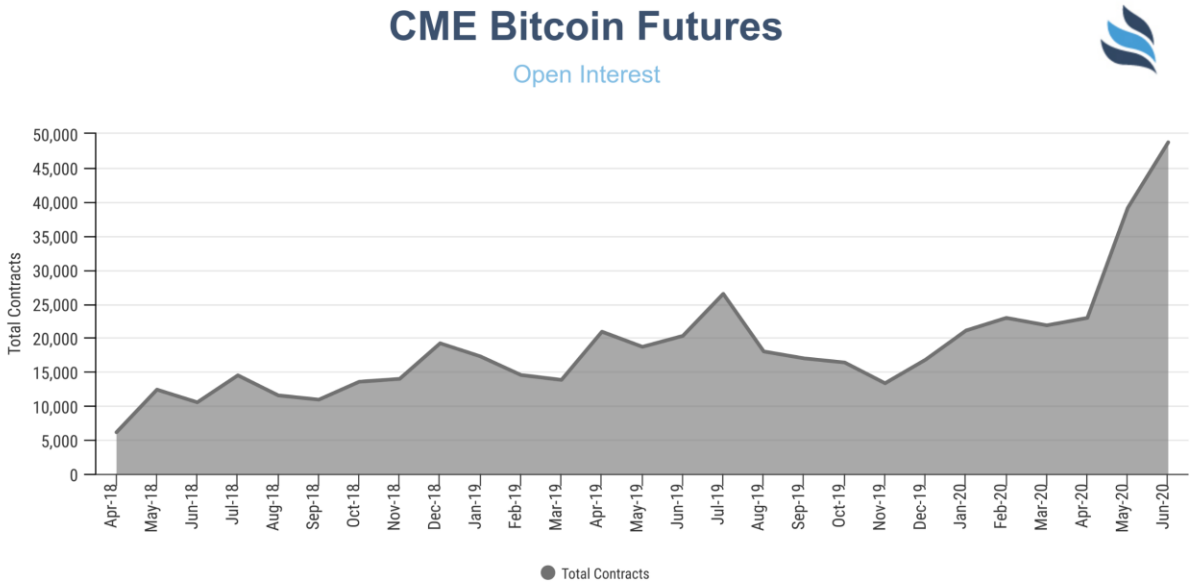
The Chicago Mercantile Exchange (CME) and its Bitcoin Futures

The spot and futures markets for commodities have historically provided a mechanism for ascertaining the value of a particular underlying commodity, as well as in many cases, variations and spreads.[5] CME Group, markets itself as the "world's leading and most diverse derivatives marketplace."[6] The daily average notional value of products traded across the CME Group marketplaces is $5.15 trillion per day for the approximately 2,059 products traded on four exchanges, including CME, CBOT, NYMEX and COMEX.[7]

Launched in 2017, CME bitcoin futures have grown to become a significant part of the bitcoin market, demonstrated not only through trading volume and open interest but also by influence on bitcoin price formation and discovery. Further evidencing the maturation of the product, options on the futures were added in January 2020.

FIGURE 2

CME bitcoin futures contracts are cash-settled based on the last Friday of each month after trading ends at 4 p.m. London Time.[8]



Source: CME

The CME CF Bitcoin Reference Rate (the "CME CF BRR" or "Index")

The CME CF BRR was created to facilitate the creation and trading of financial products based on bitcoin and incorporates the principles of the International Organization of Securities Commissions. The CME CF BRR serves as a once-a-day reference rate of the U.S. dollar price of bitcoin (USD/BTC) as observed on leading bitcoin exchanges.

In addition to serving as the rate on which bitcoin futures contracts are cash-settled in U.S. dollars at the CME, the CME CF BRR may also serve as the rate used in determining the net-asset-value calculation of investment products.[9] Further, the CME CF BRR measures the economic reality of the USD price of bitcoin by observing the exchange of bitcoin for U.S. Dollars only. This is completed by exclusively utilizing transaction data in the trading pair of Bitcoin-USD observed from the Constituent Exchanges (as defined below). This means that the CME CF BRR does not directly incorporate transactions conducted in parallel markets such as bitcoin against stable coins, other cryptocurrencies or bitcoin derivatives trading on other exchanges.

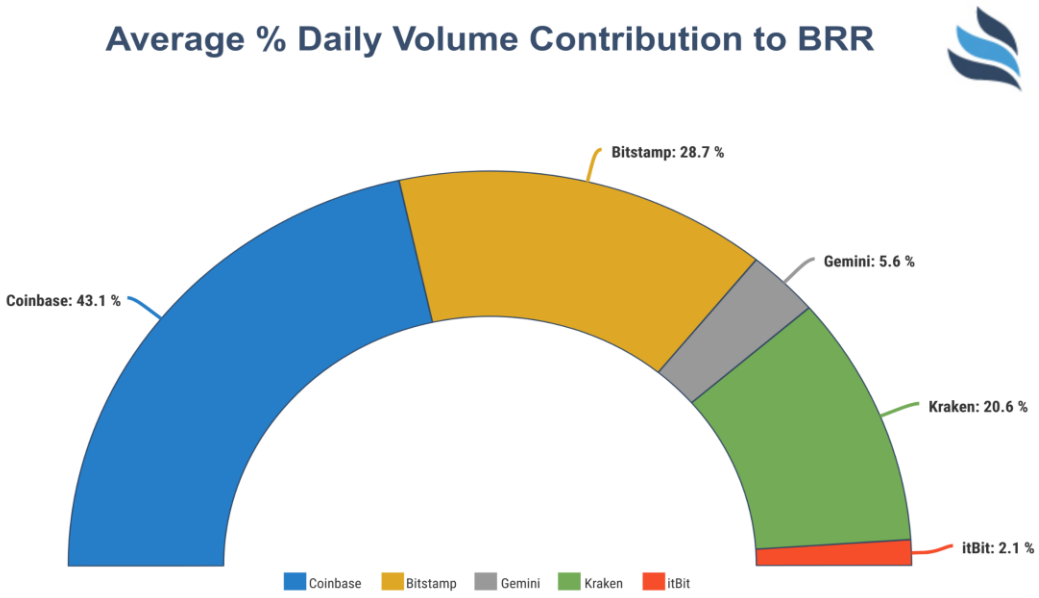
The method for calculating the Index will be assessed with respect to their ability to satisfy a set of desirable characteristics for indices, as follows[10] :

- Relevance – the index should reflect the supply and demand and the resulting true value of the underlying asset as accurately as possible.
- Timeliness – the index should refer to a specific point in time or a time interval as short as possible and shall be available as soon as possible after that point or interval.
- Manipulation Resistance – it shall be as expensive as possible to move the index away from the true value of the underlying asset.
- Martingale Property – it shall be impossible to game a derivatives market by predicting patterns in the price behavior of the index.
- Verifiability – the methodology by which the index is calculated shall be transparent and its input data shall be readily available such that calculation results can be independently verified.
- Replicability – investors shall be able to reproduce the index with minimal tracking error by trading in the spot market of the underlying asset.
- Stability – the index shall not exhibit price fluctuations other than those caused by the actual changes in the true value of the underlying asset and shall not be susceptible to outliers and data quality issues.
- Parsimony – the methodology of the index shall utilize as few arbitrary parameters as possible.

Constituent Exchanges, Index Controls, and the Oversight Committee

The Index utilizes an oversight committee, the CME CF Oversight Committee, to determine which exchanges are eligible to be a Constituent Exchange. In order to be considered for inclusion in the Index, an eligible exchange must meet certain regulatory and control practices. The CME CF Oversight Committee also analyzes additional factors related to price discovery such as liquidity, volume, and statistical deviations from different spot bitcoin exchanges.[11] From the many potentially eligible bitcoin spot exchanges, only Coinbase, Kraken, itBit, Bitstamp and Gemini (each a "Constituent Exchange") have been selected for inclusion in the CME CF BRR. For example, highly levered products listed on unregulated derivatives exchanges, such as Bitfinex are not included in the universe of potential Constituent Exchanges. Including such products in the definition of the spot market would conflict with the spot market exchanges are intended to represent within the index.[12]

FIGURE 3



Source: CF Benchmarks May 2020

To remain in the Index each Constituent Exchange is Required to:

- Have sufficient BTC/USD average daily spot trading volume (during the observation window for the CME CF BRR (see Appendix I) the average daily volume that the exchange would have contributed to the Index must exceed three percent (3%) for two consecutive calendar quarters)
- Employ policies to ensure fair and transparent market conditions at all times and have processes in place to identify and impede illegal, unfair, or manipulative trading practices
- Not impose undue barriers to entry or restrictions on market participants, and utilizing the venue must not expose market participants to undue credit risk, operational risk, legal risk, or other risks
- Cooperate with inquiries and investigations of regulators and CF Benchmarks (the "BRR Administrator") upon request and execute data sharing agreements with the BRR Administrator as well as the CME

Additionally, the Constituent Exchanges must fully comply with the BSA and AML requirements. This is also consistent with recent guidance issued by the FATF which directs certain exchanges, including the Constituent Exchanges, to comply with AML regulations. Also, to its general regulatory and enforcement jurisdiction over the virtual currency derivatives markets, the Commodities Futures Trading Commission

(the "CFTC") has jurisdiction to police fraud and manipulation in the cash or spot markets, including the Constituent Exchanges.

In addition, the CFTC has noted explicitly that "asserting legal authority over virtual currency derivatives in support of the CFTC's anti-fraud and manipulation efforts, including in underlying spot markets, is a key component in the CFTC's ability to effectively regulate these markets"(emphasis added). The CFTC has expressed its intention to continue to exercise this jurisdiction to enforce the law and prosecute fraud, abuse, manipulation, or false solicitation in both the CME bitcoin futures market as well as the underlying spot trading, including on the Constituent Exchanges.

Further, the CME has executed agreements with the Constituent Exchanges to explicitly adhere to the regulations. Effective as of August 19, 2019, the BRR Administrator, was authorized by the United Kingdom Financial Conduct Authority (the "FCA") and was granted a Part 4A permission under Part 4A of the Financial Services and Markets Act 2000 ("FSMA") to carry on the regulated activity of administering a benchmark. Because the BRR Administrator is a registered benchmark administrator under the EU Benchmark Regulations (the "EU BMR"), the Constituent Exchanges are subject to regulatory oversight by the FCA pursuant to Article 14 of the EU BMR.

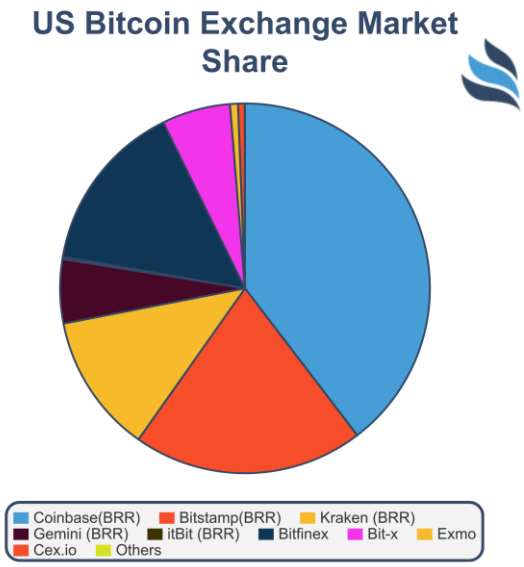
Article 14 of the EU BMR requires that the BRR Administrator (i) "establish adequate systems and effective controls to ensure the integrity of input data in order to be able to identify and report to the competent authority any conduct that may involve manipulation or attempted manipulation of a benchmark, under Regulation (EU) No 596/2014" and (ii) "monitor input data and contributors in order to be able to notify the competent authority and provide all relevant information where the administrator suspects that, in relation to the benchmark, any conduct has taken place that may involve manipulation or attempted manipulation of the benchmark, under Regulation (EU) 596/2014 including collusion to do so." Input data is defined as "the data in respect of the value of one or more underlying assets, or prices, including estimated prices, quotes, committed quotes, or other values, used by an administrator to determine a benchmark. Thus, under the EU BMR, the BRR Administrator must establish adequate systems and effective controls to detect any attempted manipulation on each of the Constituent Exchanges and report any such attempts to the FCA. Akin to the SEC's regulation of national securities exchanges, the requirements of the EU BMR are designed to detect and deter manipulation on the Constituent Exchanges.

By requiring the BRR Administrator to establish procedures to identify and report such manipulation to the FCA, the EU BMR increases market surveillance and deters would-be manipulators by mandating channels of information sharing through governmental oversight of the CME CF BRR. The EU BMR also fosters informational flow and therefore cooperation and coordination between the Constituent Exchanges and the CME. Additionally, each of the Constituent Exchanges uses established, non-discretionary methods (whether by providing a trading facility or by setting rules) under which orders interact with each other, and the buyers and sellers entering such orders agree to the terms of a trade. The sets of rules dictating the processes of the Constituent Exchanges must be in line with the CME standards in order for each Constituent Exchange to be included in the calculation of the CME CF BRR.

The Constituent Exchanges Represent a 'Market of Significant Size'

Numerous entities provide a daily bitcoin price index, however many of those indices are based on 'all of the available market' from publicly available API's without a data license. While this may bring a holistic approach, it is fraught with challenges in that certain exchanges may not be liquid by volume or order book depth, and they may be showing stale prices. Additionally, some exchanges may operate strict KYC and AML checks on their clients whereas others may not. One or more of these factors may in turn affect the bitcoin price shown on the respective exchange.

FIGURE 4



Exchange	Constituent	USD Bitcoin Market Share
Coinbase	Yes	39.7%
Bitstamp	Yes	20.2%
Kraken	Yes	12.2%
Gemini	Yes	5.6%
itBit	Yes	0.2%
Bitfinex		15.0%
Bit-x		6.0%
Exmo		0.7%
Cex.io		0.6%
Others		0.0%

Source: bitcoinity.org September 2020

Only a few major exchanges dominate in BTC:USD trading, and liquidity is concentrated in an even smaller number of exchanges. When layering the eligibility criteria of the CME CF BRR on top of this, only Coinbase, itBit, Bitstamp, Kraken and Gemini clearly fit the requirements for contributing to the CME CF BRR.

Additionally, we found that the CME bitcoin futures market is larger in size (as a percentage of spot trading) than the size of the gold futures markets are in relation to the gold OTC market (expressed as a percentage). Using the most recent data cited by the World Gold Council (WGC), the ratio of daily trading volume of Gold futures on COMEX ($28.9 billion) to daily trading volume on gold OTC markets ($167.9 billion, which is the midpoint of the estimated high and low points by the WGC) is approximately 17.2%. In comparison, using data from the CME and the Constituent Exchanges over the 6- month period

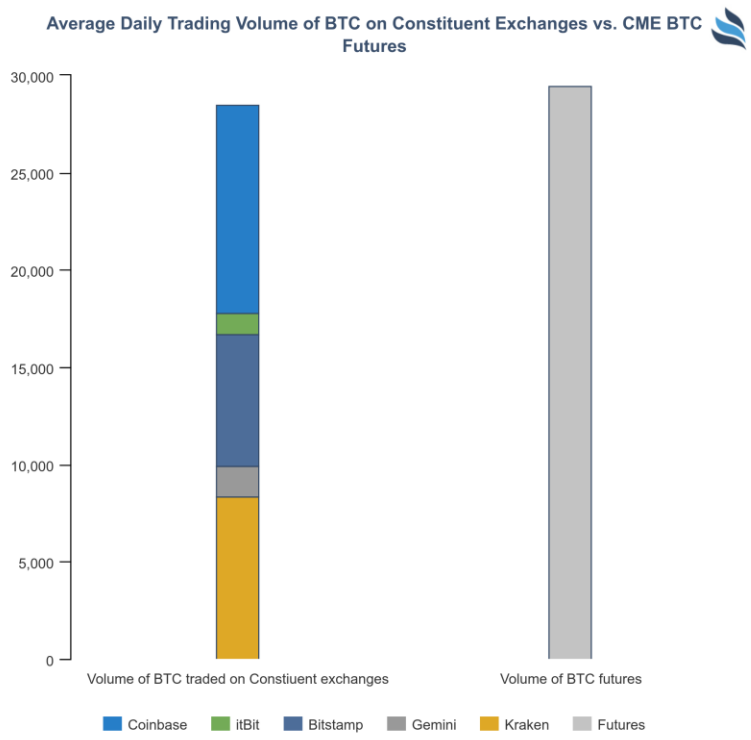
of October 1, 2018 to March 31, 2019, the ratio of daily trading volume of BTC futures on the CME ($90.4 million) to the daily trading volume of BTC/USD spot ($149.5 million) is approximately 60.5%.

Further, based on worldwide BTC:USD trading volume, the Constituent Exchanges that comprise the CME CF BRR capture 78% of the total BTC:USD traded volume. Therefore, it is reasonable to conclude that the CME CF BRR is a proper representation of the underlying BTC:USD spot market for bitcoin[13].

Price and Volume

Trade volume and trade size can partially be determinants of price discovery. Bitcoin notional volume is similar between the CME bitcoin futures market and the Constituent Exchanges in aggregate. The CME bitcoin futures trading volume is higher than each of the Constituent Exchanges when taken individually, which also facilitates price discovery within the futures market. The average size of trades on the CME bitcoin futures market are also much larger than the average size of trades on the Constituent Exchanges.[14] A relative number of small trades in a given market is typically statistically insignificant for price discovery purposes.[15] The average trade size on the CME futures market facilitates its lead in price discovery versus the Constituent Exchanges.

FIGURE 5

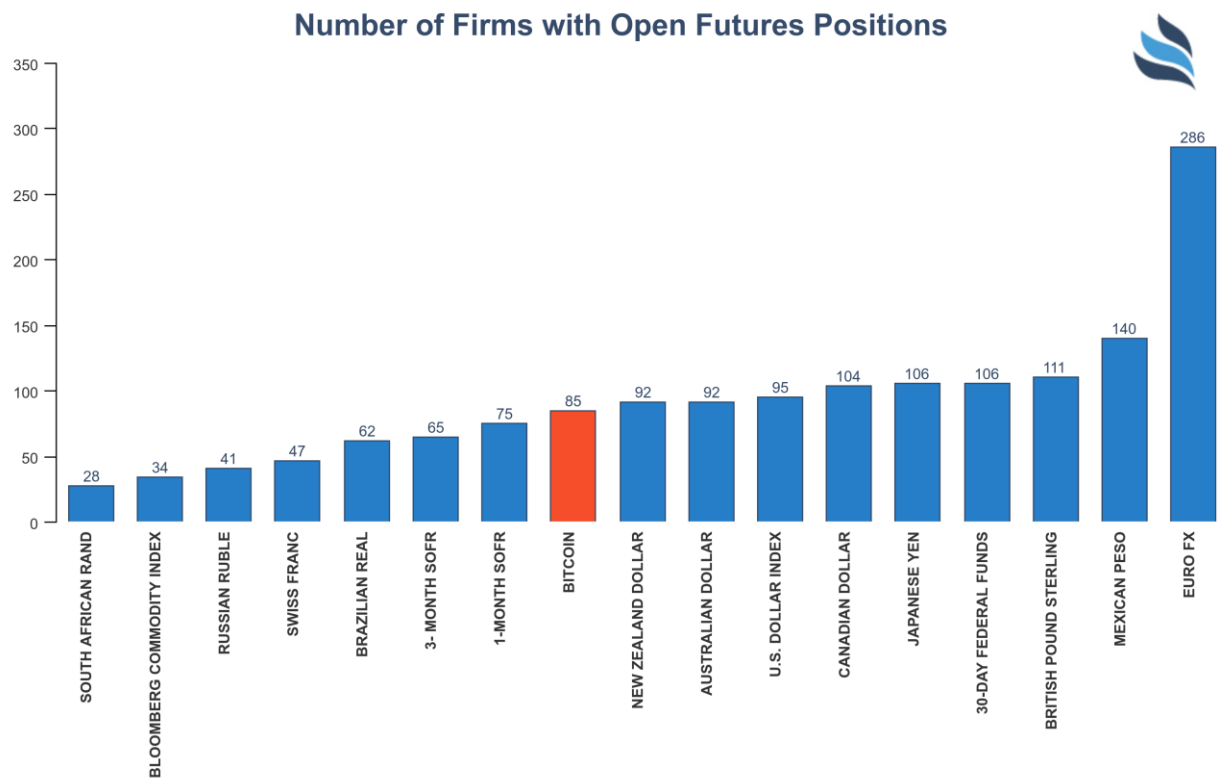


Source: Kaiko, CME July 2020

The Presence of Arbitrage

Market arbitrage is the near-simultaneous buying and selling of the same asset in different markets to take advantage of any temporary price dislocations between those markets. Generally, market arbitrage requires significant capital and can only be a viable practice if an asset is traded across different markets (in this instance, the Constituent Exchanges), and is priced dissimilarly across those markets. This lack of uniformity gives rise to market arbitrage opportunities, and conversely, if various markets exhibit uniform pricing it implies the presence of market arbitrage. The Constituent Exchanges have consistently exhibited tight spreads, which was previously demonstrated by an analysis completed by the CME.[16] This implies the presence of market arbitrage and arbitragers deploying capital to maintain uniform pricing across the Constituent Exchanges. In actual fact, the futures contract is widely traded with 85 firms having active positions as of September 1, 2020. Firms with a long history of trading in traditional financial markets also participate in cryptocurrency futures markets, including Futures Commission Merchants ("FCMs") such as Wedbush, Macquarie, and R.J. O'Brien, among others.[17]

FIGURE 6



Source: CFTC September 2020

Formal Methods for Testing Price Discovery

When interrelated securities or commodities trade in multiple markets, the information share and component share measures are statistical measures used to measure contribution to and trends in price discovery. These measures have been featured in studies of price discovery as well as in financial market policy analysis, particularly around UTP privileges, Reg NMS and new exchange features, including IEX and SIP Fees.

Using both the Gonzalo[18] and Granger[19] component share and the Hasbrouck[20] information share[21] measures, research suggests that a majority of long run price information is derived from the futures market.[22] Additionally, it has been observed that price movements in the futures markets were often accompanied or followed by price movements of the spot market in the same direction.[23] Additionally, studies on price formation between the spot and futures markets in other asset classes often find that the futures market leads.[24] As discussed above, many researchers analyzing this lead/lag relationship between bitcoin spot and futures markets have found that the majority of price discovery takes place in the futures market.[25] Research indicated that the futures market often leads the spot market due to inherent leverage, low transaction costs, the absence of short-selling restrictions and greater transparency.[26]

Our Analysis, Methodology and Findings

The analysis performed by Wilshire Phoenix was to determine whether CME bitcoin futures or the spot markets represented by the Constituent Exchanges led bitcoin price discovery. The methodology for our price formation analysis is modeled on the price discovery procedures employed by the work of Ozturk et al.[27] and de Jong et al.[28], both of which focused on price formation in fragmented markets, particularly in equities, with more than two pricing sources. The body of analysis specific to price formation in futures versus spot markets generally employs a different set of price formation metrics that focus particularly on price formation between two markets (futures and spot) and for this price formation analysis, in a two-component system, the Gonzalo and Granger component share[29] is calculated to analyze the contribution of futures and spot to price formation.[30] In addition to the static time invariant approaches noted above, research has also been performed applying the time-varying Granger causality test of Shi et al.[31] and the time-varying cointegration tests of Park & Hahn.[32] Such research has also confirmed prior findings, based on static time invariant approaches, that bitcoin futures lead the bitcoin spot market in price formation.[33]

Our study took place during the second half of 2019 and we found that the component share from the CME bitcoin futures market as compared to the related spot markets made up of the Constituent Exchanges was 62.69% in a two-component model of futures and spot. Further, based on the Gonzalo and Granger component share, our own analysis and the findings of multiple recent academic publications, we conclude that the CME bitcoin futures contribution to price formation was greater than the contribution from the related spot markets made up of the Constituent Exchanges, indicating that the

futures lead the spot markets and thus contribute more to price formation. As mentioned earlier, this analysis was performed using a methodology similar to the one employed by the Division of Economic and Risk Analysis at the SEC to evaluate the IEX exchange's contribution to price formation in the equities markets.[34]

In Conclusion

Studies on bitcoin price discovery have consistently shown an interrelationship between the prices on the CME futures market and the prices on one or more of the Constituent Exchanges (which form the basis of the USD/BTC spot market) based on the determinants of price discovery and that, in most instances, the CME futures market is the market that leads prices on the Constituent Exchanges. A leading futures market suggests the existence of a robust base of traders who may trade on such market for many reasons, including trust in the exchange venue, lower latency, and other factors.

Our results imply that the CME bitcoin futures market generally incorporates new information faster than the spot market (as represented by the Constituent Exchanges). They also imply that market-wide information is likely to be reflected in the futures market first. As a consequence, we believe that those investigating the world-wide bitcoin market response to macroeconomic news, or informational linkages between markets in different countries, should consider using futures market data rather than spot market data.

Acknowledgments

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- Chicago Mercantile Exchange
- CF Benchmarks
- Kaiko Data

Appendix I: Dataset

We utilized tick data comprising the official record of trade times and prices as well as quantities for electronic trades in bitcoin futures (Time and Sales data set) that are available via the CME DataMine market data facility.[35] Spot market data messages are available via the aggregated CME CF BRTI (which is the CME's real time Bitcoin Index). Market data messages for the CME CF BRR and CME CF BRTI are also available via CME DataMine market data facility. Data is transferred from the CME Group DataMine market data facility to an AWS S3 bucket via the TickSmith Automatic S3 Transfer service integrated in the CME DataMine market data facility. The official data sets from the CME Group are decompressed and stored on the EBS volume attached to an AWS EC2 virtual machine.

CME CF BRTI levels and rolling futures trade prices are aggregated into 1-minute intervals[36] using the respective median value in each interval during CME bitcoin futures, CME Globex and CME ClearPort daily trading hours of 5 p.m. to 4 p.m. (Central Time), Sunday through Friday. Previous values are used if data is unavailable for one of the intervals. Time stamps for all input timeseries are aligned to Central Time. Parallelized numerical calculations are performed on an AWS m5.24xlarge virtual machine instance containing ninety-six (96) virtual cores and 384GB of memory.[37]

Appendix II: Index Methodology

The CME CF BRR does not include any futures prices in its methodology. A "Relevant Transaction" is any "cryptocurrency versus legal tender spot trade that occurs during the Time-Weighted Average Price (TWAP) Period" on any Constituent Exchange in the BTC/USD pair.

The following table shows the symbols used in the mathematical representation of the CME CF BRR:

Symbol	Name	Description	Type
T	Effective time	The time as of which the CME CF BRR is calculated	4:00 p.m. London Time
r	TWAP period length	The length of the time-period prior to the effective time during which transaction data is collected	60 minutes
r̂ with $\hat{r} \leq r$ and r̂ | r	Partition length	The length of the time periods into which the TWAP period length is partitioned	5 minutes
K	Number of partitions	The number of partitions, given by $K = r/t$	Output
k with $k \in (1, ..., K)$	Partition	The *k*th partition	Output
X k for k € (1, ..., K)	TWAP period trades	The price-ordered collection of price / size trade pairs observed in the Relevant Pair on all Constituent Platforms in the *k*th partition, i.e. between times $T - r + (k - 1)$ and $T - r + k$	Input
I k	TWAP period trades count	The number of trades in the *k*th partition	Output
***X k,i* with Xk,i = (Pk,i, Sk,i) and Xk,i € Xk**	TWAP period trade	The ***i***th price / size trade pair of the *k*th partition	Input
Pk,i,	TWAP period trade price	The price of the ***i***th price/size trade pair of the *k*th partition	Input
Sk,i,	TWAP period trade size	The size of the ***i***th price/size trade pair of the *k*th partition	Input
WMCH	Weighted median	The weighted median trade price of the *k*th partition	Output
CCRRT	CCRR	The CME CF BRR at time *T*	Output

For each partition *k,* the volume-weighted median trade prices *WMk* across all Relevant Transactions is calculated as:

$$\boldsymbol{WM_k} = \boldsymbol{p_{k,j}} \text{ where } j \text{ satisfies } \sum_{i=1}^{j-1} S_{k,i} < \frac{1}{2}\sum_{i=1}^{I_k} S_{k,i} \text{ and } \sum_{i=j+1}^{I_k} S_{k,i} \leq \frac{1}{2}\sum_{i=1}^{I_k} S_{k,i}$$

$$\text{If } \sum_{i=j+1}^{I_k} S_{k,i} = \frac{1}{2}\sum_{i=1}^{I_k} s_{k,i} \text{ then } \boldsymbol{WM_k} = \frac{P_{kj} + P_{kj+1}}{2}$$

The CME CF BRR as of the effective time *T, CCRRT,* is then given by:

$$\text{CCRR}_{\boldsymbol{T}} = \frac{\boldsymbol{1}}{\boldsymbol{K}}\sum_{\boldsymbol{K=1}}^{\boldsymbol{K}} \boldsymbol{WM_k}$$

In brief, the CME CF BRR methodology divides the observation window into twelve discrete five-minute partitions. The calculation then has two key steps:

1. The volume weighted median of the transactions observed in each five-minute partition is calculated.
2. The CME CF BRR is then the arithmetic mean of the twelve volume weighted medians.

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[24] *See* Stoll, H. and Whaley, R. (1990) "The Dynamics of Stock Index and Stock Index Futures Returns", *The Journal of Financial and Quantitative Analysis*, *25*(4), 441-468 (for equities and stock indices) (available at: https://www.jstor.org/stable/2331010?seq=1); *see also* Chen, Y. and Gau, Y. (2010) "News Announcements and Price Discovery in Foreign Exchange Spot and Futures Markets", *Journal of Banking & Finance*, 34, 1628-1636 (for foreign exchange spot and futures) (available at: https://www.sciencedirect.com/science/article/abs/pii/S037842661000107X); *see also* Figuerola-Ferretti, I. and Gonzalo, J. (2010) "Modeling and Measuring Price Discovery in Commodity Markets", *Journal of Economics*, 158(1), 95-107 (for commodities spot and futures) (available at: https://www.sciencedirect.com/science/article/abs/pii/S0304407610000552); *see also* Theissen, E. (2012) "Price Discovery in Spot and Futures Markets: A Reconsideration", *The European Journal of Finance*, 18(1), 969-987 (for the DAX spot and futures) (https://www.researchgate.net/publication/48264009_Price_discovery_in_spot_and_futures_markets_A_reconsidera tion); *see also* Mizrach, B. and Otsubo, Y. (2014) "The Market Microstructure of the European Climate Exchange", *Journal of Banking and Finance*, 39, 107–116 (for markets for carbon emissions) (available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1621340); *see also* Chen, Y.L. and Tsai, W.C. (2017) "Determinants of price discovery in the VIX futures market", *Journal of Empirical Finance*, *43*, 59-73 (for markets for VIX indices) ((available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2972441); *see also* Dimpfl, T., Flad, M. and Jung, R.C. (2017) "Price Discovery in Agricultural Commodity Markets in the Presence of Futures Speculation", *Journal of Commodity Markets*, 5, 50-62 (for spot and futures of eight agricultural commodities) ((available at https://www.sciencedirect.com/science/article/pii/S2405851318300941).
[25] Alexander & Heck, supra note 22
[26] Alexander & Heck, supra note 22; *see also* Burcu Kapar & Jose Olmo, *An analysis of price discovery between Bitcoin futures and spot markets*, 174 Economics Letters 62-64 (2019).

[27] *See also* Ozturk, S., Van der Wel, M. and van Dijk, D. (2017) "Intraday Price Discovery in Fragmented Markets", *Journal of Financial Markets* 32, 28–48.
[28] *See also* De Jong, F. and Schotman, P., (2010) "Price discovery in fragmented markets", *Journal of Financial Econometrics*
[29] *See* Gonzalo, J. and Granger, C. (1995) "Estimation of common long-memory components in cointegrated systems" *Journal of Business & Economic Statistics*, 13, 27-35 (available at: https://www.jstor.org/stable/1392518) ("Gonzalo and Granger").
[30] This price formation metric is employed in several of the recent bitcoin price formation studies from different groups comparing futures and spot so there are several findings to tie to.
[31] *See* Shi, S., Phillips, P.C. and Hurn, S. (2018). "Change detection and the causal impact of the yield curve" *Journal of Time Series Analysis*, 39, 966-987.
[32] *See* Park, J.Y. and Hahn, S.B. (1999). "Cointegrating regressions with time varying coefficients" *Econometric Theory*, 15, 664-703.
[33] *See* Hu, Y., Hou, Y. and Oxley, L. (2019). "What role do futures markets play in Bitcoin pricing? Causality, cointegration and price discovery from a time-varying perspective" (available at: https://ssrn.com/abstract=3442706) ("Hu, Hou and Oxley"). ("It is clear that the IS (upper bound, lower bound and mid point) and GIS measures of the CME futures are higher than those of spot markets, indicating that the CME futures market outperforms in terms of static information shares price discovery.").
[34] Edwin Hu, Intentional Access Delays, Market Quality, and Price Discovery: Evidence from IEX Becoming an Exchange (2018).
[35] Information about CME datasets, is available at:https://www.cmegroup.com/confluence/display/EPICSANDBOX/Time+and+Sales; https://www.cmegroup.com/confluence/display/EPICSANDBOX/24-7+CME+CF+Cryptocurrency+Indices.
[36] Hu, supra note 34
[37] Amazon EC2 Instance Types - Amazon Web Services, Amazon Web Services, Inc. (2020), https://aws.amazon.com/ec2/instance-types/

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