Volmex Implied Volatility Indices

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This paper outlines a methodology for calculating the implied volatility of crypto assets using option contracts from multiple exchanges. It details the processes of consolidating and filtering option data, computing implied variance, and smoothing this variance to derive the final volatility measure. At Volmex Labs, this methodology has been implemented to develop and publish the Volmex Implied Volatility Indices.[1]

1 Introduction

Implied volatility (IV), often regarded as a **fear gauge**[2] for investors, represents the volatility extracted from option prices. It is derived by matching the price of an option to a theoretical model, providing a single value that aggregates information across all available strikes for a given expiry. IV serves as a measure of the overall expensiveness of option contracts.

The pricing of options depends not only on the price level of the underlying asset but also on its volatility, which is a latent variable. This variable, while not directly observable, can be inferred from option prices and represents the expected volatility from the present to the option's expiration. As such, option-implied volatility is a "forward-looking" measure of market participants' expectations regarding the price range of the underlying asset over the contract's lifespan.

The Volmex Implied Volatility Indices adopt a model-free approach[3] to calculate the IV of crypto assets, providing a forward-looking market view presented in an index format.

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[1] Refer to the Volmex Implied Volatility Indices Specification table in the appendix A.6 for a comprehensive list of indices and their specifications.

[2] See Whaley (2000).

[3] See Demeterfi et al. (1999)

2 Methodology

The Volmex Implied Volatility Indices calculation methodology is both model-agnostic and data-source-independent. It aggregates option data from multiple exchanges to construct a global option order book. The methodology employs the variance-swap replication formula of Demeterfi et al. (1999) to calculate implied variance in a model-free manner, followed by the application of the exponentially weighted moving average (EWMA) method to smooth the raw variance. This smoothing process reduces noise in the index while preserving immediate trends. The EWMA weights are controlled by `HALFLIFE` parameter to strike a balance between capturing emerging trends and filtering out noisy observations.

To infer implied volatility from a set of option contracts at a given maturity, the methodology involves four key steps, each integral to the calculation of the final implied volatility value:

1. **Data consolidation**: The process begins by aggregating option and futures data from multiple exchanges to construct a comprehensive global order book of options and a risk-free curve.
2. **Filtering**: Next, the methodology identifies and selects out-of-the-money (OTM) call and put option contracts for use in the variance calculation, ensuring the data set is relevant and focused.
3. **Calculation**: Using the variance-swap replication formula, the raw implied variance is computed. This involves summing the contributions of the selected options and applying adjustments to derive the raw variance, which is based solely on the current selection of contracts.
4. **Smoothing**: Finally, the raw implied variances are smoothed using the exponentially weighted moving average (EWMA) method. The final implied volatility (IV) is calculated as the square root of this smoothed variance. Smoothing minimizes noise and ensures gradual updates, even in the presence of instability in raw values.

3 Data consolidation

The methodology leverages data from multiple exchanges, each providing raw data in a unique format. To ensure consistency and usability, the raw data must be extracted, standardized into a uniform format, and subsequently consolidated into a unified dataset.

3.1 Data extraction

The sourced data must include at least bid and ask quotes for each option contract, along with a timestamp indicating when the data was collected. If available, mark prices[4] are also utilized. In the absence of mark prices, alternative reference prices such as the mid-price, imbalance-weighted mid-price, or micro price[5] can be employed.

Additionally, some providers supply corresponding forward prices for each option contract. When available, these forward prices (typically provided as mark prices) are directly used. Section 3.3.1 outlines the process of consolidating futures prices to construct a yield curve, which is crucial for the calculation.

3.2 Underlying asset price level

We assume that each exchange provides the current value of the underlying asset price. Among all available prices, the price of the venue with the highest open interest is selected as the global price and used in the calculations.[6]

3.3 Future contracts: Interest rate term structure

Option exchanges often offer futures trading, allowing futures data to be retrieved alongside option data.

If the option data includes the market-expected prices at the same expiry, such as the mark prices of corresponding futures or forward prices, we use this data directly. This approach minimizes any time discrepancies between fetching option and futures data individually and facilitates the construction of the interest rate term structure (risk-free curve) as described in Section 3.3.1. However, if such data are not included in the option dataset, we retrieve the futures quotes separately and process them as outlined in Section 3.3.2.

3.3.1 Using mark prices

We calculate the interest rate using the price level mentioned in Section 3.2 using the formula below.

$$F = S \times \mathrm{e}^{r \times t} \tag{1}$$

where F is the price level of the future contract that expires at the same time as the options, S is the underlying price level, t is year-to-maturity (YTM) and r is the annualized interest rate. Thus, the implied interest rate is

$$r_{imp} = \frac{\ln F - \ln S}{t}. \tag{2}$$

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[4] used for P&L and margin requirement calculations

[5] See Stoikov (2018)

[6] Currently, set to Deribit price.

3.3.2 Using bid-ask quotes

If future contracts data comes separately, we use bid and ask quotes to consolidate the option data and then build the yield curve based on the formula in equation 2.

3.3.3 Consolidation

Once interest rates are calculated for each data source, as described in sections 3.3.1 and 3.3.2, we calculate the average interest rate for each expiry. This gives us the yield curve for the underlying asset.

3.4 Option contracts

Processing the options data that we retrieve from various exchanges has two steps. First, we extract the option data from each of the exchange, and then combine them as a single data set of options, called "Global Order Book". Details of these two steps are discussed in the following sections.

3.4.1 Source data

1. Select near and next-term options:
    - *Near-term*: Options with longest maturity that is less than or equal to index maturity
    - *Next-term*: Options with shortest maturity that is more than index maturity
2. Eliminate invalid quotes under the following scenarios:
    - Negative bid-ask spread[7]
    - Mark price is out of bid-ask range[8]
    - Mark price is not positive.

We perform these operations for the data of each exchange, and next section uses them to create a consolidated option data set to use in the remaining steps.

3.4.2 Consolidate data

1. Combine all data in one set. Since the option data are normalized in the previous step, we do not have any issues to concatenate these data sets.
2. Select near and next-term options: Providers may have different dates as near and/or next-term expiry dates. In this case, we choose the expiry that is listed on the most exchanges.

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[7] Ask price is less than bid price

[8] Mark price is less than bid price or greater than ask price

3. Consolidate bid and ask quotes for each option contract with same type,[9] strike and expiry using the following rules:
    - Select quotes: highest bids and lowest asks available.
    - Select mark prices: mark price of the option that has the smallest bid-ask spread. If there are more than one smallest bid-ask spread, choose the one with highest mark price.[10]
4. Eliminate invalid quotes under the following scenarios:
    - Negative bid-ask spread.
    - Mark price is not positive.
5. Eliminate the quotes with large spreads following the steps below:
    - Calculate bid spread as the difference between mark price and bid price. Set the bid spread to zero if negative.
    - Calculate ask spread as the difference between ask price and mark price. Set the ask spread to zero if negative.
    - Calculate spread as the sum of bid and ask spreads.
    - Calculate the maximum allowed spread (MAS) as the minimum of bid and ask spreads, multiplied by `SPREAD_MULTIPLIER`.
    - Calculate the global maximum spread (GMS) as `SPREAD_MIN` multiplied by `SPREAD_MULTIPLIER`
    - Remove the quote if its spread is greater than both GMS and MAS, or greater than `SPREAD_MAX`.
6. Calculate mid-price as the average of bid and ask prices.
7. Calculate interest rate[11] at near and next-term tenors using yield curve introduced in Section 3.3.

Once all data are consolidated in a single data set, we move to the next stage where we select only out-of-the-money (OTM) option contracts for using in the raw implied variance calculation.

4 Filtering

1. Given the maturity that we calculate the index for, and the year convention, we calculate the years-to-maturity (YTM).[12]

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[9] i.e., call or put

[10] i.e., choosing a set with smallest spread-to-price ratio

[11] Use linear piece-wise interpolation and extrapolate further tenors at the last observed values

[12] For example, YTM is $30/365 \approx 0.082192$ years when index maturity is 30 days and year convention is that one year is 365 days.

2. Determine ATM strike and implied future price:
    - Calculate the implied future price of the strike that has minimum absolute mid-price difference between call and put options, for near and next-term options: $F_{imp} = K + F \times (C - P)$ where F is the future price, C is the call option price, P is put option price, and both options are quoted in the amounts of underlying.
    - Set the largest strike that is less than the implied forward F_{imp} as ATM strike K_{ATM} for near and next-term options.

    If there is no pair of put and call options available on the same strike, or the selected ATM strike is not close to the future price,[13] use the strike that is closest to F as the ATM strike, and set F_{imp} as F.

3. Select OTM options with respect to K_{ATM} for each set of near and next-term options and set their price as mid-price. If both call and put options are selected for the same strike (i.e., K_{ATM}), then take the average of them.

4. Select the options with strikes greater than K_{min} and less than K_{max},

    $$\begin{aligned} K_{min} &= F_{imp}/\texttt{RANGE\_MULT} \\ K_{max} &= F_{imp} \times \texttt{RANGE\_MULT} \end{aligned}$$

    where F_{imp} ensures that the range of strikes change dynamically.

5. Sort the options on strikes and eliminate the options after observing five consecutive bid prices that are equal or less than minimum bid threshold.

5 Raw implied variance calculation

Once filtering is done, we first make sure the strike range is always from K_{min} to K_{max} by log-linearly extrapolating the strikes using the slopes between top point (log-ATM strike and log-option price) and last points available on each side (lowest and highest valid strikes and option prices).

Secondly, we extend the number of strikes and option prices using log-linear[14] piece-wise interpolation[15] in order for the variance formula (equation 3) to be stable when the market becomes illiquid.

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[13] "not close" if the percent difference between selected ATM strike and future price is larger than `MAX_ATM_K_DISCREPANCY`

[14] linear in log-strike and log-price

[15] Using equally spaced strikes, say dK, where dK is the smallest distance between two consecutive strikes in the given set of option contracts in the global order book.

Near and next-term option prices are then plugged in the implied variance calculation that replicates variance swaps. The implied variance formula[16] for near and next-term options is,

$$\sigma_{i,t}^2 = \frac{1}{T_i}\left(2\sum_j w_{i,j}V(K_j) - \left(\frac{F_\mathrm{i}}{K_{i,\mathrm{ATM}}} - 1\right)^2\right) \tag{3}$$

where $w_{i,j} = \mathrm{e}^{r_i T_i}\dfrac{\Delta K_j}{K_j^2}$, $i \in \{\mathrm{NEAR}, \mathrm{NEXT}\}$, F_i is the implied forward price, $K_{i,ATM}$ is the ATM strike level, $V(K)$ is the price[17] of OTM option with strike K, and T_i is years to expiry.

Once $\sigma^2_{\mathrm{NEAR},t}$ and $\sigma^2_{\mathrm{NEXT},t}$ are calculated following the formula above, implied variance at the index maturity is interpolated using the weighting scheme below:

$$\omega_{\mathrm{NEAR},t} = \frac{(T_{\mathrm{NEXT}} - T_{\mathrm{INDEX}})/T_{\mathrm{INDEX}}}{(T_{\mathrm{NEXT}} - T_{\mathrm{NEAR}})/T_{\mathrm{NEAR}}} \tag{4}$$

$$\omega_{\mathrm{NEXT},t} = \frac{(T_{\mathrm{INDEX}} - T_{\mathrm{NEAR}})/T_{\mathrm{INDEX}}}{(T_{\mathrm{NEXT}} - T_{\mathrm{NEAR}})/T_{\mathrm{NEXT}}} \tag{5}$$

where T_{INDEX} has been set to years-to-maturity.

Thus, the raw value of implied variance at the index maturity is,

$$\sigma^2_{\mathrm{RAW},t} = \omega_{\mathrm{NEAR},t}\sigma^2_{\mathrm{NEAR},t} + \omega_{\mathrm{NEXT},t}\sigma^2_{\mathrm{NEXT},t}$$

which is calculated continuously at a frequency that we acquire new data.

6 Smoothing

Raw implied variance could suffer from noise since it is calculated when a new data set is available and it might be over-sensitive to sudden changes.

6.1 Exponentially-weighted moving average (EWMA)

To eliminate the noise in raw implied variance and capture the fundamental trends in the market, an EWMA of raw implied variance is employed as shown below:

$$\sigma^2_{\mathrm{SMOOTH},t} = \lambda\sigma^2_{\mathrm{SMOOTH},t-1} + (1-\lambda)\sigma^2_{\mathrm{RAW},t} \tag{6}$$

where $\sigma^2_{\mathrm{SMOOTH},t-1}$ is the previous value of the smoothed implied variance and its weight is the smoothing parameter λ.

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[16] See Demeterfi et al. (1999)

[17] i.e., mid-price

6.2 Half-life: Choosing the smoothing parameter

The degree of smoothing is adjusted by the smoothing parameter λ. Equation 6 could be defined recursively, as below:

$$\sigma^2_{\text{SMOOTH},t} = \lambda^\tau \sigma^2_{\text{SMOOTH},t-\tau} + (1-\lambda)\sum_{i=0}^{\tau-1} \lambda^\tau \sigma^2_{\text{RAW},t-i}$$

and we can find the smoothing parameter value that implies a specific `HALFLIFE`, parameter τ, using the derivation below,

$$\lambda^\tau = \frac{1}{2} \Rightarrow \lambda = \mathrm{e}^{-\ln(2)/\tau}.$$

Above equation gives $\lambda = 0.97716$ when we set the half-life to 30 seconds and implied variance calculation is performed every second,

$$0.97716^{30\text{sec}\times 1\text{calculation/sec}} = 0.97716^{30} \approx 0.5$$

which simply means that the weight of current smooth variance will be halved every 30 seconds (i.e., 30 calculations given that calculations are performed every second) if we choose λ as 0.97716.

6.3 Volmex Implied Volatility

The Volmex Implied Volatility of a crypto asset x, abbreviated as `xVIV`,[18] is the squared root of the smoothed implied variance that has been calculated, multiplied by 100, since it is expressed as percentage points:

$$\texttt{xVIV}_t = 100 \times \sqrt{\sigma^2_{\text{SMOOTH},t}}$$

7 Conclusion

This paper explains the Volmex Implied Volatility Indices methodology to calculate the implied volatility of crypto assets at a given tenor. It has the novel features of: i) consolidating option and futures data across multiple exchanges to create a **global option book**, and ii) **smoothing** using exponentially-weighted moving averaging, which takes every observation into account while keeping the final index moving smoothly.

References

K. Demeterfi, E. Derman, M. Kamal, and J. Zou. A guide to volatility and variance swaps. *The Journal of Derivatives*, 6(4):9–32, 1999.

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[18] e.g. BVIV is Bitcoin (BTC) and EVIV is for Ethereum (ETH)

S. Stoikov. The micro-price: a high-frequency estimator of future prices. *Quantitative Finance*, 18(12):1959–1966, 2018.

R. E. Whaley. The investor fear gauge. *The Journal of Portfolio Management*, 26(3):12–17, 2000.

Appendix A Exceptions

The Volmex Implied Volatility Indices calculation depends on the health of the data and some exchanges might experience difficulties around the time of listing new options for several reasons. In addition, option market makers may not always quickly react to the sudden changes in the market and pull their quotes for a small amount of time for re-valuation and re-quoting purposes.

These scenarios may cause significant reduction in the amount of available option quotes in the exchanges and may affect the calculation of raw implied variance.

A.1 Scenarios

Two scenarios are considered as exceptions:

1. Failure in calculating the raw implied variance numerically
2. Raw implied variance less than Black-Scholes at-the-money (ATM) implied variance (BSIV)

In the above scenarios, we use BSIV and Volatility Tail Index (VTI) to calculate the raw implied variance.

A.2 Variables

Exceptions could happen to three variables:

1. Near-term raw implied variance
2. Next-term raw implied variance
3. Raw implied variance

Each of these variables have their own BSIV and VTIs.

A.3 Black-Scholes ATM Implied Volatility (BSIV)

When we calculate the reference ATM strike, K_{ATM} for near and next-term option contracts, we select the five[19] contracts closest to K_{ATM} and calculate Black-Scholes implied volatility (BSIV) of these contracts, select two smallest of the available BSIVs, and then calculate the average of them. This gives us near and next-term BSIVs and we use the weighting scheme in Equations 4 and 5 to calculate the BSIV. All BSIVs are also expressed in percentage points.

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[19] If all of the selected quotes are invalid, try 10 first and then 15.

A.4 Volatility Tail Index (VTI)

VTI measures the percentage difference between the calculated volatility and BSIV. Since the calculated volatility uses OTM options and BSIV is only informative about ATM options, the ratio of these two would indicate how tails are priced differently than central strike region (i.e., ATM). We calculate raw VTIs using near-term, next-term BSIVs with the same weighting as done in the calculations, and then smooth these raw VTIs using the same value of λ that we use in Equation 6.

$$\begin{aligned}\mathtt{VTI}_{raw,t} &= 100 \times (\mathtt{xVIV}_t/\mathtt{BSIV}_t - 1)\\ \mathtt{VTI}_{smooth,t} &= \lambda \times \mathtt{VTI}_{smooth,t-1} + (1-\lambda) \times \mathtt{VTI}_{raw,t}\end{aligned}$$

where `xVIV` refers to the Volmex IV of crypto asset x.

A.5 Calculation

In case of any exception in the calculation of raw implied variance, or when the calculated volatility is less than BSIV,[20] we use BSIV and VTI values to calculate raw variance as shown below:

$$\sigma^2_{\mathrm{RAW},t} = \left[\frac{\mathtt{BSIV}_t}{100} \times \left(1 + \frac{\mathtt{VTI}_{smooth,t-1}}{100}\right)\right]^2$$

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[20] It should never be the case in a liquid and rational market since the tails are always more expensive then ATM options.

A.6 Index Specifications

Table 1: Volmex Implied Volatility Indices Specifications

Specification	**BTC (BVIV)**	**ETH (EVIV)**	**SOL (SVIV)**
Underlying asset	BTC	ETH	SOL
Index name	BVIV	EVIV	SVIV
Default index tenor	30-day	30-day	14-day
Term structure (in days)	1, 7, 14, 30, 60, 90, 120	1, 7, 14, 30, 60, 90, 120	1, 7, 14
Sources	Deribit, OKX	Deribit, OKX	Deribit
TICKSIZE	0.0005 BTC	0.0005 ETH	0.1 USDC
SPREAD_MULTIPLIER	10	10	10
SPREAD_MIN	TICKSIZE	TICKSIZE	TICKSIZE
SPREAD_MAX	0.1	0.1	0.1
MAX_ATM_K_DISCREPANCY (in percent)	2.0	2.0	2.0
RANGE_MULT	2.5	2.5	2.5
Minimum bid threshold	TICKSIZE	TICKSIZE	TICKSIZE
Year convention	365 days	365 days	365 days
HALFLIFE (7:30–8:30 AM UTC)	2 minutes	2 minutes	2 minutes
HALFLIFE (8:30 AM–7:30 AM UTC)	1 minute	1 minute	1 minute