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DIGITAL ASSETS UNLEASHED

CME CF Bitcoin Reference Rate (BRR)

Methodology Guide

Version: 2

Version Date: 06 March 2017

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1 Version History

Version	Version Date	Changes to Previous
1	10 November 2016	N/A
2	06 March 2017	Added description of treatment of erroneous data.

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2 Definitions

API: Application programming interface.

Calculation Day: Any day for which the BRR is published.

Constituent Exchange: A bitcoin trading venue elected by the Bitcoin Pricing Products Oversight Committee to serve as pricing source for the calculation of the BRR.[1]

Relevant Transaction: Any bitcoin versus U.S. Dollar spot trade that occurs during the TWAP Period on a Constituent Exchange and that is reported through its API to the Calculation Agent.

Retrieval Time: 4:01 p.m. London time on a given Calculation Day, as given by the server clock of the Calculation Agent.

TWAP Period: The 60 minute period up to and including 4:00 p.m. London time on a given Calculation Day.

[1] Constituent Exchanges are published on the Administrator's website.

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3 Summary Description

The CME CF Bitcoin Reference Rate ("BRR") is a daily reference rate of the U.S. Dollar price of one bitcoin as of 4:00 p.m. London time. It is representative of the bitcoin trading activity on Constituent Exchanges and is geared towards resilience and replicability.

Name	CME CF Bitcoin Reference Rate
CME Ticker Symbol	BRR
Administrator	Crypto Facilities Ltd
Calculation Agent	Crypto Facilities Ltd
Description	U.S. Dollar price of one bitcoin as of 4:00 p.m. London time
Calculation Methodology	Aggregation of trade executions occurring on Constituent Exchanges between 3:00 p.m. and 4:00 p.m. London time
Dissemination Time	Once per day, every day of the year including weekends and holidays, between 4:00 p.m. and 4:30 p.m. London time
Dissemination Precision	0.01 U.S. Dollars

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4 Methodology and Rules

4.1 Methodology

4.1.1 Qualitative Description

The BRR is calculated based on the Relevant Transactions of all Constituent Exchanges. Calculation steps for the BRR on any given Calculation Day are as follows:

1. All Relevant Transactions are added to a joint list, recording the trade price and size for each transaction.
2. The list is partitioned into 12 equally-sized time intervals of 5 minutes each.
3. For each partition separately, the volume-weighted median trade price is calculated from the trade prices and sizes of all Relevant Transactions, i.e. across all Constituent Exchanges. A volume-weighted median differs from a standard median in that a weighting factor, in this case trade size, is factored into the calculation.
4. The BRR is then given by the equally-weighted average of the volume-weighted medians of all partitions.

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4.1.2 Mathematical Representation

The following table shows the symbols used in the mathematical representation of the BRR.

Symbol	Name	Description	Type
T	Effective time	The time as of which the BRR is calculated	Parameter, set to 4:00 p.m. London time
τ	TWAP period length	The length of the time period prior to the effective time during which transaction data is collected	Parameter, set to 60 minutes
$\hat{\tau}$ with $\hat{\tau} \leq \tau$ and $\hat{\tau} \mid \tau$	Partition length	The length of the time periods into which the TWAP period length is partitioned	Parameter, set to 5 minutes
X	TWAP period trades	The time-ordered collection of price/size trade pairs observed on all Constituent Exchanges between $T - \tau$ and T	Input
x_i with $x_i = (p_i, s_i)$ and $x_i \in X$	TWAP period trade	The ith price/size trade pair	Input
p_i	TWAP period trade price	The price of the ith price/size trade pair	Input
s_i	TWAP period trade size	The size of the ith price/size trade pair	Input
K	Number of partitions	The number of partitions, given by $K = \tau/\hat{\tau} = 12$	Output
k with $k \in (1, \dots, K)$	Partition	The kth partition	Output
WM_k	Weighted median	The weighted median trade price for partition k	Output
BRR_T	BRR	The BRR at time T	Output

For each of the $K = \tau / \hat{\tau} = 12$ partitions k, the volume-weighted median trade prices WM_k across all Relevant Transactions is calculated as:

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$$WM_k = p_j \; where \; x_j \; satisfies \sum_{i=1}^{j-1} s_i < \frac{\sum_{i=1}^{I_k} s_i}{2} \; and \sum_{i=j+1}^{I_k} s_i \leq \frac{\sum_{i=1}^{I_k} s_i}{2}$$

$$If \sum_{i=j+1}^{I_k} s_i = \frac{\sum_{i=1}^{I_k} s_i}{2}, then \; WM_k = \frac{p_j + p_{j+1}}{2}$$

Eq. 1

Where i is the ith of a total of I_k price/size trade pairs observed in partition k.

The BRR as of the effective time T, $\mathrm{BRR_T}$, is then given by:

$$BRR_T = \frac{\sum_{k=1}^{K} WM_k}{K}$$

Eq. 2

4.2 A Note on Properties

The calculation methodology immunizes the BRR to a high degree against price anomalies, while being replicable though spot trading on Constituent Exchanges. This is achieved through the following design choices:

Partitions

The BRR is calculated as the equally-weighted average of the intermediate calculation steps for the 12 partitions. A single large trade or cluster of trades occurring in any one partition will therefore only have a limited effect on the BRR.

Weighting of Partitions

Partitions are equally-weighted (as opposed to volume-weighted) to facilitate BRR replication through trading on Constituent Exchanges. A trader aiming to transact Y bitcoins at the BRR can do so with little tracking error by transacting $Y/12$ bitcoins during each partition.

Medians

Bitcoin spot prices have historically varied considerably across trading venues, in particular in times of high volatility. The use of medians to calculate the weighted median trade price for each partition (as opposed to averages) greatly reduces the BRR's susceptibility to price extremes on one or more Constituent Exchanges.

Volume-Weighting of Medians

Bitcoin trading is driven to some extent by automated algorithms that may execute a high number of small trades. The use of volume-weighted medians to calculate the weighted median trade price for each partition (as opposed to simple medians) assures that the BRR appropriately reflects large trades and that whether an order is executed in parts or in full has no effect on calculation results.

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5 Contingency Calculation Rules

5.1 Delayed Data and Missing Data

Delayed data and missing data is treated according to the following rules:

1. Any Relevant Transaction for a given Calculation Day that for any reason cannot be retrieved by the Calculation Agent from a Constituent Exchange's API by the Retrieval Time is disregarded in the calculation of the BRR for that Calculation Day.

2. If no Relevant Transaction occurs on a Constituent Exchange on a given Calculation Day or one or more Relevant Transactions occur but for any reason cannot be retrieved by the Calculation Agent, the Constituent Exchange is disregarded in the calculation of the BRR for that Calculation Day.

3. If, for any of the 12 partitions of the TWAP Period, no Relevant Transaction occurs on any Constituent Exchange or one or more Relevant Transactions occur but for any reason cannot be retrieved by the Calculation Agent, the partition remains empty and will be disregarded in the calculation of the BRR for that Calculation Day. The denominator in Eq. 2 will then be decremented by the number of empty partitions.

4. If no Relevant Transaction occurs on any Constituent Exchange on a given Calculation Day or one or more Relevant Transactions occur but for any reason no Relevant Transaction can be retrieved from any Constituent Exchange by the Calculation Agent, a BRR calculation failure occurs for that Calculation Day (see Section 5.4).

5.2 Erroneous Data

All Relevant Transactions retrieved by the Calculation Agent for a given Calculation Day are subject to an automated screening for erroneous data according to the following rules:

1. If a Relevant Transaction shows a non-numeric or non-positive trade price or trade size, it is flagged as erroneous.

2. If a Relevant Transaction is reported in a format that deviates from the expected format such that it cannot be parsed, it is flagged as erroneous.

Relevant Transactions flagged as erroneous for a given Calculation Day are disregarded in the calculation of the BRR for that Calculation Day.

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If all Relevant Transactions of all Constituent Exchanges are flagged as erroneous for a given Calculation Day, a BRR calculation failure occurs for that Calculation Day (see Section 5.4).

5.3 Potentially Erroneous Data

All Relevant Transactions retrieved by the Calculation Agent for a given Calculation Day are subject to an automated screening for potentially erroneous data according to the following rules:

1. For each Constituent Exchange individually, the volume-weighted median trade price across all Relevant Transactions of that Constituent Exchange is calculated.

2. For each Constituent Exchange, the absolute percentage deviation of the volume-weighted median trade price, as calculated in the previous step, from the median of the volume-weighted median trade prices of all Constituent Exchanges is calculated.

3. If for any Constituent Exchange the absolute percentage deviation, as calculated in the previous step, exceeds 25%, all Relevant Transactions of that Constituent Exchange are flagged as potentially erroneous.

Relevant Transactions flagged as potentially erroneous for a given Calculation Day are disregarded in the calculation of the BRR for that Calculation Day. The occurrence of any such flag is reported to the Oversight Committee.

If all Relevant Transactions of all Constituent Exchanges are flagged as potentially erroneous for a given Calculation Day, a BRR calculation failure occurs for that Calculation Day (see Section 5.4).

5.4 BRR Calculation Failure

If the BRR cannot be calculated for a given Calculation Day, for instance because

- no Relevant Transaction occurs on any Constituent Exchange on that Calculation Day, or

- one or more Relevant Transactions occur but for any reason cannot be retrieved by the Calculation Agent, or

- all Relevant Transactions retrieved by the Calculation Agent are flagged as erroneous or potentially erroneous (see Section 5.2); or

- any other reason or circumstance that prevents the orderly calculation of the BRR,

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Then the BRR for that Calculation Day is given by the BRR published on the previous Calculation Day. The occurrence of any BRR calculation failure is reported to the Oversight Committee.

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