Perpetual Futures Pricing in CeFi and DeFi: Models, Microstructure, and Design Trade–offs

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Abstract

Perpetual futures ("perps") are futures without expiry whose prices are kept close to a reference index through periodic funding transfers between longs and shorts. This paper systematizes the main pricing approaches used across centralized exchanges (CeFi) and decentralized exchanges (DeFi), connects them to the cost-of-carry framework, and analyzes how market microstructure (order book vs. AMM vs. oracle-quoted pools) shapes equilibrium pricing, risk, and solvency.

Acknowledgments. This note distills practical mechanisms used across major venues and abstracts them into a research-friendly framework suitable for audits and implementation. Please, feel free to DM if you spot any errors.

Contents

1 Market View: Off-Chain (CeFi) vs On-Chain (DeFi) Perpetuals

1.1 CeFi landscape (CLOB perps)

- **Scale and share.** Crypto derivatives remain the dominant venue activity; in 2025 derivatives comprised ∼74–76% of centralized exchange volume.[2] For BTC specifically, perps accounted for ∼68% of all BTC trading volume YTD 2025.[1, 14]
- **Market structure.** Centralized limit order books (CLOBs) with hourly (or 8-hour) funding; leaders by OI/volume include Binance, Bybit, OKX.[1, 4]
- **Contract mix.** USD-margined linear perps dominate; crypto-margined (inverse) perps ¡30% of BTC/ETH volume by 2025.[5]
- **Trends.** OI at/near ATHs in 2H25; leadership shares are fluid (such as OKX and Bybit gaining vs Binance in some months).[2, 4]

1.2 DeFi landscape (on-chain perps)

- **Scale.** DEX perps hit new highs in 2025; CoinGecko estimates ∼ $1.8T DEX-perp volume in Q3'25.[3]
- **Leaders & designs.** Orderbook L1s (such as Hyperliquid) run fully on-chain matching with CEX-like funding based on impact premium and hourly settlement.[9, 10] Oracle/pool perps (such as GMX v2) quote at oracle mark, use skew/utilisation funding and capped net price impact with rebates.[7, 8] Validator-run orderbooks (such as dYdX v4) decentralize funding via per-block proposer votes and hourly ticks.[11, 12]
- **Current throughput.** Daily league tables vary, but dashboards show Hyperliquid, Lighter, Aster, edgeX frequently at the top by volume/OI in mid–late 2025.[6, 13]

Note on notation. We write $\overline{x}_t$ to denote a time-averaged value of x over a window W (e.g., a 60-minute TWAP or EMA of per-block samples). Venues smooth the raw premium to (i) reduce microstructure noise and whipsaw, (ii) harden against manipulation of single snapshots, and (iii) align with the cadence of discrete funding ticks (typically hourly). Thus, $\overline{\text{premium}}$ is the windowed average premium used in the funding formula, not the instantaneous tick premium.

1.3 Microstructure contrasts (pricing implications)

- **Price discovery.** CeFi CLOBs discover price in-book; funding is a small basis control. On oracle/pool DEXs, the oracle drives marks; funding additionally prices inventory/utilisation risk.[7]
- **Funding mechanics.** CEX/Orderbook: $F = \overline{\text{premium}} + \text{clamp}(r - \overline{\text{premium}}, \pm c)$ with impact-price premium.[9] Pool-perps: skew/utilisation-aware funding, sometimes with anchor to oracle and exit-only net price impact with rebates.[7] Validator-orderbooks: premium sampling via proposer votes, then hourly aggregate.[11]
- **Risk location.** CeFi centralizes inventory and liquidation backstops. On DEXs, risk is explicitly allocated: LP vaults (pool architectures), insurance funds/backstop vaults (orderbooks), and OI caps tied to TVL.[7, 10]

1.4 Participants, regulation, outlook

- **Participants.** CeFi remains the venue for latency-sensitive market makers and global retail; DeFi attracts crypto-native flow, systematic strategies, and LPs seeking fee/funding yield.[4]
- **Regulatory movement.** Access to perps has broadened in the U.S. via new offerings on major brokers/venues in 2025, while DEXs continue to operate globally with jurisdiction-dependent access.[14]
- **Design trend.** Convergence toward hybrid models: impact-premium anchors, and skew/utilisation terms, plus robust oracle state machines and caps. On-chain volumes and OI are increasingly competitive with mid-tier CEXs.[6, 3]

2 Models Comparison

Exchange	Venue Type	Pricing / Funding	Oracle / Mark	Notable Mechanisms
Binance	CeFi CLOB	Impact-premium vs index; 8h/1h funding with interest leg and clamps	Venue indices (spot/perp); book-driven mark	Deep order books, risk engine, insurance fund, ADL
Bybit	CeFi CLOB	Impact-premium funding; interest leg; hourly settlement	External indices; venue TWAP marks	Unified margin, tiered leverage, insurance fund
OKX	CeFi CLOB	Premium vs index with clamps; interest leg optional	External indices; venue mark/TWAP	Cross/isolated, risk tiers, ADL backstop
dYdX (v4)	On-chain order book (Cosmos)	Premium from impact bid/ask; per-block votes aggregated hourly; caps	Oracle index; mark blends index + venue microstructure	Validator-run off-chain book + on-chain settlement; epochs
Hyperliquid	On-chain CLOB (HyperBFT)	Hourly funding = avg premium + clamped interest spread; hard cap/hour	Weighted-median CEX oracle; robust mark (oracle + book EMA + ext. perps)	One-block finality; liquidator vault; margin tiers; hyperps
GMX (v2)	Oracle/pool DEX	Entry at oracle mark; adaptive funding by skew/utilisation; capped net price impact on exits	Chainlink Data Streams; oracle TWAP mark	GM Pools; OI caps; ADL for synthetic markets; rebates
Drift (v2)	Hybrid (Solana DLOB+JIT+LPs)	Oracle-led pricing; funding aligns mark to oracle with skew sensitivity	Pyth/Solana oracles; smoothed mark with stale guards	DLOB + JIT MM + passive LPs; insurance fund; re-pegs

Table 1: Real perpetual venues and their pricing/funding approaches (CeFi and DeFi). "Sources: [15, ?, ?, 9, 19, 21, 23, 26]."

3 Perpetuals in one line

Let S_t be the reference index and P_t the perp mark. For a position of size q contracts (one contract references one unit of the index), the instantaneous P&L is

$$d\Pi_t = \underbrace{\pm\, q\, dS_t}_{\text{delta to index}} \;-\; \underbrace{q\, S_t\, F_t\, dt}_{\text{funding flow}} \;-\; d\text{fees}_t\,,$$

where F_t is the funding rate (paid by longs if $F_t > 0$, paid by shorts if $F_t < 0$). Funding is designed to control the basis $B_t := P_t - S_t$ so that, in expectation, P_t remains close to S_t.

Cumulative P&L from entry to exit Entering at time 0 and exiting at time T,

$$\Pi_T = \pm\, q\,(S_T - S_0) \;-\; q\int_0^T S_t\, F_t\, dt \;-\; \sum_{k\in\mathcal{F}(0,T)} \text{fees}_k\,,$$

where $\mathcal{F}(0,T)$ indexes trading and funding fee events between 0 and T. On venues that settle funding at discrete ticks t_k with rate f_k over interval Δt_k, the integral is approximated by

$$\int_0^T S_t\, F_t\, dt \;\approx\; \sum_k S_{t_k}\, f_k\, \Delta t_k\,.$$

Notation and variables

- S_t: reference index (fair value target).
- P_t: perp mark (drives unrealized P&L, margin, liquidations).
- $B_t := P_t - S_t$: basis between perp and index.
- F_t: funding rate per unit time; sign determines payor side.
- dt: time increment for funding accrual (e.g., one hour).
- Π_t: position P&L.
- "$\pm$": $+$ for a long position, $-$ for a short position.
- fees: trading fees, borrow fees, and any venue-specific costs.

Example

Consider a long position of notional one BTC on a BTC perp.

- Start of hour: index $S_0 = \$40{,}000$, mark $P_0 = \$40{,}100$.
- End of hour: index $S_1 = \$40{,}300$, mark $P_1 = \$40{,}290$.
- One-hour funding rate $F = 0.01\%$ (longs pay, i.e., $F > 0$).
- Trading fee to open $= 0.04\%$ of notional (ignore close for now).

Delta P&L. Long one BTC gains approximately the index move:

$$\Delta\Pi_{\text{delta}} \approx +\big(S_1 - S_0\big) = +\$300.$$

Funding P&L. Funding accrues on notional (venues may use index or mark TWAPs). For a simple illustration, take \$40,100:

$$\Delta\Pi_{\text{fund}} = -\,F \times \$40{,}100 = -\,0.0001 \times 40{,}100 = -\,\$4.01.$$

Fees. Entry fee on notional at entry mark:

$$\Delta\Pi_{\text{fees}} = -\,0.0004 \times \$40{,}100 = -\,\$16.04.$$

Total for the hour.

$$\Delta\Pi \approx \$300 \;-\; \$4.01 \;-\; \$16.04 \;=\; \$279.95.$$

Remarks.

- If funding were negative, shorts would pay longs and the funding term would add to long P&L.
- Venues may compute funding on a TWAP, cap it, or include an interest component; the structure above still applies.
- The mark P_t drives liquidations and unrealized P&L; the index S_t is the fair-value anchor.

4 A minimal fair-value lens

In continuous time, a frictionless no–arb baseline with dollar collateral rate r_t implies that the expected drift of the discounted perp P&L is zero. A convenient discrete approximation over a small interval Δt is

$$\mathbb{E}_t[\Delta P] - \mathbb{E}_t[\Delta S] \;\approx\; F_t\,\Delta t \;+\; \text{frictions (inventory, utilisation, caps)}\,. \tag{1}$$

Thus, "fair" funding compensates the expected premium of P over S plus any platform frictions the mechanism wishes to encode (inventory and liquidity costs, imbalance penalties, oracle uncertainty).

5 Funding as a control law

Most venues implement F_t as a bounded function of observable state variables. Let

$$\sigma_t := \frac{\mathrm{OI}_t^L - \mathrm{OI}_t^S}{\mathrm{OI}_t^L + \mathrm{OI}_t^S + \varepsilon} \in [-1, 1] \quad \text{(skew or inventory imbalance)},$$

$$U_t := \frac{\text{open interest}}{\text{pool liquidity or limit book liquidity}} \in [0, 1] \quad \text{(utilisation)},$$

$$\pi_t := \frac{P_t - S_t}{S_t} \quad \text{(premium to the index)}.$$

A generic funding controller is

$$F_t \;=\; w_\pi\, a(\pi_t) \;+\; w_\sigma\, g(\sigma_t) \;+\; w_U\, h(U_t) \;+\; \iota_t\;,$$

with bounded Lipschitz functions a, g, h [28], weights $w_\cdot$ set by governance, and ι_t an optional interest rate leg that is often zero on crypto venues. Equation (5) nests the dominant models below.

Variable definitions

- S_t reference index used as the venue estimate of fair value
- P_t mark used for unrealized PnL margin and liquidations
- π_t percentage premium of the perp to the index
- OI_t^L notional long open interest at time t
- OI_t^S notional short open interest at time t
- σ_t signed imbalance of longs and shorts in the range minus one to plus one
- U_t utilisation of risk capacity defined as total open interest divided by available pool or book liquidity
- ε tiny positive constant to avoid division by zero
- $a(\cdot)$ basis response function for example identity or a clipped linear map
- $g(\cdot)$ skew response function for example increasing odd function through the origin
- $h(\cdot)$ utilisation response function for example convex map that steepens near one
- w_π, w_σ, w_U non negative weights chosen by governance or risk council
- ι_t deterministic interest component for example base minus quote rate differential

Simple example mappings

- **Basis driven** $a(x) = \mathrm{clip}(x, -c, c)$ with $g \equiv 0$ and $h \equiv 0$
- **Skew driven** $g(x) = k\,x$ with $a \equiv 0$ and $h \equiv 0$
- **Mixed** $a(x) = k_1 x$ and $g(x) = k_2 x$ with a cap on F_t

6 Model taxonomy

6.1 (M1) Impact premium funding (CLOB perps)

CeFi perps and some on chain order book venues estimate a premium from executable impact prices:

$$\pi_t^{\mathrm{imp}} = \frac{\max\{0,\, P_t^{\mathrm{imp,bid}} - S_t\} - \max\{0,\, S_t - P_t^{\mathrm{imp,ask}}\}}{S_t}.$$

Funding is then a smoothed average of π_t^{imp} plus an interest leg with caps:

$$F_t = \overline{\pi^{\mathrm{imp}}}_{t;W} + \mathrm{clamp}\big(r - \overline{\pi^{\mathrm{imp}}}_{t;W},\, \pm c\big).$$

Variables and functions

- S_t reference index at time t.
- $P_t^{\mathrm{imp,bid}}$ average fill price to sell an *impact notional* into the bid side of the book at time t.
- $P_t^{\mathrm{imp,ask}}$ average fill price to buy an *impact notional* into the ask side at time t.
- *Impact notional* fixed dollar size used to probe executable prices (venue parameter).
- π_t^{imp} signed premium of the perp versus the index based on executable impact prices.
- $\overline{\pi^{\mathrm{imp}}}_{t;W}$ time averaged premium over window W (for example a one hour moving average).
- r interest leg (for example base minus quote rate; often set near zero on crypto venues).
- c cap for the clamp term (for example $c = 0.05\%$ on an eight hour basis).
- $\mathrm{clamp}(x, \pm c) := \min\{\max\{x, -c\},\, c\}$ which bounds x between $-c$ and $+c$.

Intuition: If executable prices imply the perp is rich to the index (impact bid above S_t or impact ask close to or above S_t), the premium π_t^{imp} is positive, so F_t is positive and longs pay shorts. That attracts sellers or shorts and pulls the basis toward zero.

Mini example

- $S_t = \$40{,}000$, impact notional set by venue.
- $P_t^{\mathrm{imp,bid}} = \$40{,}050$, $P_t^{\mathrm{imp,ask}} = \$40{,}060$.
- Then $\pi_t^{\mathrm{imp}} = \frac{\max(0,50) - \max(0,-60)}{40{,}000} = 50/40{,}000 = 0.125\%$.
- Suppose $\overline{\pi^{\mathrm{imp}}}_{t;W} = 0.10\%$, $r = 0.01\%$, $c = 0.05\%$ (all on an eight hour basis).
- Clamp term: $\mathrm{clamp}(0.01\% - 0.10\%, \pm 0.05\%) = \mathrm{clamp}(-0.09\%, \pm 0.05\%) = -0.05\%$.
- Funding: $F_t = 0.10\% + (-0.05\%) = 0.05\%$ (longs pay shorts on the funding tick).

6.2 (M2) Inventory or skew based funding

Market makers target an inventory band; funding is proportional to signed skew:

$$F_t \;=\; k\,\sigma_t \quad \text{optionally bounded by } \pm F_{\max} \text{ and with hysteresis.}$$

Variables and functions

- $\sigma_t := \dfrac{\mathrm{OI}_t^L - \mathrm{OI}_t^S}{\mathrm{OI}_t^L + \mathrm{OI}_t^S + \varepsilon} \in [-1,1]$ signed long minus short imbalance.
- $k \geq 0$ proportional gain that sets how aggressively funding reacts to skew.
- $F_{\max} \geq 0$ hard cap on the magnitude of F_t.
- *Hysteresis* optional dead band so that small σ_t near zero produces $F_t = 0$ to avoid chattering, for example set $F_t = 0$ if $|\sigma_t| \leq \sigma_{\min}$.

Intuition The crowded side pays even if the instantaneous basis is small. This stabilizes inventory and reduces tail slippage during runs.

Mini example

- $\mathrm{OI}_t^L = 120$ million, $\mathrm{OI}_t^S = 80$ million, so $\sigma_t \approx 0.20$.
- Gain $k = 0.15\%$ per unit skew on an eight hour basis, cap $F_{\max} = 0.10\%$.
- Raw $F_t = 0.15\% \times 0.20 = 0.03\%$ so longs pay shorts 0.03% on the tick.

6.3 (M3) Oracle anchored pool pricing for AMM or pool perps

Pool based perps quote entry at a mark derived from an oracle TWAP of S_t. Funding depends on pool state:

$$F_t \;=\; w_\sigma\, g(\sigma_t) \;+\; w_U\, h(U_t) \quad \text{anchor leg small or zero.}$$

Some designs add net price impact on exits and rebates when users reduce imbalances. Liquidity and solvency depend on pool TVL, per market open interest caps, and ADL rules for synthetic markets.

Variables and functions

- S_t reference index, often a TWAP over external venues.
- P_t pool mark derived from the oracle for entry and risk.
- $U_t := \dfrac{\text{open interest}}{\text{pool liquidity}} \in [0,1]$ utilisation of available liquidity.
- σ_t long minus short skew as above.
- $g(\cdot)$ skew response, for example $g(x) = k_\sigma x$ with an optional cap.
- $h(\cdot)$ utilisation response, for example convex so that funding steepens as U_t approaches one.
- $w_\sigma, w_U \geq 0$ weights chosen by governance or risk council.

Intuition When longs crowd the pool or when utilisation is high, funding increases for longs to attract the opposite flow and to compensate LPs for scarce capacity. The oracle anchored mark keeps entry close to the index.

Mini example

- Pool TVL \$200 million, total perp notional open \$150 million so $U_t = 0.75$.
- Skew $\sigma_t = +0.25$, choose $g(x) = 0.08\% \cdot x$ and $h(u) = 0.02\% \cdot \dfrac{u}{1-u}$ per eight hours.
- $w_\sigma = 1$, $w_U = 1$. Then $F_t = 0.08\% \times 0.25 + 0.02\% \times \dfrac{0.75}{0.25} = 0.02\% + 0.06\% = 0.08\%$ paid by longs.

6.4 (M4) Hybrid anchor with utilisation damping and leverage haircuts

A practical hybrid uses the controller with a small anchor for fast mean reversion, a skew term for crowd control, a utilisation term for scarce liquidity, and leverage haircuts so high leverage positions contribute less effective notional to funding:

$$N^{\text{eff}} \;=\; N \cdot \Big(\frac{L}{L_{\text{ref}}}\Big)^{\beta}, \qquad \beta \in [0.4, 0.6].$$

Funding is netted long minus short up to matched effective notional. Any unmatched tail pays the liquidity providers at a fixed share.

Variables and functions

- $a(\pi_t)$ basis response on the premium $\pi_t := \dfrac{P_t - S_t}{S_t}$ with small weight for quick anchoring.
- $g(\sigma_t)$ skew response and $h(U_t)$ utilisation response as above.
- N gross notional of a position, L chosen leverage, L_{ref} reference leverage for haircuts, for example five times.
- β haircut exponent that reduces the effective weight of high leverage positions in funding nets.
- N^{eff} effective notional used for netting and for the unmatched tail calculation that flows to LPs.
- $\phi \in [0, 1]$ optional fixed share of unmatched tail paid to LPs.

Intuition The anchor term pulls quickly toward the index, the skew term balances inventory, the utilisation term prices scarce capacity, and haircuts keep very high leverage positions from dominating the funding signal.

Mini example

- Two longs: \$20 million at $L = 10$ and \$10 million at $L = 3$. Two shorts: \$15 million at $L = 5$.
- Set $L_{\text{ref}} = 5$, $\beta = 0.5$.
- Effective notionals: long one $= 20 \cdot (10/5)^{0.5} \approx 20 \cdot \sqrt{2} \approx 28.28$ million; long two $= 10 \cdot (3/5)^{0.5} \approx 7.75$ million; total long eff ≈ 36.03 million. Short eff $= 15 \cdot (5/5)^{0.5} = 15$ million.
- Matched eff $= 15$ million. Unmatched long tail $= 21.03$ million.
- Suppose controller yields $F_t = 0.06\%$ per eight hours. The matched leg nets between longs and shorts. The unmatched tail pays LPs at share $\phi = 20\%$, so LP flow is $0.20 \times 0.06\% \times 21.03$ million $\approx$ \$2,523 on the tick.

7 Oracle and mark construction (DeFi)

Index oracle. Use multiple independent sources, normalize to the same units, and publish a rolling TWAP/TWAR over hours with: (i) rate-of-change caps, (ii) outlier trimming (median/MAD), (iii) freshness rules and state flags (OK/Degraded/Close-only/Frozen).

Mark. The mark for funding and risk is a smoothed blend of the index and local venue information (book mid, EMA of book-index gap, other perp mids), updated on a fixed cadence and bounded by per-sample and rolling caps to prevent spikes.

8 Microstructure and risk transfer

Order book venues

Price discovery happens in the book; funding is the tax/subsidy that aligns perp price to index. Latency, queue priority, and impact costs dominate microstructure P&L. Liquidations route to the book first; backstop mechanisms absorb residual risk.

Pool/oracle venues

Entry is at oracle mark; *inventory risk* sits with the pool. Funding and utilisation fees shape flow. Design needs: (i) OI caps tied to TVL, (ii) ADL or partial fills to keep solvency, (iii) explicit rules for stale oracles (raise margins, disable anchor, close-only).

9 Connecting to cost-of-carry

When the underlying embeds a carry c_t (such as yield-bearing tokens or basis between collateral and quote), equation (1) implies

$$\mathbb{E}_t[\Delta B] \approx F_t - c_t + \text{frictions}.$$

Thus a "neutral" long-run funding target is $F_t \approx c_t$ absent frictions. Real venues deviate to pay for inventory, utilisation, and risk capital.

10 Design patterns that work

(a) **Bounded, additive controllers.** Prefer $F = w_\pi a(\pi) + w_\sigma g(\sigma) + w_U h(U)$ with caps and hysteresis, rather than multiplicative boosts that become pro–cyclical at stress.
(b) **Leverage haircuts.** Compute funding on effective notionals to prevent levered farming and reduce liquidation cascades.
(c) **Matched vs. unmatched accounting.** Net long/short up to the matched leg; route the unmatched tail to LPs at a fixed share. Prove a conservation identity for funding flows.
(d) **Oracle states.** On degraded or frozen data: turn anchor to zero, raise initial/maintenance margins, reduce OI caps, and prefer close–only.
(e) **Caps and rate limiters.** Cap per–sample funding, cap cumulative windowed funding, and cap *changes* (max ΔF) to dampen oscillations.

11 Worked example (hybrid controller)

Let

$$a(\pi) = \tanh(\pi/\pi_0), \quad g(\sigma) = \tanh(\sigma/\sigma_0), \quad h(U) = h_{\max} \cdot \mathrm{smoothstep}(U/U_\star).$$

Set F_t by (5) with (w_π, w_σ, w_U) calibrated so that skew halves in 2–4 hours under typical flow, and liquidation incidence meets a daily risk budget. Enforce $|F_t| \le F_{\max}$ and $|F_t - F_{t-\Delta}| \le \delta_F$. Compute funding on N^{eff} and implement matched/unmatched logic with LP share ϕ.

12 Lessons learned

- **Funding is a control knob, not a price.** Treat it like a bounded PID controller acting on premium, skew, and utilisation; avoid pro–cyclical amplification.
- **Microstructure dictates model choice.** CLOBs should lean on impact–premium; pools must encode utilisation and TVL constraints explicitly.
- **Zero–sum (plus LP).** Funding should conserve cashflows long–short, with a transparent, bounded carve–out to LPs who absorb unmatched risk.
- **Leverage must be weighted.** Haircuts on effective notional are more robust than ad–hoc funding multipliers at high L.
- **State machines save solvency.** Clear oracle states and automatic margin/OI responses prevent rare events from turning into insolvency.

13 Future outlook

- **Permissionless listings.** HIP–style deployer models with stake/slashing and standardized oracles will expand the asset set while keeping risk bounded.
- **Composability.** Native hooks for lending, options, and vaults (hedged LP) will turn perps into settlement rails for structured products.
- **On-chain risk metrics.** Publishing real–time state (skew, utilisation, windowed funding, oracle flags) improves user behavior and reduces regime switches.

14 Conclusion

Perpetual futures remain the same linear instrument across CeFi and DeFi; what differs is how funding is computed and how microstructure allocates liquidity and risk. A unifying view treats funding as a bounded controller acting on premium, skew, and utilisation, with leverage haircuts and explicit cashflow conservation. With robust oracles, stateful risk responses, and clear LP economics, on–chain perps can achieve price integrity comparable to CeFi while retaining programmability and composability.

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