cfbenchmarks

CME CF Cryptocurrency Real Time Indices

Methodology Guide

Version: 9

Version Date: 20th May 2020

Table of Contents

1 Version History

Version	Version Date	Changes to Previous
1	10th November 2016	N/A
2	6th March 2017	Added description of treatment of erroneous data. Changed calculation methodology from static to dynamic depth. **Effective: 18 March 2017, 16:30:00 London time.**
3	14th May 2018	Clarified use of spacing parameter. Generalised methodology to support multiple real time indices.
3.1	17th October 2018	Changed ETH_RTI_USD ticker symbol to ETHUSD_RTI. Specified usage of spacing parameter for utilized depth fallback.
4	3rd January 2019	Parameterisation of Rule 5.3 for different Real Time Indices
4.1	14th March 2019	Change of order size cap for ETHUSD_RTI
4.2	16 July 2019	Remove constituent list (documented separately)
5	16th July 2019	Rebrand for CF Benchmarks
6	11th September 2019	Update legal text with BMR registration
7	2nd December 2019	Change order size cap from static to dynamic
8	10th February 2020	Change potentially erroneous data parameter
9	20th May 2020	Clarify use of orderbook price levels

2 Overview

Responding to the need for enhanced pricing information on the rapidly growing cryptocurrency asset class, CME Group and CF Benchmarks have developed standardized cryptocurrency reference rates and real time indices.

Each reference rate and real time index represent transparent indicators with independent governance and oversight and build on our experience to accelerate the professionalization of cryptocurrency trading.

This document covers the CME CF Cryptocurrency Real Time Indices. A summary of specifications is provided in Section 7.

3 Definitions

API: Application programming interface.

Calculation Time: Any time as of which a CME CF Cryptocurrency Real Time Index is published.

Constituent Exchange: A cryptocurrency trading venue approved by the CME CF Cryptocurrency Indices Oversight Committee to serve as pricing source for the calculation of a CME CF Cryptocurrency Real Time Index.[1]

Relevant Pair: The cryptocurrency versus legal tender pair referenced by a CME CF Cryptocurrency Real Time Index, as defined in Section 6.

Relevant Order Book: The universe of the currently unmatched limit orders to buy or sell a unit of cryptocurrency versus legal tender on a Constituent Exchange in the Relevant Pair, aggregated by price, that is reported through its API to the Calculation Agent.

Retrieval Time: The time, as given by the server clock of the Calculation Agent, as of which the Relevant Order Book of a Constituent Exchange is requested by the Calculation Agent through the API of the Constituent Exchange.

---

[1] Constituent Exchanges are published on the Administrator's website https://www.cfbenchmarks.com.

4   Methodology and Rules

4.1   Methodology

4.1.1 Qualitative Description

CME CF Cryptocurrency Real Time Indices are calculated in real time based on the Relevant Order Books of all Constituent Exchanges. An order book is a list of buy and sell orders with associated limit prices and sizes that have not yet been matched due to lack of supply or demand to trade at that price. It therefore informs about the price at which a trader can buy or sell a certain amount of cryptocurrency as of now. In line with existing cryptocurrency market practises, the "order size" refers to the aggregated sizes of all orders at the same price, the price/sizes tuples of buy orders ("bids") descend by price and the price/size tuples of sell orders ("asks") ascend by price.

Calculation steps are as follows:

1. At the Effective Time, the Relevant Order Book of each Constituent Exchange is added to a joint list of order books.

2. The joint list of order books is aggregated into one consolidated order book. If the size at the bid or ask order price level exceeds the order size cap, it enters the consolidated order book with a size equal to the order size cap.

3. The cumulative bid price-volume curve, ask price-volume curve, mid price-volume curve and mid spread-volume curve are calculated from the consolidated order book at a granularity equal to the spacing parameter.

    a. The bid price-volume curve maps transaction volume to the marginal price per cryptocurrency unit a seller is required to accept in order to sell this volume to the consolidated order book.

    b. The ask price-volume curve maps a transaction volume to the marginal price per cryptocurrency unit a buyer is required to pay in order to purchase this volume from the consolidated order book.

    c. The mid price-volume curve represents the average of the bid price-volume curve and the ask price-volume curve.

    d. The mid spread-volume curve represents the percentage deviation of the ask price-volume curve from the mid price-volume curve.

4. The utilized depth is calculated as the maximum cumulative volume for which the mid spread-volume curve does not exceed a certain percentage deviation from the mid price. If this volume is less than the spacing parameter, the utilized depth is set to the spacing parameter.

5. The mid price-volume curve is weighted by the normalized probability density of the exponential distribution up to the utilized depth.

6. The CME CF Cryptocurrency Real Time Index is then given by the sum of the weighted mid price-volume curve obtained in the previous step.

4.1.2 Mathematical Representation

The following table shows the symbols used in the mathematical representation of CME CF Cryptocurrency Real Time Indices.

Symbol	Name	Description	Type
T	Effective time	The time at which a CME CF Cryptocurrency Real Time Index is calculated	Parameter, see Section 6
C_T	Order size cap	The size above which any excess size of a bid or ask order price level is discarded	Internal variable, see Section 4.1.3
D	Deviation from mid	The maximum percentage deviation of a limit order price level from the mid price-volume curve, until which that limit order price level is used for the calculation of a CME CF Cryptocurrency Real Time Index	Parameter, see Section 6
λ	Lambda	A parameter that determines the shape of the probability density function of the exponential distribution	Parameter, see Section 6
s	Spacing	The spacing granularity of a price-volume curve	Parameter, see Section 6
v	Volume	The independent variable of a price-volume curve	Internal variable
A_T	Ask orders	The ask order price levels of the consolidated order book as of the effective time, ordered ascending by price	Input
$a_{T,i}$ with $a_{T,i} = (ap_{T,i}, a\dot{s}_{T,i})$, $a_{T,i} \in A_T, a\dot{s}_{T,i} = \min\{as_{T,i}, C\}$	Ask order	The ith price/size ask order pair of the consolidated order book	Input

B_T	Bid orders	The bid order price levels of the consolidated order book as of the effective time, ordered descending by price	Input
$b_{T,i}$ with $b_{T,i} = (bp_{T,i}, b\dot{s}_{T,i})$, $b_{T,i} \in B, b\dot{s}_{T,i} = \min\{bs_{T,i}, C\}$	Bid order	The ith price/size bid order pair of the consolidated order book	Input
NF	Normalization factor	A parameter chosen such that $\frac{1}{NF}\sum_{v \in \{s,2s,\cdots,\bar{v}_T\}} \lambda e^{-\lambda v} = 1$	Output
$CCRTI_T$	CCRTI	The CME CF Cryptocurrency Real Time Index at time T	Output

Using the above notation, we define the ask price-volume curve, $askPV_T$, the bid price-volume curve, $bidPV_T$, the mid-price volume curve, $midPV_T$, and the mid spread-volume curve, $midSV_T$, in each case as of the effective time T, as:

$$\widehat{askPV}_T(v) = ap_{T,j+1} \ where \sum_{i=1}^{j} a\dot{s}_{T,i} < v \ and \sum_{i=1}^{j+1} a\dot{s}_{T,i} \geq v$$	Eq. 1a
$$\widehat{bidPV}_T(v) = bp_{T,j+1} \ where \sum_{i=1}^{j} b\dot{s}_{T,i} < v \ and \sum_{i=1}^{j+1} b\dot{s}_{T,i} \geq v$$	Eq. 1b
$$askPV_T(v) = \widehat{askPV}_T\left(s\left\lceil\frac{v}{s}\right\rceil\right)$$	Eq. 1c
$$bidPV_T(v) = \widehat{bidPV}_T\left(s\left\lceil\frac{v}{s}\right\rceil\right)$$	Eq. 1d
$$midPV_T(v) = \frac{askPV_T(v) + bidPV_T(v)}{2}$$	Eq. 1e
$$midSV_T(v) = \frac{askPV_T(v)}{midPV_T(v)} - 1$$	Eq. 1f

The utilized depth, $\bar{v}_T$, is calculated as:

$$\bar{v}_T = max(v_i \ where \ midSV_T(v_i) \leq D \ and \ midSV_T(v_{i+1}) > D, s)$$	Eq. 2

The CME CF Cryptocurrency Real Time Index as of the effective time T, $CCRTI_T$, is then given by:

$$CCRTI_T = \sum_{v \in \{s, 2s, \cdots, \bar{v}_T\}} midPV_T(v) \frac{1}{NF} \lambda e^{-\lambda v}$$ | **Eq. 3**

4.1.3 Dynamic Order Size Cap

The order size cap is calculated from the uncapped consolidated order book. The following symbols are used in the calculation of the order size cap:

Symbol	Name	Description
ac_T	Ask sample size	The number of samples used for ask-side sizes
bc_T	Bid sample size	The number of samples used for bid-side sizes
$S_T = \{s_{T,1}, s_{T,2}, \cdots s_{T,n_T}\}$	Size sample set	The consolidated set of sizes, ordered by ascending size
k	Trimming / winsorizing size	The number of samples to trim or winsorize from S_T
$\bar{s}$	Trimmed mean	The trimmed mean of the sample set S_T
$S'_T = \{s'_{T,1}, s'_{T,2}, \cdots s'_{T,n_T}\}$	Winsorized sample set	The winsorized sample set of S_T
$\bar{s}'$	Winsorized mean	The mean of the winsorized sample set S'_T
σ	Winsorized sample standard deviation	The sample standard deviation of the winsorized sample set S'_T

Using the above notation, the dynamic order size cap is derived as follows:

$ac_T = max\left(\max\limits_{1 \leq i \leq |A_T|} \{i \mid ap_{T,i} \leq 1.05ap_{T,1}\}, min(|A_T|, 50) \right)$	Eq. 4a
$bc_T = max\left(\max\limits_{1 \leq i \leq |B_T|} \{i \mid bp_{T,i} \geq 0.95bp_{T,1}\}, min(|B_T|, 50) \right)$	Eq. 4b
$S_T = \left[bs_{T,1}, bs_{T,2}, \cdots, bs_{T,bc_T}\right] \cup \left[as_{T,1}, as_{T,2}, \cdots, as_{T,ac_T}\right]$ $S_T = \left[s_{T,1}, s_{T,2}, \cdots, s_{T,n_T}\right]$ where $s_{T,1} \leq s_{T,2} \leq \cdots \leq s_{T,n_T}$	Eq. 4c
$k = \lfloor 0.01n_T \rfloor$	Eq. 4d
$\bar{s} = \dfrac{1}{n_T - 2k} \sum\limits_{i=k+1}^{n_T-k} s_{T,i}$	Eq. 4e
$s'_{T,i} = s_{T,k+1}$ if $i \leq k$ $s'_{T,i} = s_{T,n-k}$ if $i > n - k$ $s'_{T,i} = s_{T,i}$ otherwise	Eq. 4f
$\bar{s}' = \dfrac{1}{n_T} \sum\limits_{i=1}^{n_T} s'_{T,i}$	Eq. 4g
$\sigma = \sqrt{\dfrac{1}{n_T - 1} \sum\limits_{i=1}^{n_T} (s'_{T,i} - \bar{s}')}$	Eq. 4h

The order size cap as of the effective time T, C_T, is then given by:

$C_T = \bar{s} + 5\sigma$	Eq. 5

4.2   A Note on Properties

CME CF Cryptocurrency Real Time Indices reflect the instantaneous supply and demand of a given cryptocurrency and result in a robust, yet highly timely indication of the current price. This is achieved through the following design choices:

Order Book Data

CME CF Cryptocurrency Real Time Indices are calculated from order book data, as opposed to, for instance, trade data. Order book data is composed of unmatched limit orders to buy or sell cryptocurrency. The order books retrieved from the constituent exchanges are aggregated by price. They inform about the price at which a trader can buy or sell cryptocurrency now or in the future and are therefore forward-looking by nature. Further, absent retrieval constraints, order book data is always up to date. This

is in contrast to trade data, which is produced in stochastic intervals only and informs about the price at which the cryptocurrency has traded in the past.

Mid Price Volume Curve

The mid price-volume curve represents the average of the marginal price at which a certain amount of cryptocurrency can be sold and bought. By averaging across the mid price-volume curve, CME CF Cryptocurrency Real Time Indices represent a blend of such (hypothetical) transactions at various transaction sizes.

Utilized Depth

CME CF Cryptocurrency Real Time Indices are calculated from the section of the mid price-volume curve for which ask limit order price levels at a certain depth diverge by no more than a certain percentage from the mid-price at that depth. It therefore reflects a significant portion of the top of the consolidated order book (as opposed to, for instance, the best bid and ask prices only) but discards limit order price levels that are less likely to be matched. This makes it a meaningful representation of true liquidity and robust to local changes in order books.

Note that utilized depth will always include any crossing section of the consolidated order book, as well as the non-crossing section with limit orders up to a certain percentage away from the crossing point. If zero size resides in both these sections, utilized depth is set to the spacing parameter. The CME CF Cryptocurrency Real Time Indices is then effectively equal to the mid-price of the consolidated order book.

Exponential Weighting

The mid price-volume curve is weighted by the normalized probability density of the exponential distribution. The exponential distribution and its first derivative are monotonically decreasing, resulting in a higher emphasis on the initial section of the mid price-volume curve, i.e. bid and ask prices that are closest to the global best bid and ask price.

Markov Process and Martingale

Indices are frequently based on historical data, such as recent trade prices or volumes. This can result in certain predictability, for instance due to the expectation that stale prices will be updated or that a price will drop out of a weighting window.

By relying solely on order book data, CME CF Cryptocurrency Real Time Indices are both a Markov process and a martingale. A Markov process is a stochastic process with a probability distribution that depends only on the current information set, not on historical information sets. The martingale property implies that the best prediction of the next CME CF Cryptocurrency Real Time Index value is its current value:

$$E(CCRTI_{t+1}|CCRTI_1, CCRTI_2, \ldots, CCRTI_t) = CCRTI_t$$

This makes CME CF Cryptocurrency Real Time Indices useful for applications that require an unbiased estimator of the future price.

5 Contingency Calculation Rules

5.1 Delayed Data

Delayed data is treated according to the following rules:

1. If the Retrieval Time of the Relevant Order Book of a Constituent Exchange is at least 30 seconds older than the Calculation Time, the Constituent Exchange is disregarded in the calculation of the CME CF Cryptocurrency Real Time Index for that Calculation Time.

If the Retrieval Times of the Relevant Order Books of all Constituent Exchanges are each at least 30 seconds older than the Calculation Time, a CME CF Cryptocurrency Real Time Index calculation failure occurs for that Calculation Time (see Section 5.4).

5.2 Erroneous Data

5.2.1 Erroneous Books

All Relevant Order Books are subject to an automated screening for erroneous data according to the following rules:

1. If the format of a Relevant Order Book deviates from the expected format such that it cannot be parsed, it is flagged as erroneous.

2. If the Relevant Order Book contains no bid orders or no ask orders, it is flagged as erroneous.

3. If the Relevant Order Book crosses, it is flagged as erroneous.

Relevant Order Books flagged as erroneous for a given Calculation Time are disregarded in the calculation of the CME CF Cryptocurrency Real Time Index for that Calculation Time.

If the Relevant Order Books of all Constituent Exchanges are flagged as erroneous for a given Calculation Time, a CME CF Cryptocurrency Real Time Index calculation failure occurs for that Calculation Time (see Section 5.4).

5.2.2 Erroneous Prices

All Relevant Order Books are subject to an automated filtering process according to the following rule.

1. If a Relevant Order Book contains any entries with a non-numeric or non-positive limit price or size then any such entries are flagged as erroneous.

All entries in a Relevant Order Book which are flagged as erroneous for a given Calculation Time are disregarded in the calculation of the CME CF Cryptocurrency Real Time Index for that Calculation Time.

5.3   Potentially Erroneous Data

All Relevant Order Books are subject to an automated screening for potentially erroneous data according to the following rules:

1. For each Constituent Exchange individually, the current mid-price is calculated as the average of the highest bid price and the lowest ask price of the Relevant Order Book.

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

3. If for any Constituent Exchange the absolute percentage deviation, as calculated in the previous step, exceeds the Potentially Erroneous Data Parameter for the respective Real Time Index represented in Real Time Index Parameters (section 6) then the Relevant Order Book of that Constituent Exchange for the affected Real Time Index is flagged as potentially erroneous.

Relevant Order Books flagged as potentially erroneous for a given Calculation Time are disregarded in the calculation of the CME CF Cryptocurrency Real Time Index for that Calculation Time. The occurrence of any such flag is reported to the Oversight Committee.

If the Relevant Order Books of all Constituent Exchanges are flagged as potentially erroneous for a given Calculation Time, a CME CF Cryptocurrency Real Time Index calculation failure occurs for that Calculation Time (see Section 5.4).

5.4   Calculation Failure

If a CME CF Cryptocurrency Real Time Index cannot be calculated for a given Calculation Time, for instance because:

- the Retrieval Times of the Relevant Order Books of all Constituent Exchanges are each at least 30 seconds older than the Calculation Time, or

- all Relevant Order Books are flagged as erroneous or potentially erroneous (see Section 5.2); or

- any other reason or circumstance that prevents the orderly calculation of a CME CF Cryptocurrency Real Time Index,

then the CME CF Cryptocurrency Real Time Index for that Calculation Time is not published. The occurrence of any CME CF Cryptocurrency Real Time Index calculation failure is reported to the Oversight Committee.

6 Real Time Index Parameters

The following table summarizes the parameters for the currently supported CME CF Cryptocurrency Real Time Indices:

	CME CF Bitcoin Real Time Index	CME CF Ether-Dollar Real Time Index
Ticker Symbol	BRTI	ETHUSD_RTI
Relevant Pair	Bitcoin vs. U.S. Dollars	Ether vs. U.S. Dollars
Effective Time (T)	Approximately every second[i] of each day for the entire year including weekends and holidays.	
Spacing (s)	1	25
Deviation from Mid (D)	0.50%	1.00%
Lambda (λ)	$\dfrac{1}{0.3\bar{v}_T}$	$\dfrac{1}{0.3\bar{v}_T}$
Potentially Erroneous Data Parameter	10%	10%

7   Real Time Index Specifications

	CME CF Bitcoin Real Time Index	CME CF Ether-Dollar Real Time Index
CME Ticker Symbol	BRTI	ETHUSD_RTI
Administrator	CF Benchmarks Ltd	
Calculation Agent	CF Benchmarks Ltd	
Description	Instantaneous U.S. Dollar price of one bitcoin	Instantaneous U.S. Dollar price of one ether
Calculation Methodology	Real time aggregation of order book data of Constituent Exchanges	
Dissemination Time	Approximately every second of each day for the entire year including weekends and holidays.	
Dissemination Precision	0.01 U.S. Dollars	0.01 U.S. Dollars

Contact Information

Chicago Mercantile Exchange Inc.

Address	Contact
CME Group Inc. Attention: Market Data 20 South Wacker Drive Chicago, IL 60606	Web: https://www.cmegroup.com/cryptocurrency-indices Phone: +1 312 634 8395 Email: marketdata@cmegroup.com

CF Benchmarks Ltd

Address	Contact
CF Benchmarks Ltd 4th Floor 25 Copthall Avenue London EC2R 7BP United Kingdom	Web: https://www.cfbenchmarks.com Phone: +44 20 7655 6085 Email: contact@cfbenchmarks.com

Notice and Disclaimer

CF Benchmarks Ltd is registered in England with registered number 11654816 and registered office at 25 Copthall Avenue, London EC2R 7BP, United Kingdom. CF Benchmarks is authorised by the UK Financial Conduct Authority as a registered Benchmark Administrator (FRN 847100).

This document and all of the information contained in it, including without limitation all methods, processes, concepts, text, data, graphs, charts (collectively, the "Information") is the property of CF Benchmarks Ltd or its licensors, direct or indirect suppliers or any third party involved in making or compiling any Information (collectively, with CF Benchmarks Ltd, the "Information Providers") and is provided for informational purposes only. The Information may not be reproduced or disseminated in whole or in part without prior written consent from CF Benchmarks Ltd.

The Information may not be used to create derivative works or to verify or correct other data or information without prior written consent from CF Benchmarks Ltd. For example (but without limitation), the Information may not be used to create indices, databases, risk models, analytics, software, or in connection with the issuing, offering, sponsoring, managing or marketing of any securities, portfolios, financial products or other investment vehicles utilizing or based on, linked to, tracking or otherwise derived from the Information or any other CF Benchmarks Ltd data, information, products or services.

The user of the Information assumes the entire risk of any use it may make or permit to be made of the Information. CF BENCHMARKS SOEA NOT MAKE ANY EXPRESS OR IMPLIED WARRANTIES OR REPRESENTATIONS WITH RESPECT TO THE INFORMATION (OR THE RESULTS TO BE OBTAINED BY THE USE THEREOF), AND TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, IT EXPRESSLY DISCLAIMS ALL IMPLIED WARRANTIES (INCLUDING, WITHOUT LIMITATION, ANY IMPLIED WARRANTIES OF ORIGINALITY, ACCURACY, TIMELINESS, NON-INFRINGEMENT, COMPLETENESS, MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE) WITH RESPECT TO ANY OF THE INFORMATION.

Without limiting any of the foregoing and to the maximum extent permitted by applicable law, in no event shall CF Benchmarks have any liability regarding any of the Information for any direct, indirect, special, punitive, consequential (including lost profits) or any other damages even if notified of the possibility of such damages. The foregoing shall not exclude or limit any liability that may not by applicable law be excluded or limited, including without limitation (as applicable), any liability for death or personal injury to the extent that such injury results from the negligence or wilful default of itself, its servants, agents or sub-contractors.

None of CF Benchmarks Ltd's products or services recommends, endorses, approves or otherwise expresses any opinion regarding any issuer, securities, financial products or instruments or trading strategies and none of CF Benchmarks Ltd's products or services is intended to constitute investment advice or a recommendation to make (or refrain from making) any kind of investment decision and may not be relied on as such.

Any use of or access to products, services or information of CF Benchmarks Ltd requires a license from CF Benchmarks Ltd.

CME Group and CME are trademarks of Chicago Mercantile Exchange Inc., used here with permission. All other trademarks are the property of their respective owners.

---

[i] Second as defined by UTC-SLS such that each day has 86,400 seconds.