Market Efficiency in Prediction Markets

A Comparison with Derivatives

Decentralized Finance & Crypto Workshop - SNS Pisa

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Motivation

- **Decentralized prediction markets** let users trade on future events (e.g., elections, macro announcements, sports, Bitcoin prices).
- **Contracts are binary**: \$1 if the event occurs, \$0 otherwise.
  - These payoffs resemble digital options.
  - There is a recent boom in 0DTE options (short-term, binary payoffs).
- Most recent studies analyze Polymarket for real-world events (e.g., Trump election)
- **What about financial markets?** At the same time:
  - **Polymarket** hosts active BTC prediction markets.
  - **Deribit** hosts the world's deepest BTC options market.
- **Unique opportunity: same underlying, two very different market structures.**

Why Compare Prediction Markets and Options?

- Both markets aggregate beliefs about future BTC prices.
- But they differ in:
  - *participants*: retail vs. institutional,
  - *frictions*: blockchain settlement, liquidity, attention,
- **Question:** Do Polymarket probabilities line up with option-implied probabilities?
- **If not, what drives the differences?**

This Paper

What we do

- Map Polymarket BTC bets into option-like payoffs.
- Recover option-implied probabilities from derivatives markets using risk-neutral densities.
- Perform a **systematic comparison of Polymarket and derivatives market**, made possible by the unique coexistence of both markets on the **same underlying**.

What do we find?

Preview of Results

- **Polymarket broadly tracks option-implied benchmarks**
  - Very tight alignment for simple, terminal-value bets.
- **Systematic deviations emerge**
  - Larger gaps for complex/path-dependent bets.
  - Behavioral patterns: overattention to salient thresholds (e.g. "BTC reach 200k"); overconfidence in tail events.
- **Mispricing over time**
  - Largest at listing; reappears near expiry; higher on weekends.
- **Determinants of deviations**
  - Returns and volatility (BTC, USDC).
  - Blockchain frictions (L2 Risk).
  - Market fragmentation (Binance vs. Deribit); order-flow imbalance (NBP).
  - Sentiment (Fear & Greed); macro/news days (FOMC, tariffs).

What is Polymarket?

- A **decentralized exchange** using a central limit order book (CLOB) where users trade **binary claims** on future events.
- Trades happen on a **CLOB**:
  - fast matching off–chain (no AMM),
  - settlement on–chain on Polygon (Layer-2 on Ethereum).
- Every market has two tokens: **Yes** and **No**.
  - Fully collateralized (via smart contract): Yes + No = 1 USDC.
  - At resolution: the correct token pays 1 USDC.
- Prices are between $[0, 1]$ and represent **probabilities**.
  Yes price of 0.42 USDC implies a 42% probability of the event.
- Users can **enter or exit** positions **at any time** by lifting existing orders (market orders) or posting limit orders.

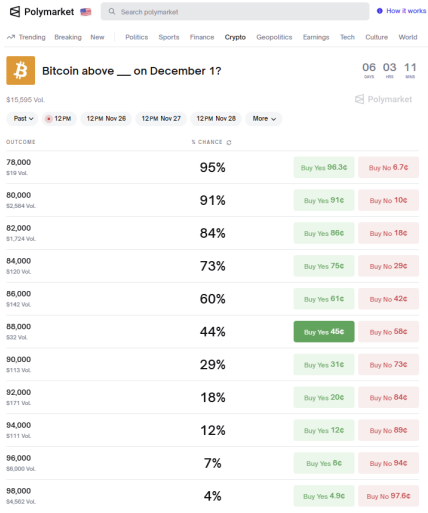
Polymarket BTC Bet Types

Polymarket offers four BTC-linked contingent claims:

- **Terminal-value bets** - resolve at maturity:
  - **Above**: BTC finishes above a specified price at maturity.
    "Will BTC be above $90,000 on July 31?"
  - **Range**: BTC ends inside a price band at maturity.
    "Will BTC be between $50,000 and $60,000 on July 31?"
- **Path-dependent bets** - resolve if the barrier is hit:
  - **Reach**: BTC hits or exceeds a price at any time pre-expiry.
    "Will BTC reach $130,000 before August 31?"
  - **Dip**: BTC falls below a price at any time before expiry.
    "Will BTC fall below $45,000 before August 1?"

Resolution: Oracle uses Binance 1-minute candles; if the condition is met at any time, the market resolves Yes.

Example: Above Bet



BTC at snapshot (25 Nov 2025): 87,134 USD.

Example: Above Bet

Different strike → different price sensitivity.

Polymarket Data

- **Market data**
  - Obtain bets via API; identify all BTC bets; manually classify into Above, Range, Reach, Dip.
  - Hourly CLOB mid-prices for Yes/No shares (probability series).
- **Trade data**
  - Executed trades: side, volume, price, wallet.
  - Enables **NBP** (net buying pressure) following Bollen and Whaley (2004).
- **On-chain data (Polygon)**
  - Gas usage from transaction receipts
    $\rightarrow$ per-trade fees (avg. < 1.5 cents).
  - Block-time gaps used to construct the **L2 Risk** measure.
- **Summary of the sample**
  - **255** BTC markets, 4 bet types (2024–2025).
  - **324k** trades in total.
  - **Maturities**: Above/Range $\approx$ 1 week; Reach/Dip $\approx$ 1 month.

Option Data and Risk-Neutral Density (RND)

Option data (Deribit via Amberdata)

- Hourly *floating-maturity* IV surfaces for BTC options

Matching options to each Polymarket bet

- Interpolate IVs *across time* to match the bet's exact maturity.
- Fit a *quadratic IV smile* across strikes (Figlewski, 2018).

Constructing the risk-neutral density $f(K)$

- Apply extended Breeden–Litzenberger formula:

$$f(K) \approx e^{rT} \frac{\partial^2 C(T,K)}{\partial K^2}.$$

  - Evaluate on a dense strike grid using fitted IVs and derivatives.
  - Append *log-normal tails* for stability.

$\rightarrow$ *smooth, arbitrage-free RND for BTC at each Polymarket expiry.*

Option-Implied Prices (OIP)

Using the risk-neutral density $f(K)$, we compute benchmark probabilities for each Polymarket payoff.

- **Above (terminal threshold):**

$$\mathrm{OIP}_{\mathrm{Above}} = \int_{K^*}^{\infty} f(K)\, dK.$$

- **Range (terminal band):**

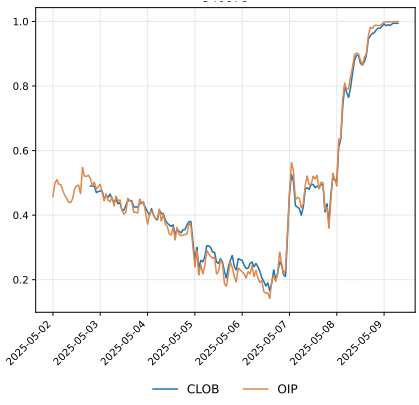
$$\mathrm{OIP}_{\mathrm{Range}} = \int_{K_1}^{K_2} f(K)\, dK.$$

- **Reach / Dip (knock-in):** Approximate via reflection principle under Black–Scholes:

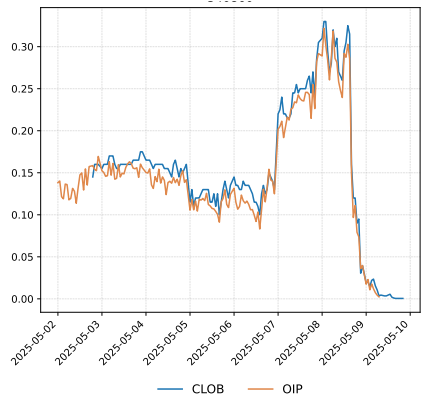
$$\mathrm{OIP}_{\mathrm{Knock\text{-}In}} = 2\Phi\left(-\frac{|\log(K^*/S_0)|}{\sigma(K^*)\sqrt{T}}\right).$$

- These are our **option-implied probabilities** (OIP) we compare with Polymarket prices.

Polymarket vs Options
Simple bets



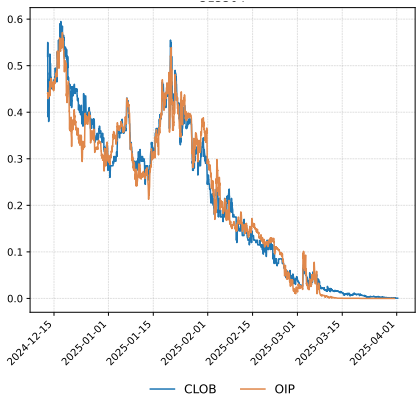
(a) BTC above 97k



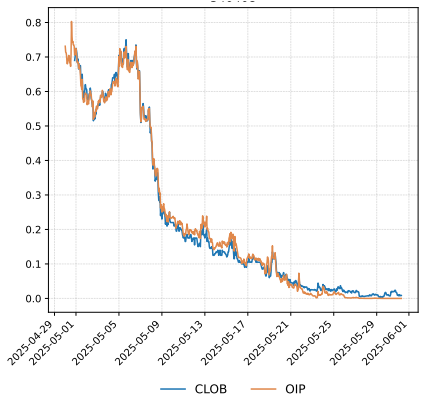
(b) BTC between 97k / 99k

Above and Range markets track option-implied probabilities closely.

Polymarket vs Options
Path-dependent bets



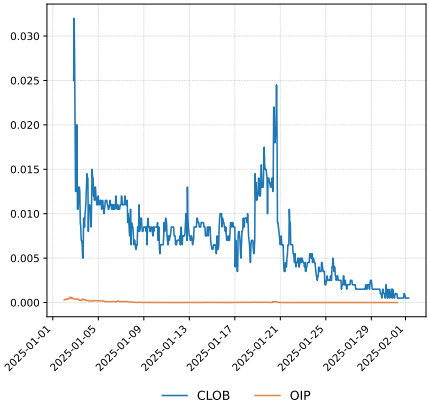
(a) BTC reach 130k



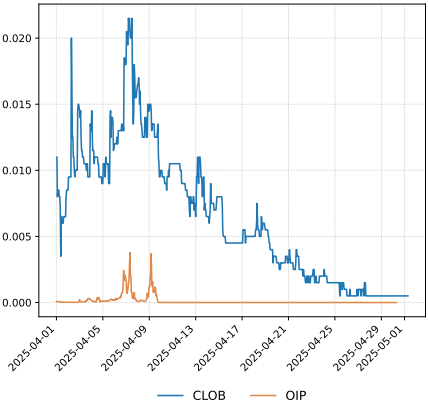
(b) BTC dip 90k

Reach and Dip markets show a similar pattern for most of the bets.

Polymarket vs Options
Behavioral Biases: Extreme Events



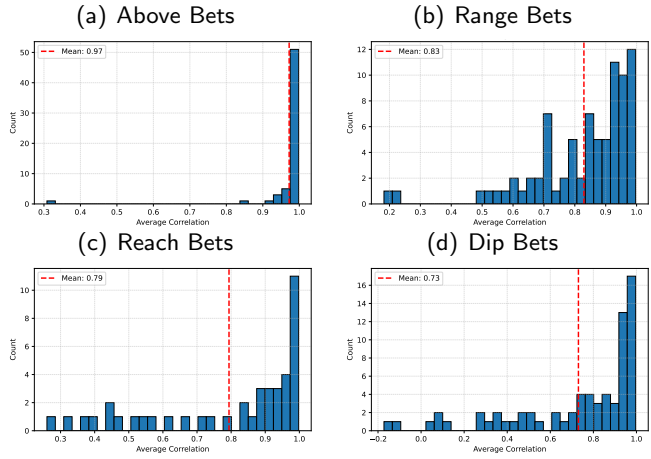
(a) BTC reach 200,000



(b) BTC dip 40,000

Reach and Dip show larger deviations for tail events.

Polymarket vs Options – Correlation



Correlation declines with contract complexity: Above bets (0.97), Range bets (0.83), Reach/Dip bets (0.79, 0.73).

Behavioral Biases Over Time

Time segmentation, we split each bet in:

- **Beginning**: first 24 hours after listing
- **Middle**: remaining life of the market
- **End**: last 24 hours before resolution

Empirical patterns

- **Above / Range bets**: largest mispricing at the beginning, steadily declines toward the end.
- **Reach / Dip bets**: U-shaped pattern; high at beginning, compresses in middle, rises again at end.
- **Weekend effect**: mispricing consistently larger on weekends (thinner liquidity, attention spikes).

Determinants of Mispricing: Setup

- We define the price deviation as:

$$\text{Diff}_{i,t} = \text{CLOB}_{i,t} - \text{OIP}_{i,t}$$

  for bet i at time t.

- We run a panel regression (pooled OLS):

$$\text{Diff}_{i,t} = \alpha_i + \beta' X_{i,t} + \varepsilon_{i,t}.$$

- Where $X_{i,t}$ includes:
  - **BTC / USDC returns** and **realized volatilities**, **BTC VIX**
  - **Moneyness** and **Time-to-expiry (Maturity)**
  - **L2 Risk**: longest block-time gap within one hour (Polygon)
  - **Diff Underlying**: Binance vs Deribit BTC price
  - **NBP**: (Buy - Sell)/Total Volume (Bollen and Whaley, 2004)
  - **Fear & Greed** (sentiment index), high value means greed
  - **Weekend**, **Announcement** (FOMC, Trump tariffs) dummies

Panel Regression – Overall Interpretation

Mispricing widens with blockchain risk, fragmentation, order-flow imbalances, weekends and announcement days.

- **Operational / market-structure drivers:** L2 Risk & Diff Underlying $\uparrow \Rightarrow$ Diff $\uparrow$.
- **Order flow:** NBP $\uparrow \Rightarrow$ Diff $\uparrow$: temporary demand-driven gaps.
- **Timing:** Weekend and Announcement show systematically larger deviations.
- **Heterogeneity by bet type:** coefficients on returns, vols, and sentiment vary strongly by payoff.

Panel Regression – Reach Bets (CLOB–OIP)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BTC Vol_{30}		-0.146***							
		(0.006)							
USDC Vol_{30}			-0.038***						
			(0.006)						
VIX_{BTC}				-0.047***					
				(0.007)					
L2 Risk					-0.008				
					(0.007)				
Diff Underlying						0.021***			
						(0.006)			
NBP							0.024**		
							(0.010)		
Fear & Greed								0.023***	
								(0.005)	
Announcement									0.031***
									(0.007)
Δ BTC (%)	0.025***	0.025***	0.025***	0.026***	0.025***	0.025***	0.044***	0.025***	0.024***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.012)	(0.006)	(0.006)
Δ USDC (%)	0.001	0.001	0.001	0.001	0.001	0.001	-0.004	0.001	0.001
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.010)	(0.003)	(0.003)
Weekend	0.044***	0.038***	0.042***	0.041***	0.044***	0.044***	0.115***	0.043***	0.050***
	(0.007)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.014)	(0.007)	(0.007)
Moneyness	0.189***	0.168***	0.193***	0.194***	0.191***	0.189***	0.483***	0.184***	0.190***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.011)	(0.006)	(0.006)
Maturity	-0.126***	-0.123***	-0.126***	-0.113***	-0.125***	-0.130***	-0.411***	-0.131***	-0.126***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.011)	(0.006)	(0.005)
R^2 Adj	0.062	0.083	0.064	0.064	0.062	0.063	0.418	0.063	0.063
Obs.	45,048	45,048	45,048	45,039	45,048	45,048	5,815	45,048	45,048

Table 1: Panel Regression – Reach Bets – CLOB-OIP.

Reach Bets: Interpretation

Reach bets show evidence of overreaction to bullish signals, especially when markets are calm.

- **Returns (positive)**: Upside moves widen CLOB–OIP $\Rightarrow$ overreaction to bullish trends on Polymarket.
- **Volatility (negative)**: Overpricing is strongest in low-volatility, euphoric regimes.
- **Fear & Greed (positive)**: Higher greed coincides with a larger difference.
- **NBP (positive)**: Buy-dominated flow amplifies temporary dislocations.
- **Contract features:** ATM and short-to-expiry markets show larger differences.

Panel Regression – Dip Bets (CLOB–OIP)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BTC Vol_{30}		0.027***							
		(0.005)							
USDC Vol_{30}			-0.082***						
			(0.006)						
VIX_{BTC}				0.063***					
				(0.005)					
L2 Risk					0.090***				
					(0.007)				
Diff Underlying						0.104***			
						(0.006)			
NBP							-0.035***		
							(0.013)		
Fear & Greed								-0.031***	
								(0.006)	
Announcement									0.004
									(0.005)
Δ BTC (%)	-0.021***	-0.021***	-0.021***	-0.022***	-0.020***	-0.023***	-0.033*	-0.022***	-0.021***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.017)	(0.006)	(0.006)
Δ USDC (%)	-0.000	-0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.011)	(0.003)	(0.003)
Weekend	0.041***	0.042***	0.041***	0.043***	0.038***	0.039***	0.125***	0.041***	0.042***
	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)	(0.021)	(0.007)	(0.007)
Moneyness	0.027***	0.026***	0.026***	0.012*	0.002	0.040***	0.417***	0.023***	0.027***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.023)	(0.007)	(0.007)
Maturity	-0.211***	-0.214***	-0.206***	-0.230***	-0.228***	-0.233***	-0.577***	-0.208***	-0.211***
	(0.007)	(0.007)	(0.007)	(0.008)	(0.007)	(0.008)	(0.026)	(0.007)	(0.007)
R^2 Adj	0.047	0.048	0.054	0.051	0.054	0.057	0.253	0.048	0.047
Obs.	28,975	28,975	28,975	28,966	28,975	28,975	4,472	28,975	28,975

Table 2: Panel Regression – Dip Bets – CLOB-OIP.

Dip Bets: Interpretation

Dip bets behave like expensive crash insurance in prediction markets.

- **Negative returns:** When BTC drops, the difference increases, consistent with larger differences in bear markets (or smaller differences during rallies).
- **Volatility (positive):** Higher BTC vol increases the gap;
- **Fear & Greed (negative)**: higher fear (lower index) leads to a larger difference.
- **Contract features:** Mispricing is larger for ATM bets and increases toward resolution.

Conclusion

- We construct option-implied benchmarks and compare them to Polymarket prices.
- **Main takeaways:**
  - strong alignment for simple, terminal-value bets,
  - persistent mispricing for complex or tail-sensitive bets,
  - deviations linked to returns, volatility, L2 risk, fragmentation, sentiment, and order flow.
- **Implications:**
  - prediction markets aggregate information, but frictions matter,
  - decentralized design and a retail-heavy user base influence pricing dynamics.
- **Ongoing work:** microstructure tests, alternative benchmarks (ETH), and theoretical foundations.

Thank you!

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Related Literature

Prediction markets

- Wolfers and Zitzewitz (2004, 2006): Prediction-market prices as probabilities.
- Manski (2006): Interpretation limits of market-implied beliefs.
- Ng et al. (2025): Polymarket leads price discovery in major events.
- Eichengreen et al. (2025): Polymarket expectations and monetary policy credibility.

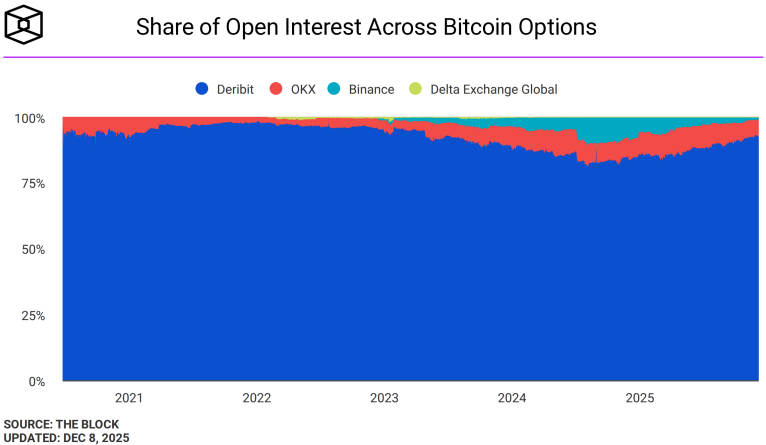
Behavioral biases

- Barber and Odean (2000, 2001, 2008): Overconfidence and attention-driven retail trading.
- Da et al. (2011): Search activity as a real-time measure of investor attention.
- Statman et al. (2006): Overconfidence and excess trading volume.

Option-implied information

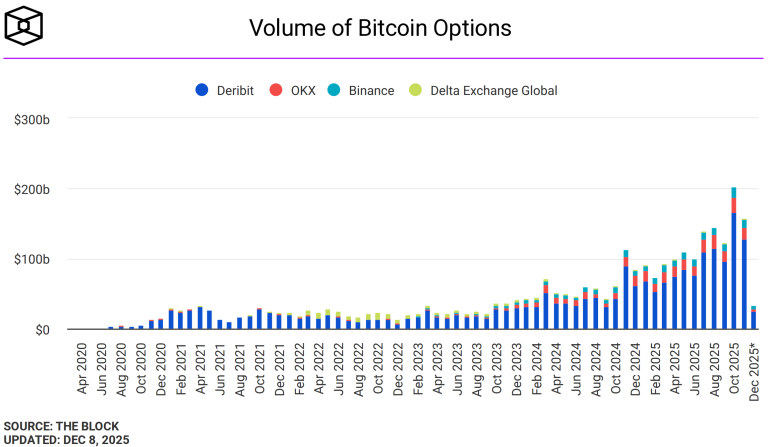
- Breeden and Litzenberger (1978), Figlewski (2018), Bollen and Whaley (2004)

Share of Bitcoin options across exchanges



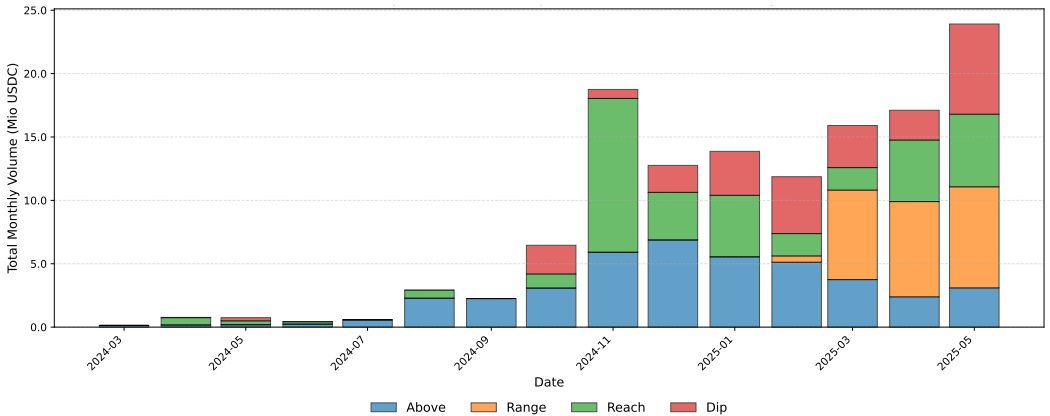
The share of Bitcoin options open interest across cryptocurrency exchanges, where open interest is calculated as the estimated notional value of all open options positions, or the aggregate dollar value of outstanding contract specified BTC deliverables.

Bitcoin options trading volume



Bitcoin options trading volume, in dollar terms, across cryptocurrency exchanges.

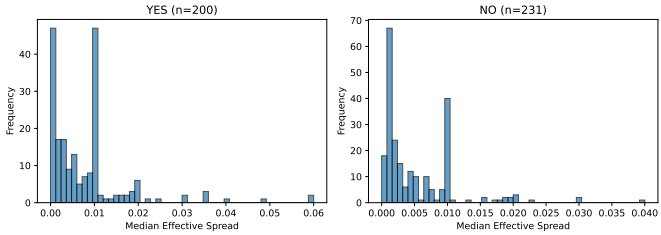
Bitcoin Polymarket bets trading volume



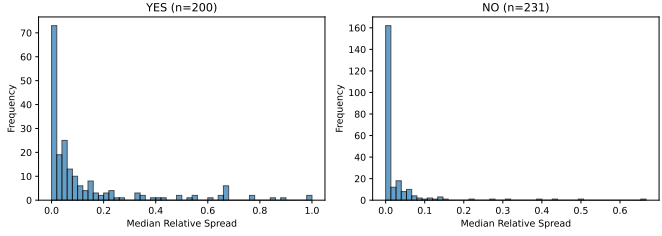
Total Monthly Transaction Volume by Betting Type.
Measured in notional USD terms as the total number of contracts traded; since each contract pays out 1 USD, this corresponds directly to the total notional amount exchanged.

Median spreads per side, computed separately for YES and NO

(a) BTC – Median Effective Spreads



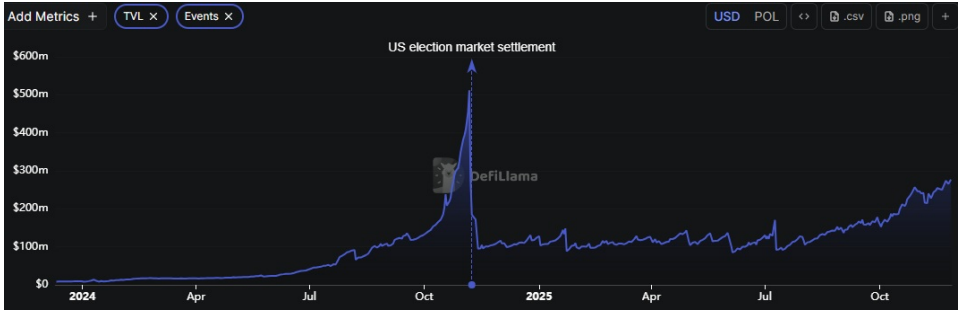
(b) BTC – Median Relative Spreads



Evaluation Day	Event
11/5/2024	Election Day
1/21/2025	Inauguration Day (Jan 20, 2025)
2/3/2025	On February 1, Trump issued EO announcing tariffs on Canada, Mexico, and China.
2/10/2025	Trump announced 25 percent import tariffs on steel and separate proclamation imposing 25 percent tariffs on aluminum as of March 12.
3/4/2025	EOs to raise the new tariffs on all imports from China from 10 percent to 20 percent, impose 10 percent tariffs on imports of Canadian oil and energy products and 25 percent tariffs on the remainder of imports from Canada.
3/25/2025	The White House issued secondary tariffs on third countries importing Venezuelan oil.
3/26/2025	The White House imposed 25 percent tariffs on automobiles and certain automobile parts.
4/3/2025	On April 2, the White House invoked IEEPA to impose baseline 10 percent tariff starting April 5 and then "reciprocal" tariffs starting April 9.
4/8/2025	The White House amended to impose additional 50 percent tariff on imports from China, increasing to 84 percent.
4/9/2025	The US imposed an additional country-specific tariff on China; then paused other "reciprocal" tariffs for 90 days, except for China. China will now face 125 percent of tariffs.
4/11/2025	The White House issued a list of products, including smartphones and semiconductors, to be excluded from the April 2 executive order.
4/29/2025	The White House issued a proclamation and an executive order to address concerns over stacking tariffs and avoiding the cumulative tariffs. The proclamation also amended previous tariffs under Section 232 regarding automobiles and automobile parts.

Table 3: Trump's Tariff Announcements Dates. The table lists the key tariff-related policy communication dates identified in the AIER analysis ("How Equity Markets Reacted to Trump's Tariff Announcements," American Institute for Economic Research).

Polymarket – TVL



Panel Regression – Range Bets (CLOB–OIP)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BTC Vol_{30}		0.008							
		(0.017)							
USDC Vol_{30}			0.076***						
			(0.016)						
VIX_{BTC}				0.015					
				(0.014)					
L2 Risk					0.086***				
					(0.014)				
Diff Underlying						0.019			
						(0.015)			
NBP							-0.006		
							(0.015)		
Fear & Greed								0.025	
								(0.017)	
Announcement									-0.048***
									(0.014)
Δ BTC (%)	-0.012	-0.012	-0.010	-0.012	-0.011	-0.012	-0.018	-0.011	-0.010
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.013)	(0.012)	(0.013)	(0.013)
Δ USDC (%)	0.009	0.009	0.010	0.009	0.010	0.009	0.005	0.009	0.009
	(0.012)	(0.012)	(0.013)	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Weekend	-0.308***	-0.308***	-0.299***	-0.308***	-0.304***	-0.309***	-0.033*	-0.308***	-0.319***
	(0.041)	(0.041)	(0.041)	(0.041)	(0.041)	(0.041)	(0.020)	(0.041)	(0.042)
Moneyness	0.056***	0.057***	0.057***	0.060***	0.057***	0.058***	0.138***	0.050***	0.061***
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.006)	(0.017)	(0.007)	(0.007)
Maturity	0.481***	0.480***	0.473***	0.479***	0.469***	0.480***	0.168***	0.482***	0.478***
	(0.050)	(0.050)	(0.050)	(0.050)	(0.050)	(0.050)	(0.025)	(0.050)	(0.050)
R^2 Adj	0.151	0.151	0.157	0.152	0.159	0.152	0.050	0.152	0.153
Obs.	12,366	12,366	12,366	12,361	12,366	12,366	4,483	12,366	12,366

Table 4: Panel Regression – Range Bets – CLOB-OIP.

Range Bets: Interpretation

For Range bets, mispricing is driven by funding/settlement risk (USDC volatility, L2)

- Returns for BTC and USDC (positive but not significant)
- Volatility (positive): High stablecoin volatility (USDC 30d vol) increases the difference
- Contract features: The difference is larger for ATM bets and shrinks as time passes.

Panel Regression – Above Bets (CLOB–OIP)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BTC Vol_{30}		-0.016*							
		(0.009)							
USDC Vol_{30}			0.142***						
			(0.009)						
VIX_{BTC}				0.200***					
				(0.014)					
L2 Risk					0.139***				
					(0.017)				
Diff Underlying						0.228***			
						(0.009)			
NBP							0.001		
							(0.015)		
Fear & Greed								0.333***	
								(0.010)	
Announcement									-0.020**
									(0.009)
Δ BTC (%)	0.019	0.019	0.018	0.016	0.019	0.016	-0.027*	0.019	0.019
	(0.013)	(0.013)	(0.013)	(0.014)	(0.013)	(0.013)	(0.016)	(0.013)	(0.013)
Δ USDC (%)	0.003	0.003	0.002	0.004	0.003	0.004	0.003	0.003	0.003
	(0.023)	(0.023)	(0.022)	(0.024)	(0.023)	(0.021)	(0.020)	(0.021)	(0.023)
Weekend	0.072***	0.071***	0.067***	0.085***	0.066***	0.051***	-0.048***	0.044***	0.068***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.010)	(0.010)	(0.018)	(0.010)	(0.011)
Moneyness	-0.425***	-0.425***	-0.413***	-0.439***	-0.426***	-0.437***	-0.484***	-0.532***	-0.427***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.015)	(0.013)	(0.012)
Maturity	-0.023***	-0.023***	-0.004	-0.033***	-0.022***	0.026***	0.205***	0.030***	-0.023***
	(0.008)	(0.008)	(0.008)	(0.007)	(0.008)	(0.008)	(0.019)	(0.008)	(0.008)
R^2 Adj	0.184	0.184	0.204	0.224	0.203	0.233	0.277	0.279	0.184
Obs.	10,019	10,019	10,019	10,016	10,019	10,019	3,180	10,019	10,019

Table 5: Panel Regression – Above Bets – CLOB-OIP.

Above Bets: Interpretation

Above bets behave like bullish options, whereas differences increase in sentiment and volatility.

- Volatility: BTC VIX (positive and highly significant).
  - Higher volatility coincides with a larger difference (the probability of finishing above the strike increases with volatility)
- Fear & Greed (positive) - more greed coincides with a larger difference
- Returns (positive but not significant): upside moves in BTC increase the difference.
- Contract features: mispricing is larger for OTM contracts

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