BVUS: BVIV-US Index
Volmex Bitcoin ETF Volatility

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This paper outlines a novel methodology for calculating the volatility of Bitcoin implied by the option contracts of spot Bitcoin ETFs. It details the processes of filtering option data, computing implied variance, and smoothing this variance to derive the final volatility measure.

1 Introduction

Implied volatility (IV), often regarded as a **fear gauge**[1] for investors, represents the volatility extracted from and implied by option contracts. It provides a single value that aggregates information across all available strikes for a given expiry and serves as a measure of the overall expensiveness of option contracts.

The pricing of options depends not only on the current price level of the underlying asset but also on the uncertainty around this price level, which can be proxied by future volatility, which is a latent variable. The future volatility, 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 BVIV-US Index (Volmex Bitcoin ETF Volatility) adopts a model-free approach[2] to calculate the 30-day IV of spot BTC ETFs,[3] providing a forward-looking market view presented in an index format.

[1] See Whaley (2000).
[2] See Demeterfi et al. (1999)
[3] Currently, using only iShares Bitcoin Trust ETF (IBIT)

2 Methodology

The calculation methodology of the BVIV-US Index is model-free and it leverages NBBO option data from multiple exchanges to ensure robustness. Methodology employs the variance-swap replication formula of Demeterfi et al. (1999) to calculate implied variance without relying on any specific model. It then applies an exponentially weighted moving average (EWMA) to smooth the raw variance, enhancing stability. This smoothing process helps mitigate potential manipulation attempts, reduce noise and preserve immediate market trends. The EWMA weights are controlled by `HALFLIFE` parameter which is set to a value to strike a balance between capturing emerging trends and filtering out noisy observations.[4]

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

1. **Data collection**: The calculation process begins by gathering the price of the underlying,[5] yield curve,[6] and NBBO option bid and ask quotes.

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. **Interpolation/extrapolation**: Once the OTM options are selected, the methodology ensures a consistent set of options for the subsequent steps. To achieve this, interpolation and extrapolation are applied as needed.

4. **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.

5. **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 collection

The calculation methodology of the BVIV-US Index requires three sets of information:

[4] `HALFLIFE` is set as 60 seconds
[5] i.e., IBIT
[6] extracted from T-bills and government bonds

1. Underlying price
2. Yield curve
3. NBBO option quotes

Following sections provide details of these data and fallback logic if any of them is missing.

3.1 Underlying asset price level

We assume that the price of the underlying asset is provided with its timestamp.

3.2 Yield curve

Options traded on U.S. exchanges do not carry counter-party risk because they are cleared by a central clearinghouse, the Options Clearing Corporation (OCC). Since the OCC guarantees all obligations, we use Treasury bills and government bonds to derive **continuously compounded, annualized** risk-free interest rate for our calculations. Whenever available, we source these rates directly from data vendors. For any missing tenors, we apply linear interpolation and flat extrapolation to ensure a complete yield curve.[7]

3.3 Option data

The NBBO option data must include at least bid and ask quotes for each option contract, along with a timestamp indicating when the data was collected.

4 Filtering

4.1 Processing raw data

1. Eliminate the quotes under the following scenarios:
   - Negative bid-ask spread[8]
   - Bid quotes less than lower bounds:
     - ◇ $\max(S - K \times \exp(r_t \times t), 0)$ is the lower bound for call options,
     - ◇ $\max(K \times \exp(r_t \times t) - S, 0)$ is the lower bound for put options,

     where S is the price level of the underlying asset, r_t is the interest rate at tenor t, K is the strike price and t is the year-to-maturity of the option.
2. For options with strikes $K_1 < K_2 < \cdots < K_n$ at time t,

[7]We use 2-year yield in practice as the risk-free rate.
[8]Ask price is less than bid price

- Call Options (sorted by ascending strike):
  $Bid_t(K_i) > \max_{j>i} Bid_t(K_j)$
  $Ask_t(K_i) < \min_{j<i} Ask_t(K_j)$
- Put Options (sorted by descending strike):
  $Bid_t(K_i) > \max_{j<i} Bid_t(K_j)$
  $Ask_t(K_i) < \min_{j>i} Ask_t(K_j)$
- Update the quotes that yields static arbitrage as follows:
  - For call options:
    If $Bid_t(K_i)$ has arbitrage, then set $Bid_t(K_i) = \max_{j>i} Bid_t(K_j)$
    If $Askt(Ki)$ has arbitrage, then set $Ask_t(K_i) = \min_{j<i} Ask_t(K_j)$
  - For put options:
    If $Bidt(Ki)$ has arbitrage, then set $Bid_t(K_i) = \max_{j<i} Bid_t(K_j)$
    If $Askt(Ki)$ has arbitrage, then set $Ask_t(K_i) = \min_{j>i} Ask_t(K_j)$

3. Eliminate the quotes with large spreads following the rule below:
   - Bid-ask spread is greater than $S \times$ `SPREAD_MAX`[9]
4. Select near and next-term options:
   - *Near-term*: Options with longest maturity that is less than or equal to index maturity.[10]
   - *Next-term*: Options with shortest maturity that is more than index maturity.
5. For each tenor, eliminate the quotes starting from the third zero bid quote:[11]
   - Sort near/next-term call options by their strike. Start from smallest strike and select the ones with positive bid quotes. Continue iterating over (increasing) strikes until having third consecutive zero bid.
   - Sort near/next-term put options by their strike. Start from largest strike and select the ones with positive bid quotes. Continue iterating over (decreasing) strikes until having third consecutive zero bid.

4.2 Selecting OTM options

1. Given the index maturity, and the year convention of 365 days in a year, we calculate the years-to-maturity (YTM). For example: $30/365 \approx 0.082192$ years when index maturity is 30 days.
2. For each tenor,[12] calculate the continuously-compounded annualized interest rate, r_t, using linear interpolation and flat extrapolation when needed.

[9] `SPREAD_MAX` is set as 2.5%
[10] Index maturity is 30 days (30/365 in years)
[11] First two included
[12] At this point, we only have near and next-term tenors

3. Calculate yield curve-implied future prices, F_0, for each tenor t, as

$$F_{0,t} = S \times \exp(r_t \times t)$$

where S is the underlying asset price.

4. Determine ATM strike and implied future price:

   - Set the strike that is closest to F_0 as ATM strike K_{ATM} for near and next-term options.
   - Calculate the Black-Scholes implied volatility (BSIV) of ATM options for near and next-term options, and set the near and next-term ATM BSIV as these values:

$$BSIV_{i,ATM} = BSIV_{i,CallATM} \quad \text{if only call option is available}$$
$$BSIV_{i,ATM} = BSIV_{i,PutATM} \quad \text{if only put option is available}$$

   for $i \in \{\text{NEAR}, \text{NEXT}\}$. If both call and put options are available for K_{ATM} then set their mean as near and next-term ATM BSIV, $BSIV_{ATM}$.

$$BSIV_{i,ATM} = (BSIV_{i,CallATM} + BSIV_{i,PutATM})/2$$

   for $i \in \{\text{NEAR}, \text{NEXT}\}$.
   - Calculate the implied future price for near and next-term options:

$$F_{imp} = K_{ATM} + F_0 \times \big(C(K_{ATM}) - P(K_{ATM})\big)/S$$

   where $C(K)$ is the call option and $P(K)$ is put mid-option price for strike K.
   - If there is no pair of put and call options available on the ATM strike, then set $F_{imp} = F_0$.

5. Select ATM and OTM options:

   - Select OTM options with respect to K_{ATM} for each set of near and next-term options and set their price as mid-price.
   - For K_{ATM}, if both call and put options are available, use the average mid-price of them as the price of the ATM option with the strike K_{ATM}. Otherwise (i.e., if only a call or only a put option is available at the strike K_{ATM}) use the mid-price of this option as the price of the ATM option

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

$$K_{min} = round(F_{imp}/\texttt{RANGE\_MULT})$$
$$K_{max} = round(F_{imp} \times \texttt{RANGE\_MULT})$$

where F_{imp} ensures that the range of strikes change dynamically. Multiplication and division by same value, `RANGE_MULT`,[13] ensures symmetry in log-scale.

[13] `RANGE_MULT` is set as 3.0

5 Interpolation/extrapolation

The BVIV-US Index is designed to measure implied volatility without bias. To ensure accuracy, we must address any potential sources of distortion, particularly downward bias. One common issue arises when liquidity drops significantly, urging market makers to remove quotes for deep out-of-the-money (OTM) options. This can artificially suppress implied volatility, contradicting the fact that illiquidity increases uncertainty and, therefore, volatility. To mitigate this, we ensure a wide range of strikes that includes deep OTM options by extrapolating the strikes into (K_{min}, K_{max}) range.

Additionally, to maintain consistency and minimize the impact of missing quotes, we apply interpolation, ensuring a robust and stable volatility measure.

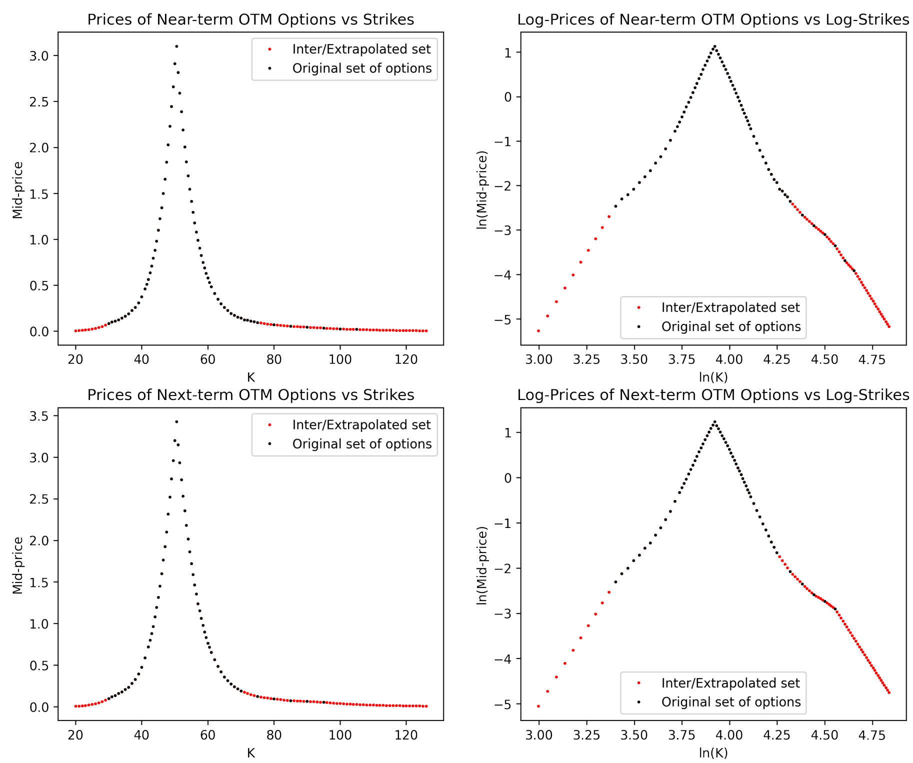

Figure 1: Interpolation and extrapolation of IBIT options data (March 7, 2025 10:45 ET)

5.1 Extrapolation

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 (ATM strike and option price) and last points available on each side (lowest and highest valid strikes and option prices).

This can easily be seen in the Figure 1. The plots in the left column display option prices against strikes, while the right column presents them in logarithmic scale, making the extrapolation easier to visualize. The extrapolated red points extend beyond the black points and align on a straight line, which also passes through the last (right or left) and highest black point.

5.2 Interpolation

Once making sure covering (K_{min}, K_{max}) range, we extend the number of strikes and option prices using log-linear piece-wise interpolation[14] in order for the variance formula (i.e., Equation 1) to be stable when the market becomes illiquid.

6 Raw implied variance calculation

Near and next-term option prices are plugged in the implied variance calculation that replicates variance swaps. The implied variance formula[15] for near and next-term options is,

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

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[16] 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:

$$\omega_{\mathrm{NEAR},t} = \frac{(T_{\mathrm{NEXT}} - T_{\mathrm{INDEX}})/T_{\mathrm{INDEX}}}{(T_{\mathrm{NEXT}} - T_{\mathrm{NEAR}})/T_{\mathrm{NEAR}}} \tag{2}$$

$$\omega_{\mathrm{NEXT},t} = \frac{(T_{\mathrm{INDEX}} - T_{\mathrm{NEAR}})/T_{\mathrm{INDEX}}}{(T_{\mathrm{NEXT}} - T_{\mathrm{NEAR}})/T_{\mathrm{NEXT}}} \tag{3}$$

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.

[14] Using equally-spaced strikes of ΔK which is the smallest possible distance between two consecutive strikes, i.e. $\Delta K = 0.5$, i.e. 50 cents, for IBIT options

[15] See Demeterfi et al. (1999)

[16] i.e., mid-price

7 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.

7.1 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:

$$\sigma^2_{\text{SMOOTH},t} = \lambda\sigma^2_{\text{SMOOTH},t-1} + (1-\lambda)\sigma^2_{\text{RAW},t} \tag{4}$$

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

7.2 Half-life: Choosing the smoothing parameter

The degree of smoothing is adjusted by the smoothing parameter λ. Equation 4 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 $\lambda \approx 0.986233$ when we set the half-life to 5 seconds and implied variance calculation is performed every 100 millisecond,

$$0.986233^{5\text{sec}\times 10\text{calculation/sec}} = 0.986233^{50} \approx 0.5$$

which simply means that the weight of current smooth variance will be halved every 5 seconds (i.e., 50 calculations given that calculations are performed every 100 millisecond) if we choose λ as 0.986233.

7.3 Volmex Bitcoin ETF Volatility

The Volmex Bitcoin ETF Volatility Index is the squared root of the smoothed implied variance that has been calculated, multiplied by 100, since it is expressed as percentage points:

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

where $\texttt{INDEX}_t$ is the Volmex Bitcoin ETF Volatility Index value at time t.

8 Conclusion

This paper explains the Volmex Bitcoin ETF Volatility Index methodology to calculate the implied volatility of Bitcoin ETFs, particularly IBIT, at 30-day maturity. It has the novel features of: i) **interpolation/extrapolation** to maintain consistency and to avoid downward bias, 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.

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

Appendix A Fallback Mechanisms

The BVIV-US Index calculation depends on the health of the data. Option market makers may not always quickly react to the sudden changes in the market and they can 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 for the calculation of the near and next-term implied variances:

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 Tail Premium (TP) 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

Each of these variables have their own BSIV and TPs.

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

We calculate Black-Scholes implied volatility (BSIV) for ATM strikes,[17] K_{ATM}, and then calculate the average of them. This gives us near and next-term ATM BSIVs and we use the smoothing mechanism to calculate smoothed ATM BSIVs.

$$\texttt{BSIV}_{NEAR,t} = \lambda \times \texttt{BSIV}_{NEAR,t-1} + (1-\lambda) \times \texttt{BSIV}_{NEAR,raw,t}$$
$$\texttt{BSIV}_{NEXT,t} = \lambda \times \texttt{BSIV}_{NEXT,t-1} + (1-\lambda) \times \texttt{BSIV}_{NEXT,raw,t}$$

After that, we use the weighting scheme in Equations 2 and 3 to calculate the BSIV at 30-day maturity. All BSIVs are also expressed in percentage points.

$$\texttt{BSIV}_t = 100 \times \sqrt{\omega_{\text{NEAR},t}\texttt{BSIV}^2_{NEAR,t-1} + \omega_{\text{NEXT},t}\texttt{BSIV}^2_{NEXT,t-1}}$$

[17] one call and one put

A.4 Tail Premium (TP)

TP measures the percentage difference between the calculated volatility and ATM 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 TPs using near-term and next-term BSIVs with the same weighting as done in the calculations, and then smooth these raw TPs using the same value of λ that we use in Equation 4.

$$\begin{aligned}
\texttt{TP}_{NEAR,raw,t} &= 100 \times (\texttt{INDEX}_{NEAR,t}/\texttt{BSIV}_{NEAR,t} - 1)\\
\texttt{TP}_{NEAR,t} &= \lambda \times \texttt{TP}_{NEAR,t-1} + (1-\lambda) \times \texttt{TP}_{NEAR,raw,t}\\
\texttt{TP}_{NEXT,raw,t} &= 100 \times (\texttt{INDEX}_{NEXT,t}/\texttt{BSIV}_{NEXT,t} - 1)\\
\texttt{TP}_{NEXT,t} &= \lambda \times \texttt{TP}_{NEXT,t-1} + (1-\lambda) \times \texttt{TP}_{NEXT,raw,t}
\end{aligned}$$

A.5 Calculation

In case of any exception in the calculation of raw implied variances, or when the calculated volatility is less than BSIV,[18] we use the current BSIV and the most recent (i.e. previous) TP values to calculate raw near and next-term variances as shown below:

$$\begin{aligned}
\sigma^2_{\text{NEAR},t} &= \left[\frac{\texttt{BSIV}_{NEAR,t}}{100} \times \left(1 + \frac{\texttt{TP}_{NEAR,t-1}}{100}\right)\right]^2\\
\sigma^2_{\text{NEXT},t} &= \left[\frac{\texttt{BSIV}_{NEXT,t}}{100} \times \left(1 + \frac{\texttt{TP}_{NEXT,t-1}}{100}\right)\right]^2
\end{aligned}$$

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