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An analysis of the suitability of the CME CF BRR for the creation of regulated financial products

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Abstract

Increasing Bitcoin adoption has drawn concerns that institutions have about active participation in the Bitcoin market into sharp focus. Chiefly, for firms looking to create and manage financial products, there are doubts over price discovery, market integrity and the perception that a lack of capital markets regulation in Bitcoin trading venues implies risks inherent to the process of participation that are too material to tolerate.

This paper proposes a framework through which regulated financial product providers can overcome these risks by utilising the CME CF Bitcoin Reference Rate (BRR) as the settlement, valuation and performance benchmark for Bitcoin products.

This paper will first outline the risks, then describe in detail how they are mitigated through the use of the BRR. The paper will then describe a practical application of the BRR by demonstrating that the slippage that is likely to be incurred relative to the BRR when trading Bitcoins at scale would be low.

The qualities of the BRR and tracking error analysis outlined herein will thereby demonstrate how to deploy the BRR as the benchmark for Bitcoin financial products in a way that keeps those risks to a satisfactory minimum.

Cryptocurrency Milestones, Opportunities and Risks

2020 progress

Bitcoin passed several significant milestones on the path towards mass-market adoption in 2020. These include PayPal becoming the first major consumer platform to offer individuals the ability to make purchases of and with crypto, large U.S. corporations Square and MicroStrategy announcing significant investments in the biggest cryptocurrency by market capitalisation and Kraken, the popular exchange operator, being awarded a Special Purpose Depository Institution license from Wyoming regulators, making it the first crypto bank. In the summer, the U.S.'s Office of the Comptroller of the Currency (OCC), an arm of the Treasury, had confirmed that banks were authorized to custody cryptos for customers. Perhaps it is little wonder that among 800 U.S. and European institutional investors surveyed in June 2020 by Fidelity Digital Assets, a subsidiary of the global investment group, 60% indicated that digital assets should have a place in their portfolios, compared with 36% already invested in them.[1]

Deepening corporate and institutional engagement in cryptocurrency ownership, custody and investment in Bitcoin had an approximate corollary in broadening public interest tied in a virtuously circuitous manner to the rapid elevation of Bitcoin's price in the second half of 2020. On 30th November 2020, the CF Bitcoin Reference Rate, published by regulated benchmark administrator CF Benchmarks, was up 85.84% from 2nd October's $10,529.71 one-month low, to a new record high of $19,567.95.

Institutionalization

As adoption pressure from retail and institutional clients of financial services providers rises, it should not be surprising that institutional brokers (which traditionally execute client orders only at venues or with counterparties that are subject to capital markets regulations) are showing increased interest in participating in the Bitcoin market by means of futures contracts.

Bitcoin futures open Interest (the volume of active or unsettled contracts) at the world's largest derivatives exchange, CME Group, in November 2020 surpassed such volumes at all other known venues at which Bitcoin futures trade. Citing data provider Skew.com, the cryptocurrency news website Cointelegraph[2] reported that the value of open interest in Bitcoin contracts had more than doubled over a month to reach $1.16bn, overtaking volumes at the erstwhile leader in Bitcoin open interest, OKEx, an unregulated venue operating in Hong Kong whilst registered in Malta. OKEx's Bitcoin contract open interest rose slightly to $1.07bn over that stretch. Note that the CME's primary regulator is the U.S. Commodity Futures Trading Commission (CFTC). Therefore, the rise in Bitcoin futures open interest at the CME is a strong indication of quickening participation among the institutional subcategory of the financial trading community.

That brings us to the pertinence of this paper at this time. The chief subject of this publication is the frictions that institutional participants will need to grapple with conceptually in order to

ascertain whether active participation in the Bitcoin market is possible in a compliant and commercially satisfactory manner.

Regulatory deficits

Any trader or asset manager who has attempted to purchase Bitcoin at scale will have been confronted by a novel set of problems that are unlikely to be encountered in other asset classes. Partly as a consequence of their relatively recent development, cryptocurrency markets are more variable in terms of adherence to capital markets regulations compared to venues on which more established asset classes are traded. The net effect is that institutional participants face uncertainty in trying to establish the extent to which regulatory standards apply at cryptocurrency trading venues. Indeed, many such venues simply do not pass muster on AML/KYC compliance and market integrity - codified by transparent rules in line with regulation and enforced by surveillance and sanctions; with an unequivocal domicile status that establishes clear lines of regulatory oversight.

These regulatory deficits raise doubts about the integrity and fairness of the Bitcoin market. Upholding those principles is among the key goals of securities regulations aimed at eliminating market abuse, promoting non-discriminatory market access and ensuring that transparent and accurate information is available to all participants at the same time.[3] By extension, if we accept that Bitcoin trading venues do not yet universally perform essential functions widely agreed to be critical for the orderly operation of financial markets[4], we also need to grant that the Bitcoin market often fails to live up to the principles of fairness and integrity sought by regulators.

Given the variability of regulatory standards across cryptocurrency trading venues, one of the chief deficits that undermine the principles of fairness and integrity from a regulatory standpoint concerns oversight that is adequate enough to prevent potential market manipulation.

The sections below outline two types of potential fundamental market manipulation that have emerged in recent years as of particular concern regarding the Bitcoin market. The first relates to integrity of trading volumes. The second relates to integrity of pricing, a principle that securities regulators have flagged as among the most pertinent to the Bitcoin market[7].

Fake liquidity

Forbes estimated in 2018 that there were already more than 200 venues supporting the active trade of cryptocurrencies. [5.] The industry has also seen the proliferation of numerous decentralized exchanges in recent years. As the number of marketplaces expands, it follows that the quality of several factors at these marketplaces will vary, particularly given that exchanges in most jurisdictions are unregulated. One factor with the most variable levels of 'quality' is the veracity of cryptocurrency trading volume itself. As much as 95% of aggregated spot Bitcoin trading volume published by data aggregators such as coinmarketcap.com consisted of faked 'wash trades' according to several studies over the last few years, including research by Bitwise Asset Management published in March 2019.[6] Wash trading is a practice aimed at artificially

inflating the volume of transactions on an exchange. Fake liquidity is obviously a red flag as to the integrity of other aspects of any venue that tolerates it, though the specific danger to any trading participant is that trades cannot be executed at an intended price point because a perceived offer simply does not exist. The overall dearth of market integrity in many Bitcoin trading facilities also poses difficulties for financial services product providers looking to offer regulated Bitcoin products, such as ETFs, or seeking to benchmark the value of Bitcoin in relation to a variety of consumer or commercial services.

Price manipulation

Obviously, a significant level of 'trading' that, in effect, has not happened from the perspective of a bona fide marketplace, undermines notions of price integrity in as much as it comprehensively erodes confidence in the merits of participating in cryptocurrency markets overall. Furthermore, the U.S. Securities and Exchange Commission (SEC) has clearly flagged one of its chief concerns with respect to cryptocurrency regulation[8]. The then Chairman of the SEC, Jay Clayton, noted in December 2017: "A number of concerns have been raised regarding the cryptocurrency and ICO markets, including that, as they are currently operating, there is substantially less investor protection than in our traditional securities markets, with correspondingly greater opportunities for fraud and manipulation." [8] Price manipulation can occur in various forms. It is the implied impact on price integrity, as defined by markets regulation, that is most salient to securities regulators as that consideration influences their judgements of the suitability of cryptocurrency assets and markets to form the basis of regulated products.

Tainted trading places

The largely unregulated standing of cryptocurrency trading venues and the reality that some venues apply prescribed capital markets standards whilst others do not, can preclude institutional participation. Chief among these standards from a regulatory perspective is oversight that is adequate enough to prevent potential market manipulation. Additionally, the concern is whether or not cryptocurrency exchanges have mechanisms in place to report and remediate manipulation as appropriate. Furthermore, there is related uncertainty over the extent of KYC/AML compliance at such exchanges. In effect, queries over whether such issues are applicable to cryptocurrency trading venues or not present more frictions for professional counterparties of all kinds. By extension, regardless of the quality of market liquidity at such venues, price data derived from non-compliant exchanges must be deemed tainted in the strictest sense, thereby casting doubt on any instruments or derivatives served by that data.

The idiosyncrasies of the Bitcoin market can thereby imply risks in addition to those that are not germane to participation in the crypto asset class. Even so, there is one particular hazard that can arise when institutions attempt to execute significant investments into any asset through open-market purchases to which Bitcoin evinces enhanced susceptibility, as outlined below.

Letting slip

The typical wariness institutions must exercise when executing significant orders in the market also applies to their trading of Bitcoin. The risk that a large order might alert other participants and thereby trigger a chain reaction that ultimately drives the price of the asset higher before the order can be completed applies to institutional trading in general. This is one cause of what is known in market trading parlance as 'slippage'. Given concerns over the integrity of Bitcoin liquidity discussed earlier, one implication is that the subsection of Bitcoin trading that qualifies as a genuine market is therefore smaller than is generally recognized. This suggests a higher risk that a deficit of liquidity at a given price point could destabilize the bid/ask spread; an occurrence that could reveal to external participants that a significant order is being worked. A contained Bitcoin market thereby poses enhanced risk that larger-than-average orders can be readily surveilled.

The broad purpose of the second half of this paper is to propose a framework by which regulated financial product providers can overcome the concerns about Bitcoin market integrity and exposure to the risks inherent to participation in that market as outlined above. More specifically, this paper will first detail the CME CF Bitcoin Reference Rate (BRR), a transparent, regulated Bitcoin benchmark. Next, evidence of the representativeness of the BRR of the verifiable Bitcoin market will be presented. Subsequently, measures pursued to ensure that the BRR is possessed of price integrity and, in particular, is free of manipulation of any kind, will be described. Finally, the replicability of the BRR's benchmark prices will be demonstrated in terms of the achievability of BRR prices when purchasing Bitcoin 'at scale' at any time of the trading day.

Representation

The CME CF Bitcoin Reference Rate

The CME CF Bitcoin Reference Rate (BRR) is a once-a-day benchmark index price for Bitcoin denominated in US Dollars. Input data is obtained from major cryptocurrency exchanges that conform to the CME CF Constituent Exchange Criteria. Calculated every day since its launch on 14th November 2016, the BRR is a highly trusted source of Bitcoin pricing and the pre-eminent price benchmark for Bitcoin risk settlement being a Registered Benchmark under the European Union's Benchmark Regulation regime. The BRR is the settlement index for futures contracts listed by CME Group and the Crypto Facilities MTF, Kraken Futures, as well as being the pricing source for NAV/iNAV determinations for investment products offered by major financial institutions including WisdomTree Europe.

Calculation Methodology

The BRR calculation methodology aggregates transactions of Bitcoins in U.S. dollars that are only conducted on the most liquid markets for which data is publicly available and operated by exchanges that meet the CME CF Constituent Exchange Criteria.

The list of Constituent Exchanges and information about changes to its composition are available at the following URL:

www.cfbenchmarkscom/docs/CME+CF+Constituent+Exchanges+Criteria.pdf

The full methodology is also available:

www.cfbenchmarks.com/docsCME+CF+Constituent+Exchanges+Criteria.pdf

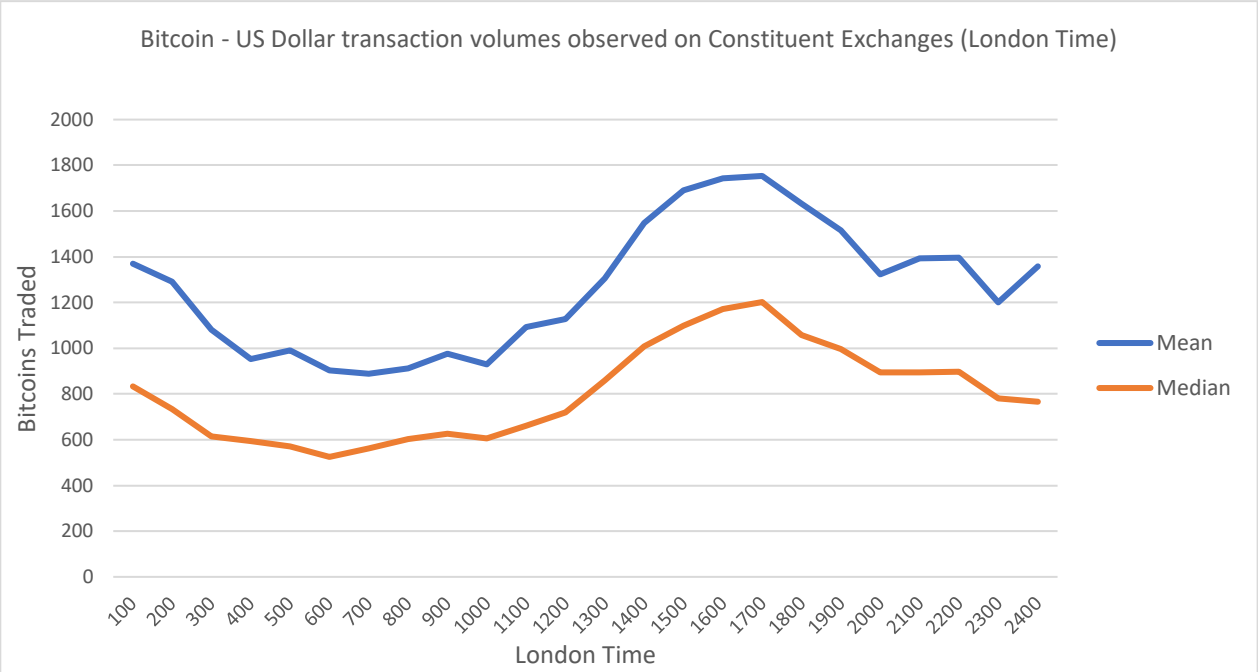
The methodology can be summarised thus:

- Transactions conducted on Constituent Exchanges are observed during a one-hour window from 15.00 to 16.00 London Time
- The one-hour window is divided into 12 partitions of equal length (five minutes each)
- For each partition, a volume-weighted median (VWM) is calculated
- The index value is expressed as the arithmetic mean of the 12 VWMs calculated in the previous step

Suitability of 16.00 London Time as CME CF Bitcoin Reference Rate calculation time

The graph in Figure 1 illustrates the rationale of calculating the CME CF Bitcoin Reference (BRR) rate at 16.00 London Time. For the data set illustrated, Bitcoin-U.S. dollar transaction volumes on Constituent Exchanges were measured over an observation period of January 1st, 2019 to November 22nd, 2020.

Figure 1



Unlike most traditional assets, Bitcoin can be traded at any time of the day. But the trading data graphed above clearly indicate that Bitcoin market participation volume adheres quite closely to times when traditional markets tend to experience their own high trading volumes.

The most liquid time of the day for Constituent Exchange volumes, together with the typical 4pm traditional market closing time of several large European cities, pointed to an optimal time of 15.00 to 16.00 London Time to measure transactions for a daily benchmark price of Bitcoin.

Benchmark validity and volume sufficiency

For the BRR to be deemed a valid benchmark, the volume observed in its calculation must be sufficient for that purpose. From a practical perspective, the BRR needs to have sufficient volume in its calculation in order to be replicable by institutional market participants and institutional product and service providers. These prerequisites are addressed by data presented in Tables 1 and 2 below.

The tables describe the volume of transactions per day during the observation period in both Bitcoin and USD terms. The parameters provided are range, median and average transactions per day. It is important to note that the CME CF BRR is calculated every day of the year, including public holidays, due to the Bitcoin market trading 24 hours a day, 365 days a year. The data summaries below include all CME CF BRR calculations from throughout the observation period.

Attention is drawn to the times when Gemini was a CME CF Benchmarks Bitcoin Reference Rate Constituent Exchange and when it was not. Gemini became a Constituent on August 31st, 2019.

Table 1

Metrics		Total Trades Observed	Total Volume Observed (Bitcoins)	Total Volume Observed ($)
MAX	For the entire period - including when Gemini was NOT a Constituent Exchange	47,959	17,725	177,550,546
MIN		1,686	140	823,354
MEDIAN		5,037	1,169	9,812,719
MEAN		6,656	1,763	15,575,064

As Gemini has only been a Constituent Exchange since August 31st, 2019, for the sake of transparency, the portion of the January 1st, 2019 to November 20th, 2020 observation period that includes data from Gemini Exchange, is presented separately in Table 2.

Table 2

Metrics		Total Trades Observed	Total Volume Observed (Bitcoins)	Total Volume Observed ($)
MAX	For the period since August 31st, 2019 - when Gemini was included as a Constituent Exchange	47,959	17,725	177,550,546
MIN		1,812	140	1,322,185
MEDIAN		5,732	1,210	11,153,237
MEAN		7,447	1,848	17,440,453

Comparing the observations filtered by inclusion of Gemini with the overall data set, it is clear that any differences are negligible.

Regarding the complete set of observations, note that on average 1,848 Bitcoins were traded over an average of 7,447 transactions, worth in excess of an average $17 million (at contemporaneous prices) during the one-hour measurement window of 15.00 to 16.00 London Time. This qualifies as significant volume. Furthermore, given that the measurement window captured on average in excess of $17 million worth of Bitcoins per day traded at BRR Constituent Exchanges during the observation period, there is evidence that the CME CF Bitcoin Reference Rate is replicable at institutional scale without undue slippage, a notion that will be explored later in this paper.

Integrity

This section will address the question of whether the CME CF Bitcoin Reference Rate is possessed of integrity in the specific sense of securities regulation described earlier in this paper. The practical imperative is that a benchmark requires integrity because it will be used for asset valuation and settling financial risk. Specifically, the benchmark must be free of manipulation. Furthermore, it must be administered and calculated in a manner that deters and impedes manipulation.

The methodological design underlying the CME CF Bitcoin Reference Rate and its system of administration incorporate measures that promote integrity as outlined in the sub-sections below.

Data integrity by data selection

CF Benchmarks exclusively sources input data from Constituent Exchanges that meet published criteria as set out in its Constituent Exchanges Criteria. The criteria are available at this link: https://docs-cfbenchmarks.s3.amazonaws.com/CF+Constituent+Exchanges+Criteria.pdf

Particular attention is drawn to the following statement from the Constituent Exchanges Criteria document (part 3 of Section 5, page 4: 'Eligibility Criteria'):

"*The venue has published policies to ensure fair and transparent market conditions at all times and has processes in place to identify and impede illegal, unfair or manipulative trading practices.*"

CF Benchmarks ascertains the presence of fair and transparent market conditions and processes to identify and impede illegal, unfair or manipulative practices by conducting a thorough review of any exchange under consideration for inclusion as a Constituent Exchange. The arrangements of all Constituent Exchanges are reviewed annually to ensure that they continue to meet all criteria. This due diligence is documented, and the information is distributed to CF Benchmarks' oversight committees and provided to its regulator, the UK Financial Conduct Authority (FCA).

Manipulation resistance by design

Resistance to manipulation is a priority aim of the design methodology underlying the CME CF Bitcoin Reference Rate. The methodology takes an observation period and divides it into equal partitions of time. The volume-weighted median of all transactions within each partition is then calculated. The benchmark index value is determined from the arithmetic mean of the volume-weighted medians, equally weighted. The benefits of this process with respect to achieving manipulation resistance are outlined below.

- **Use of partitions**

Individual trades of large size have limited effect on the Index level as they only influence the level of the volume-weighted median for that specific partition

A cluster of trades in a short period of time will also only influence the volume-weighted median of the partition or partitions they were conducted in

- **Use of volume-weighted medians**

Use of volume-weighted medians as opposed to volume-weighted means ensures that transactions conducted at outlying prices do not have an undue effect on the value of a specific partition

- **Equal weighting of partitions**

By not volume weighting partitions, trades of large size or clusters of trades over a short period of time will not have an undue influence on the index level

- **Equal weighting of constituent exchanges**

CF Benchmarks applies equal weight to transactions observed from constituent platforms. With no pre-set weights, potential manipulators cannot target one platform for the conduct of manipulative trades

- **Use of arithmetic mean of partitions**

Using the arithmetic mean of partitions of equal weight further denudes the effect of trades of large size at prices that deviate from the prevailing price having undue influence on the benchmark level

For a detailed analysis of measures instigated to ensure the Reference Rate's manipulation resistance, please see "*Analysis of the CME CF Bitcoin Reference Rate and CME CF Bitcoin Real Time Index*"[9]

Manipulation resistance by exclusion of input data

A specific procedure for dealing with potentially erroneous data is incorporated into the methodology of the CME CF BRR. Although volume-weighted medians of transaction prices from individual data sources are not a part of the benchmark determination process, they are calculated as a means of quality control and manipulation resistance.

In the event of an instance of index calculation in which a Constituent Exchange's volume-weighted median transaction price exhibits an absolute percentage deviation from the volume-weighted median price of other Constituent Exchange transactions greater than the potentially erroneous data parameter (10%), then transactions from that Constituent Exchange are deemed potentially erroneous and excluded from the index calculation. All instances of data excluded from a calculation trigger a Benchmark Surveillance Alert that is investigated.

Since January 1st, 2019 the potentially erroneous data parameter of the methodology for the CME CF Bitcoin Reference Rate has never been triggered. Analysis of the volume-weighted median per exchange during the observation period produced the results in Table 3. The results illustrate that during the observation period, no Constituent Exchange's input data needed to be excluded due to exhibiting potential manipulation.

Table 3

Absolute Volume Weighted Median Deviation Per Exchange (USD)				
Bitstamp	Coinbase	Gemini	itbit	Kraken
0.4978%	0.5639%	0.7164%	1.9613%	1.1893%
0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
0.0265%	0.0205%	0.0109%	0.0429%	0.0297%
0.0543%	0.0339%	0.0537%	0.0837%	0.0470%

Benchmark Surveillance

Although a series of measures have been undertaken to mitigate the risk of benchmark manipulation, CF Benchmarks remains vigilant against attempted benchmark manipulation and monitors input data continuously. To that end, CF Benchmarks has implemented a benchmark surveillance programme for the investigation of alerts. Instances of suspected benchmark manipulation are escalated through appropriate regulatory channels in accordance with CF Benchmarks' obligations under European Union Benchmark Regulation (EU BMR). Regarding benchmark manipulation, Article 14 of the EU BMR, Reporting of Infringements, states:

1. An administrator shall 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.

2. An administrator shall 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 a benchmark, any conduct has taken place that may involve manipulation or attempted manipulation of the benchmark, under Regulation (EU) No 596/2014, including collusion to do so."

As a Regulated Benchmark Administrator, CF Benchmarks is subject to supervision by the UK FCA. This supervision ensures CF Benchmarks is in compliance with all aspects of EU BMR requirements.

Furthermore, CF Benchmarks' Control Procedures with respect to compliance with the EU BMR have been audited by 'Big Four' accountancy firm Deloitte. The Independent Assurance Report on Control Procedures Noted by CF Benchmarks Regarding Compliance with EU Benchmark Regulation as of 31 July 2020 is available at the following link:

www.cfbenchmarks.com/docs/Deloitte_CF+Benchmarks+SOC1+Audit+Report.pdf

This further verification of CF Benchmarks' compliance with EU BMR places the CME CF Bitcoin Reference Rate on the same level of scrutiny applied to widely used traditional financial benchmarks like ICESWAP, SONIA and ICE LIBOR.

Assessing CME CF BRR values and input data for signs of manipulation

Whilst the CME CF BRR was designed and is administered to the highest standards, including efforts to uphold provisions of EU BMR, the proof of the pudding is in the eating and further analysis of the data is required.

Were there to be a lack of integrity in the input data that could in turn affect the integrity of the benchmark, one would expect to see one of a number of phenomena reflected in the input data provided by Constituent Exchanges. One potential example would be significant price dislocations between Constituent Exchanges.

What happens when an exchange is removed from the calculation?

- The CME CF Bitcoin Reference Rate methodology aggregates trades observed on Constituent Exchanges during a one-hour observation period between 15.00 and 16.00 London Time
- One means of detecting dislocations in price between different Constituent Exchanges is to recompute the CME CF BRR calculation without the participation of one of the exchanges and to repeat this process for each of the exchanges in turn. This process gives a strong indication of how closely the exchanges track each other in terms of price per unit of volume transacted
- In the period analysed – January 1st, 2019 to November 20th – absolute impacts exhibited when each exchange was removed from the index calculation versus index values are summarised in Table 4 below

Table 4

Metrics	Absolute Difference W/O Exchange				
	Bitstamp	Coinbase	Gemini	ItBit	Kraken
MAX	4.83	10.76	2.46	0.88	4.29
MIN	0.01	0.02	0.00	0.00	0.00
MEDIAN	0.36	0.74	0.14	0.08	0.35
MEAN	0.56	0.99	0.23	0.12	0.49

- As well as the absolute impact of removing individual exchanges from the index calculation, the proportionate impact on the CME CF BRR from the same exercise in the same period can also be shown, as in Table 5 below.

Table 5

Metrics	% Difference W/O Exchange				
	Bitstamp	Coinbase	Gemini	ItBit	Kraken
MAX	0.0470%	0.0987%	0.0305%	0.0133%	0.0440%
MIN	0.0002%	0.0006%	0.0000%	0.0000%	0.0000%
MEDIAN	0.0046%	0.0092%	0.0005%	0.0009%	0.0042%
MEAN	0.0067%	0.0117%	0.0016%	0.0015%	0.0060%

It is clear that Constituent Exchanges exhibit very similar price action to each other when analysed through the lens of the CME CF BRR methodology. This in turn demonstrates that the CME CF BRR has not been subject to manipulation through manipulation of prices on individual Constituent Exchanges.

Even so, examination of relationships between Constituent Exchange price characteristics can be taken a step further. The pair-wise correlation between each Constituent Exchange can also be scrutinised. This may reveal indications of potential manipulation within CME CF BRR Constituent Exchange prices that may be occurring on a subtler or smaller scale than would be captured by the potentially erroneous data parameter and by which the CME CF BRR index value itself is not impacted due to its aggregating heuristic.

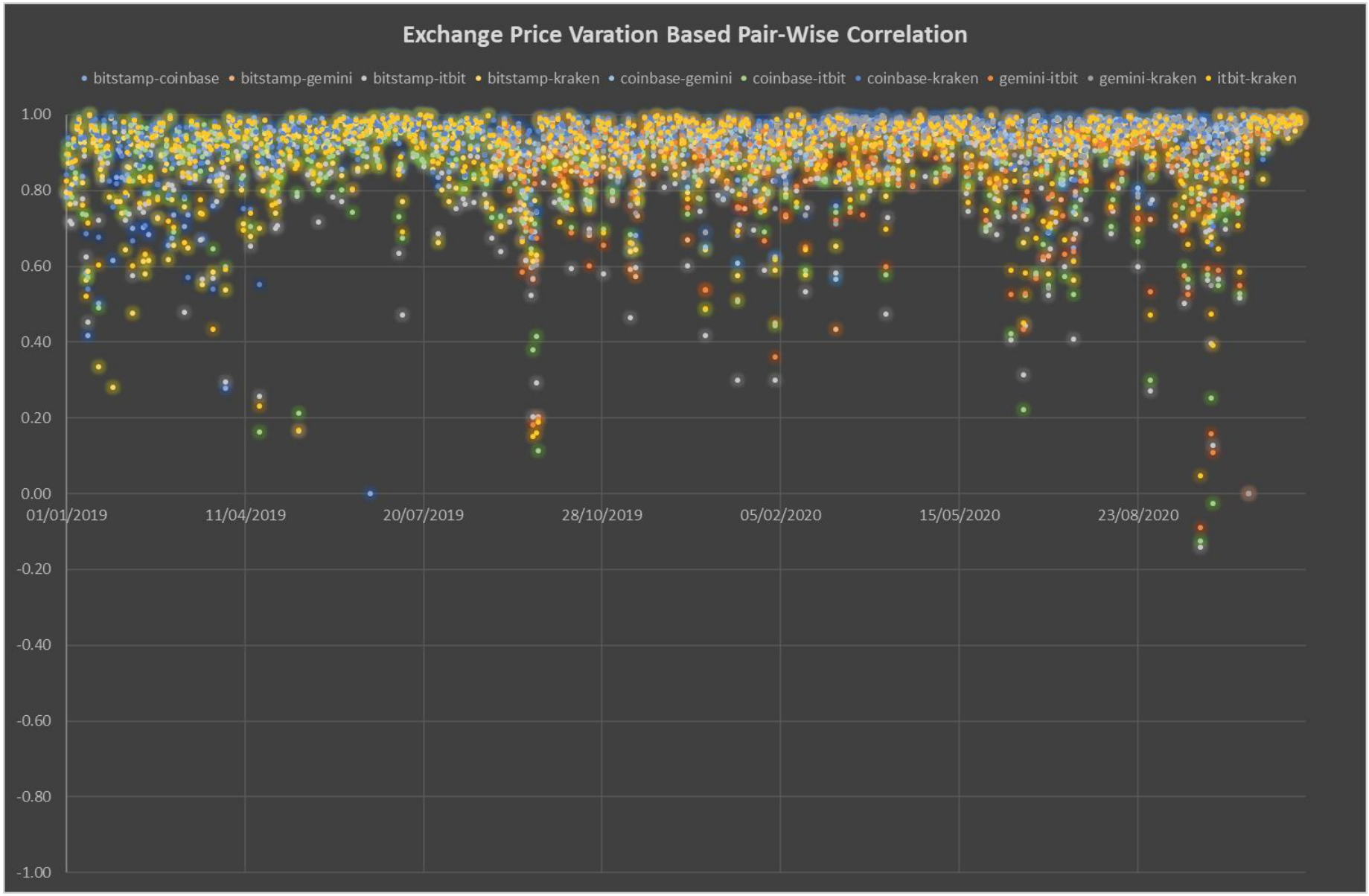
How well corelated are Constituent Exchange prices?

An analysis was undertaken of the pair-wise correlation of prices from Constituent Exchanges on a per-minute basis (the price difference between transactions for each minute at each exchange) during the observation period. The results of this analysis are in shown in Table 6.

Table 6

Pair-Wise Correlation of Constituent Exchanges to the CME CF BRR			
Constituent Exchange Pair	**Mean Correlation %**	**Median Correlation %**	**Standard Deviation**
Bitstamp - Coinbase	93.98%	96.56%	8.30%
Bitstamp – Gemini	91.87%	94.97%	9.61%
Bitstamp – ItBit	86.13%	89.93%	14.20%
Bitstamp – Kraken	91.40%	94.61%	9.38%
Coinbase – Gemini	94.74%	96.78%	7.41%
Coinbase – ItBit	88.76%	92.57%	12.99%
Coinbase – Kraken	94.48%	96.48%	6.46%
Gemini – ItBit	88.52%	92.64%	13.75%
Gemini - Kraken	93.89%	96.14%	8.03%
ItBit - Kraken	89.92%	93.56%	11.78%

To illustrate the data analysed in Table 6 more perspicaciously, the graphic in Figure 2 displays the full data set. The clustering towards correlation coefficients of 1.00 and less than 1% of days when any exchange had a correlation with another exchange below 0.5 demonstrate strong price correlation between the Constituent Exchanges.


Exchange Price Varation Based Pair-Wise Correlation
bitstamp-coinbase
bitstamp-gemini
bitstamp-itbit
bitstamp-kraken
coinbase-gemini
coinbase-itbit
coinbase-kraken
gemini-itbit
gemini-kraken
itbit-kraken
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
01/01/2019
11/04/2019
20/07/2019
28/10/2019
05/02/2020
15/05/2020
23/08/2020
Figure 2

Replicability and Implementation

The final characteristic of the CME CF Bitcoin Reference Rate that this paper will examine with respect to its merits as a benchmark price is its replicability. In other words, that the CME CF BRR benchmark price can be transacted in practice on any given day.

How to buy 50 Bitcoins at Benchmark prices, discreetly

To begin demonstrating the replicability—or to use another term, the achievability—of the strategy presented in this paper for purchasing Bitcoin 'at scale', observations taken whilst modelling the purchase of a notional large amount of Bitcoin are presented below. The purchase of 50 Bitcoins was simulated on each day between 1st January 2019 and 20th November 2020, an observation period of 686 days. It was decided that the purchase of 50 Bitcoins was at an adequate scale to represent a large Bitcoin trade of the kind that institutional traders might need to undertake for a major client, or that an issuer of a financial product (such as an ETF or a derivative) would be required to execute, in order to facilitate trading of that product. A simple replication simulation was thereby conducted to exemplify the extent of slippage that implementation of the CME CF BRR would probably encounter.

It is worth noting that in the 'real world', institutions deploy algorithmic systems to execute large-scale asset purchases. It is probable that conducting the exercise presented here by means of algorithmic systems would have produced outcomes even more favourable than those described in this paper. For research purposes, a simplified simulation methodology was favoured.

Simulation Methodology

- Trades are executed on *n* (5) Constituent Exchanges, during a 3,600-second calculation window
- One trade is executed every second and the price achieved is assumed to be the last execution price observed in that second. Its associated volume is assumed to be the volume executed during that second
- If no trade is completed in any single-second period, then the price achieved is assumed to be the price achieved in the previous second, but the associated volume from the previous second is not added to the volume executed in the latest second

The results of this exercise are displayed in Figure 3. The data are summarised in Table 7.

Figure 3

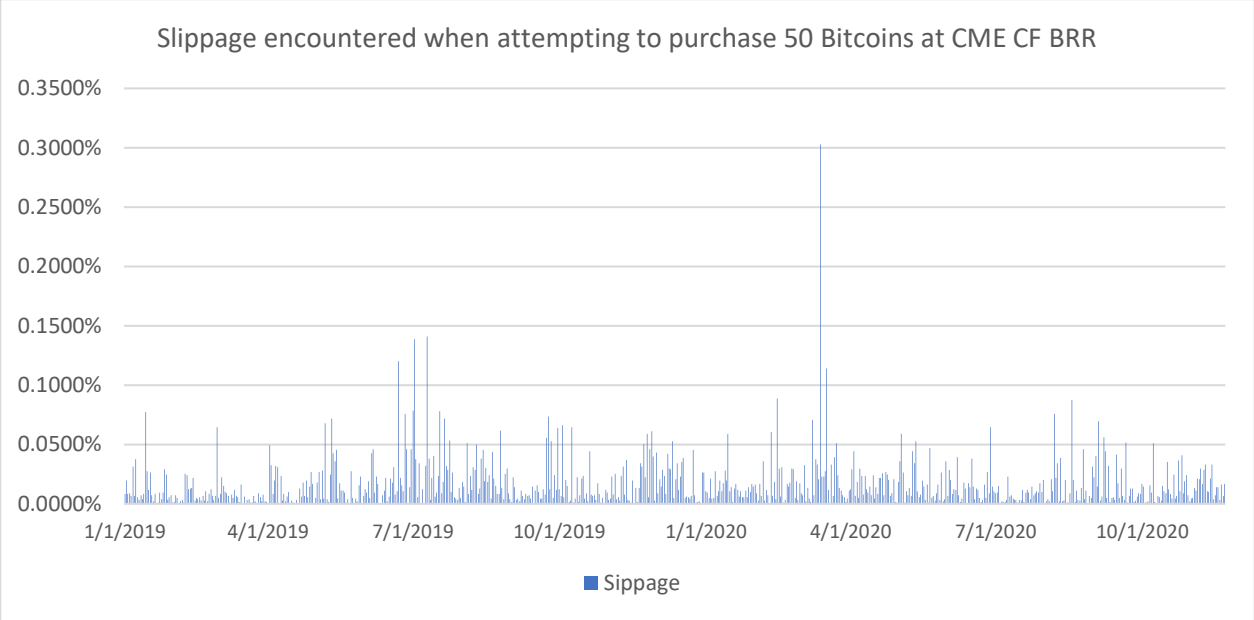


Table 7

Slippage %	
MAX	0.3029%
MIN	0.0000%
MEDIAN	0.0099%
MEAN	0.0167%

The need to restrict information leakage

Information leakage can often exacerbate slippage during 'real world' transactions. In order to measure the level of slippage that would probably occur when transacting 50 Bitcoins as per our simulation, an estimate of the market impact of a trade of 50 Bitcoins within a 3,600-second calculation window of our simulation is required.

Table 8 below contains maximum, minimum, median, arithmetical mean and spread (standard deviation) represented by the purchase of 50 Bitcoins during the observation period as percentages of total CME CF Bitcoin Reference Rate (BRR) volume.

Table 8

% of BRR Volume Represented by 50 Bitcoins		
Metric	**All Days**	**Weekdays Only**
Maximum	87.02%	52.77%
Minimum	1.95%	1.95%
Median	12.30%	10.66%
Mean	15.39%	11.54%
Standard Deviation	11.15%	5.85%

Conclusion

Considering the profile of BRR trading volumes suggested by Figure 1, it is clear that the liquidity of the Bitcoin market peaks at times that cohere with traditional market trading times. It is therefore reasonable to suggest that weekdays are more pertinent for the exercise of purchasing Bitcoin 'at scale', as working days are the likeliest times that institutional participants would seek to do so. On that basis, the salient data in the exercise presented here are the maximum and average weekday BRR Constituent Exchange volume that would be represented by the purchase of 50 Bitcoins during the observation period, together with the standard deviation of the percentage of volumes represented over the observation period.

The maximum volume of the BRR that would have occurred was 52.77%. The average volume over the observation period was 11.54%. The spread between all volumes observed was 5.85%. These figures indicate reasonable ease to achieve (or replicate) the BRR price on any given day during the observation period.

Table 9 presents the rate at which some discrete percentages of BRR volume occurred during the observation period. As stated, and explained above, weekday volumes are the most salient. On that basis, a 0.14% rate of occurrence of 50% of the volume traded on CME CF Bitcoin Reference Rate Constituent Exchanges when purchasing 50 Bitcoins demonstrates a low proportion of days when that purchase represented a relatively high market volume. In turn, it is indicated that purchasing 50 Bitcoins when it was a low proportionate volume of a verified market occurred frequently, whilst it was only possible to make such purchases when they were a relatively large proportion of that market very infrequently.

Combined, the readings from Table 8 and Table 9 support the replicability of purchasing 50 Bitcoin (or notionally, purchasing Bitcoin 'at scale') at the same price as the CME CF Bitcoin Reference Rate. Furthermore, the readings support the position that purchases of the stated amount of Bitcoin by deployment of the strategy outlined in this paper will reduce to a minimum the kind of slippage that can be caused by third-party participants being alerted to such trades. The analysis presented here assumes that trading is confined to the Constituent Exchanges and is not executed on other venues such as those in the OTC market. If the OTC market were to be

taken into account, it is likely that the measured price impact of attempts to replicate the BRR would be lower than that described in this paper.

Table 9

Days where 50 Bitcoins exceeded 10%, 25% and 50% of BRR Volumes		
Percentage	**All Days**	**Weekdays Only**
10%	64.36%	39.25%
25%	11.98%	1.73%
50%	2.17%	0.14%

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