Execution Quality, Depth, and Channel Firmness in On-Chain Real-World Asset Perpetuals Versus Regulated Home Venues

Fermi Labs Research

Fermi Labs
https://fermilabs.xyz

Abstract. Perpetual futures on real-world assets (RWAs) traded about $800 billion in August 2026. We ask whether any on-chain venue matches the regulated home market at institutional size. We rebuild CME Globex and U.S. equity order books from 1.6 billion market-by-order messages (1 October–12 November 2026) and compare them, channel by channel, with our own on-chain captures and with dated third-party snapshots of order books, request-for-quote (RFQ) swaps and an oracle vault. At $1 million, firm on-chain books in equity-index products cost 7.5–83 times CME in seven observations, five of them above 20 times; in mega-cap stocks they mostly could not fill the order, and where they could they cost 4–9 times a single-venue Nasdaq walk. Crude oil is the exception, at 2–11 times CME in October. Dealer-hedged RFQ swaps quote index and crude products at 3–6 times CME, but those quotes are indicative, subject to last look and position caps, and offered only in market hours. The evidence supports an order-of-magnitude gap in firm index liquidity, not in every product or channel. We specify what a 20-day capture, to be pre-registered, would add: firm RFQ fills, rejection rates, book replenishment, and the order size at which the gap reaches tenfold.

Keywords: Market microstructure · Perpetual futures · Real-world assets · Order-book depth · Request for quote · Last look

1 Introduction

Perpetual futures that reference real-world assets (RWAs)—single equities, equity indices, commodities and currencies—have become the fastest-growing segment of crypto derivatives. Across the 19 centralized (CEX) and decentralized (DEX) venues tracked by CoinMarketCap Research [17],[1] monthly volume rose from $105.2 billion in January 2026 to $799.5 billion in August, and totalled $3.16 trillion between 29 December 2025 and 31 August 2026. The on-chain share fell over the same period, from about 45% to 13.1%, while Binance alone cleared 50.4% of cumulative volume. That tracker omits Variational, one of the two largest on-chain RWA venues (Sect. 2.1).

[1] All web sources cited in this paper were last accessed on 24 November 2026.

These contracts reference assets whose primary markets run on regulated rails: CME Globex for index and crude-oil futures, and Nasdaq and the other U.S. exchanges for large technology stocks. For an institutional desk, the comparison that matters is the cost and reliability of executing a large order—$1 million and above—against that home market. This paper measures that comparison.

The answer depends on how an order reaches liquidity. On-chain, a $1 million order can sweep a firm central limit order book (CLOB), request a quote from a dealer that may still reject it (RFQ with last look), or trade against an oracle-priced vault; centralized exchanges offer a fourth route for comparison. These channels differ in what a displayed price commits the venue to, so we keep them separate throughout and never pool an indicative quote with a book walk.

We make four contributions. First, we rebuild full-depth regulated books from 1,598,298,606 market-by-order (MBO) messages in 556 checksum-verified files (1 October–12 November 2026), validate them against an independent order-map implementation, and state the direction of every measurement bias. Second, we compare $1 million execution by channel, combining our own 1 October on-chain captures with dated third-party snapshots, each labelled by date, session and fee basis. Third, we set out from primary documentation what the non-firm channels do and do not commit to, and give a simple expression for the expected cost of last look (Eq. (4)). Fourth, we state what remains unmeasured—firm RFQ fills, rejection rates, book replenishment and the size V^* at which the gap reaches tenfold—and specify the capture that would measure it. Appendix A maps six likely objections to the evidence and its status.

Main result. At $1 million, firm on-chain books in equity-index products cost 7.5–83 times CME in the seven observations available, five of them above 20 times. The two below 10 times come from one third-party snapshot of trade.xyz, taken before fees and across the U.S. cash close. In mega-cap single stocks, firm books mostly could not fill $1 million; where they did, they cost 4.4–8.6 times a single-venue Nasdaq walk, a home benchmark that overstates the consolidated cost. Crude oil is the exception, at 2.1–10.9 times CME in October. Variational's dealer-hedged swaps quote index and crude products at 3.3–5.9 times CME, but those quotes are indicative, subject to last look and position caps, and available only while the home market is open.

Section 2 reviews market growth and venue designs, with a matched WTI crude-oil comparison. Section 3 describes the data, reconstruction and biases. Section 4 reports results by channel, Sect. 5 covers off-hours trading, and Sect. 6 summarizes mechanisms behind the gap. Section 7 sets out limitations and the planned capture, and Sect. 8 concludes.

2 Market Context and Venue Designs

2.1 Growth, Composition and Top On-Chain Tickers

Figure 1 plots combined CEX and DEX volume in RWA perpetuals for January–August 2026. In January, precious metals and energy carried 81.0% of volume

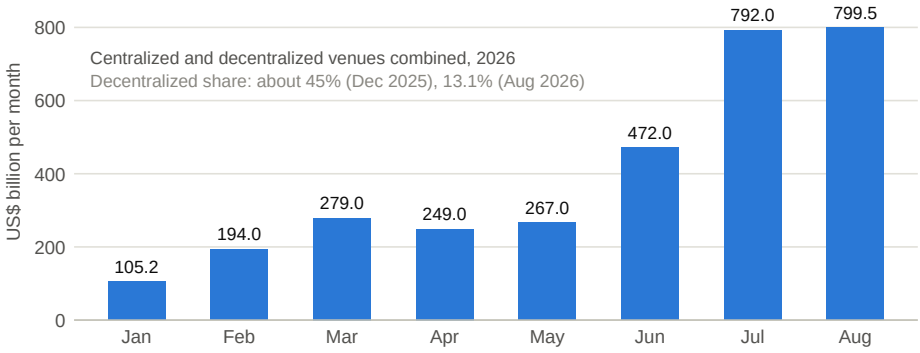


Fig. 1. Monthly RWA perpetual volume, centralized and decentralized venues combined, January–August 2026, in US$ billion (a further $4.1 billion traded on 29–31 December 2025). Source: CoinMarketCap Research [17], whose tracker does not include Variational.

and single stocks 9.0%; activity peaked in March with the Strait of Hormuz oil shock. From the week of 1 June, single stocks overtook commodities, reaching 62.3% of August volume against 18.8%. Over the 36-week window, single stocks cleared $1,361.3 billion (43.1%), indices and ETFs $469.0 billion (14.8%), and commodities $1,314.3 billion (41.6%) [17]. DefiLlama tracked 753 real-world underlyings across 3,605 perpetual markets on about 40 venues, with on-chain RWA open interest of $4.9 billion by September 2026 [21].

CoinMarketCap's tracker covers 12 on-chain venues and leaves out Variational, so both its 13.1% on-chain share and its 81.7% Hyperliquid HIP-3 share of August DEX volume exclude it. Castle Labs puts Variational and trade.xyz together at 90% of $123 billion of on-chain RWA perpetual volume in August [10], and Alea Research estimates that Variational's share of traditional-market volume, measured against trade.xyz and Aster, rose from 6.1% in July to 32.9% in September [2]. Any on-chain comparison therefore has to include both venues.

Volume concentrates in high-beta semiconductor and newly listed names. Over the CoinMarketCap window, SanDisk (`SNDK`) traded $365.9 billion ($185.9 billion in August alone), SK hynix's two lines $253.9 billion (KRX `SKHYNIX` $193.4 billion and the Nasdaq ADR `SKHY` $60.5 billion), SpaceX (`SPCX`) $171.2 billion and Micron (`MU`) $165.7 billion [17]. All four have regulated U.S. home markets: SpaceX began trading on Nasdaq on 12 June 2026 after raising $75 billion at $135 a share [52], and SK hynix ADRs began trading on Nasdaq on 10 July 2026 [51]. Even in these flagship names, trade.xyz's 24-hour volume in mid-November—$199.8 million in `SNDK`, $153.0 million in `MU` and $118.5 million in `SPCX`, besides $274.6 million in `xyz:SKHX` [1,9]—was about 0.6–2.2% of the three U.S. stocks' consolidated dollar turnover ($9–11.8 billion a day in `SNDK`, $18–25 billion in `MU` and $12.5–14.2 billion in `SPCX` [43,31]).

On-chain venues also act as listing incubators, listing pre-IPO names a median 161 days before CEXs, commodities 21 days before and indices 19.5 days before.

Across 64 symbols that Binance listed after at least 30 days of on-chain trading, the on-chain share fell from a median 76.4% to 30.3% (falling in 61 of 64 cases), while total daily volume in the symbol rose 5.2-fold. Over the full window, Binance cleared $1,591.9 billion (50.4%) and Hyperliquid's HIP-3 markets $542.8 billion (17.2%) [17].

2.2 Venue Designs by Execution Channel

Table 1 summarizes the on-chain venues we study. trade.xyz (on Hyperliquid's HIP-3) and Aster run public on-chain CLOBs in which cancellations are processed ahead of takers [35]. Lighter runs a zero-knowledge-rollup CLOB, supplemented since May 2026 by an optional RFQ leg in which whitelisted makers inject quotes into the public book [39]. Variational's Omni platform has no public book: one Variational-seeded liquidity provider (OLP) quotes every request and hedges its exposure elsewhere [60,57]. Omni offers perpetuals, which trade around the clock on crypto-native liquidity, and, since 1 September 2026, swaps hedged with traditional dealers, which follow the home market's hours [59,22]. Ostium prices trades from oracles against a hedging vault [47], and Helix on Injective clears each block in a uniform-price batch auction [36].

2.3 A Matched Multi-Channel Benchmark: WTI Crude Oil

WTI crude oil trades on all three on-chain models as well as on NYMEX via CME Globex (`CL`), one of the deepest commodity futures books (Table 2). Trailing 30-day notional on trade.xyz ($6.45 billion) is about 0.4% of CME's ($73–77 billion a day over 21 trading days); Lighter ($0.447 billion) and Variational ($0.644 billion) are each below 0.05%. CME's median trade ($90,450) is 167 times trade.xyz's ($543). Within 10 bps of mid, CME holds $6.02–6.91 million per side in outright orders alone, 16–19 times Lighter's $360–380 thousand.

A $1 million order costs 1.45–1.69 bps on CME in our data (`CLX6` 1.68–1.69; `CLZ6` 1.45–1.46), and 10.67–12.81 bps on Lighter on 1 October (6.4–7.6 times `CLX6`). Our 1 October trade.xyz ladder is truncated (Sect. 3.3). Two third-party measurements disagree: Alea Research's 8 October snapshot put trade.xyz at 3.47 bps one-way before fees (about 2.1 times `CLX6`) [2], while Castle Labs' March tick reconstruction put it at 15.4 bps against 0.79 bps on CME `CLJ6` in the same period (about 20 times) [11]. Variational's swap quoted 5.5 bps (indicative) in our November quotes and 5.96 bps in Alea's snapshot (3.3–3.5 times `CLX6`); its perpetual returned no quote at $1 million. Crude oil is the clearest exception to an order-of-magnitude gap among the products we benchmark.

3 Data, Reconstruction and Direction of Bias

3.1 Regulated Home-Venue Corpus and Validation

The listed-market benchmark uses every checksum-valid file in our Databento acquisition manifest: 556 files totalling 26.41 GB compressed across five feeds,

Table 1. Designs of the on-chain RWA perpetual venues studied.

Venue	Channel	Ordering and quote firmness	When the home market is closed
trade.xyz (Hyperliquid HIP-3)	Public on-chain CLOB	Cancels processed before takers in each block; displayed quotes are firm until cancelled [35].	Trades 24/7; the mark is a 30-minute EWMA of internal impact prices, clamped to discovery bounds.
Lighter	ZK-rollup CLOB with optional RFQ leg	Standard accounts: 300 ms taker delay vs. 0 ms maker cancels; quotes injected by the RFQ leg are not locked [38,40].	Trades 24/7; weekend index divergence of up to 30 bps, with funding spikes.
Aster	On-chain CLOB (Pro mode)	Cancel priority; hidden iceberg orders.	Trades 24/7; thin resting depth outside primary hours.
Variational (Omni)	Single-dealer RFQ; no public book	Quotes shown while browsing are indicative; a firm quote issued on submission passes a last look against eleven documented risk checks whose thresholds are not published; no published quote validity or rejection rate [60,57,58].	Swaps follow home-market hours (closed at weekends as of November 2026; liquidations wait for the reopen); perpetuals trade 24/7, with equity-index perpetuals in a fixed mode at weekends [59].
Ostium	Oracle-priced hedging vault	Vault is the counterparty, at the oracle price plus a dynamic spread [47].	Closed at weekends (market orders rejected); stocks trade 09:30–16:00 ET; positions above the overnight cap are closed at 15:45 ET [48].
Helix (Injective)	CLOB cleared by per-block batch auction	Uniform-price frequent batch auction in each block [36].	Orders accepted 24/7, subject to oracle-staleness guards.

Taker fees. trade.xyz: 0.9 bps per side on index markets [2]. Lighter: none on standard accounts; 1 bp on RFQ fills [39]. Aster: 1.25 bps on traditional-market perpetuals from 7 September 2026 [2]. Variational: none; the protocol keeps 20% of OLP's spread [56,5]. Ostium: 3–6 bps opening fee plus a dynamic spread and a $0.10 oracle fee [48].

Table 2. WTI crude oil: CME Globex versus three on-chain execution models. Costs are one-way, bps of mid, for $1 million.

Metric	**CME Globex (CL)**	**trade.xyz (CLOB)**	**Lighter (CLOB + RFQ)**	**Variational (RFQ)**
Execution model	Price–time priority CLOB	On-chain CLOB; cancel priority	ZK-rollup CLOB; unlocked RFQ leg	Single-dealer RFQ; last look
Volume, trailing 30 days	≈849K contracts/day (≈$73–77B/day)	$6.45B (≈$215M/day)	$0.447B (≈$15M/day)	$0.644B (perp + swap)
Share of CME notional	100%	≈0.4%	≈0.03%	≈0.04%
Median trade size	$90,450	$543	—	—
Depth ≤10 bps per side, ours (Oct)	$6.02M / $6.04M (CLX6)	≥$62.8K / ≥$37.0K (truncated)	$360.0K / $380.1K	No public book
Depth ≤2 bps, two-sided, Castle Labs (Mar)	$19.0M	$152K (5-min executable)	—	—
$1M cost, ours (buy / sell)	1.69 / 1.68 (CLX6); 1.46 / 1.45 (CLZ6)	n.m. (truncated)	12.81 / 10.67 (1 Oct)	Swap 5.5 (indicative, Nov); perp: no quote
$1M cost, third-party	0.79 (CLJ6, Mar reconstruction)	3.47 (Alea, 8 Oct, before fees); 15.4 (Mar reconstruction)	—	Swap 5.96 (Alea, 8 Oct)
$1M full-walk rate, ours	100% / 100%	n.m.	100% / 100%	—

CME: CLX6 regular-session medians of day medians, 1–20 October 2026; CLZ6, 21 October–10 November. On-chain: 1 October snapshots ($N = 22$ per side for Lighter). Castle Labs' March 2026 figures [11] reconstruct ticks for xyz:CL and CME CLJ6 in the same period and are not comparable with our October medians. Alea's figures [2] are medians of six snapshots taken 15:14–18:36 ET on 8 October, round trips halved. n.m.: not measurable because the ladder was truncated at 20 levels.

Table 3. Regulated listed-market MBO corpus, 1 October–12 November 2026.

Feed	Venue and scope	Files	GB	Sessions analysed (ET)
GLBX.MDP3	CME Globex (ES, NQ, CL; gold quarantined)	32	8.257	Regular: CL 09:00–14:30; ES/NQ 09:30–16:00 (8 UTC days to 10 Nov)
XNAS.ITCH	Nasdaq TotalView-ITCH (AAPL, MSFT, NVDA, TSLA)	128	11.457	Pre 04:00–09:30; regular 09:30–16:00; post 16:00–20:00 (32 days)
ARCX.PILLAR	NYSE Arca Pillar (same four stocks)	124	4.814	As Nasdaq (31 days)
XNYS.PILLAR	NYSE Pillar (same four stocks)	124	1.633	Early 07:00–09:30; regular 09:30–16:00 (31 days)
OCEA.MEMOIR	Blue Ocean ATS (same four stocks)	148	0.245	Overnight 20:00–04:00, Sun–Thu, mapped to next trade date (37 days)
Total	**1,598,298,606 MBO messages**	**556**	**26.41**	**375,761 qualified minutes**

reconstructing 1,598,298,606 MBO messages (Table 3). Books are rebuilt on a 60-second receive-time grid (`ts_recv`) with no state carried across files. Of 800,084 grid minutes, 54.45% held a valid two-sided book, 25.15% were one-sided or empty, 20.38% were uninitialized or mid-event, and 0.02% were locked or crossed. Filtering to scheduled New York sessions (allowing for the 1 November DST change), valid uncrossed books and receive recency of at most 120 seconds, and excluding quarantined gold, leaves 375,761 qualified minutes. An independent full-order-map validator matched all 10,073 grid rows and 312,706 field checks across seven 1 October files spanning all five feeds; Python and native back ends matched on all 513,723 numeric fields; and 15-second resampling moved spread and 10-bps depth medians by at most 9.1%.

3.2 Contracts, Rolls, Rounding and Excluded CME Liquidity

Continuous front-month symbology resolves by nearest expiry [19]: `ESZ6` and `NQZ6` throughout, and `CLX6` (to 20 October) and `CLZ6` (from 21 October), reported as separate unadjusted regimes. For COMEX gold (`GC.c.0`), nearest-expiry symbology selected thin serial months (`GCV6`/`GCX6`, 23–1,810 MBO messages a day) rather than the active December contract (`GCZ6`), so all 11,512 gold minutes are quarantined. Listed walks round the target notional up to whole contracts or shares: at sample prices a nominal $1 million walk executes $1.00–1.07 million in `CL`, about $1.17 million in `ES` and $1.0–1.5 million in `NQ`, which makes home-venue costs conservative.

CME MBO feeds carry outright orders only [18]. Implied liquidity derived from calendar and crack spreads, which CME disseminates on its price-level feeds, and the hidden reserve of native iceberg orders are both invisible to our static walks, so home depth is understated.

3.3 On-Chain Register, Truncation and Third-Party Sources

Our audited on-chain register contains 6,522 rows from 17 files (5,434 book-derived, 335 model or oracle, 100 indicative RFQ quotes and 653 context, fee or

trade rows), after quarantining 581 rows that mislabelled Thursday 1 October as a weekend and suppressing 740 overlapping legacy rows. Hyperliquid's public `l2Book` API returns at most 20 levels per side; on 3 November 2026 that covered only $20 of price on BTC, against 62,500 resting orders in the full L4 book [23]. Every 1 October trade.xyz ladder, and Lighter's `AAPL` ladder, is therefore right-censored: we report depth as a lower bound and walk completion as not measurable (n.m.).

We have not yet captured untruncated books ourselves. Instead, we report dated third-party measurements that do not share this limit: full-depth figures from Hydromancer (July 2026) [34] and Blockworks Intel (June–July 2026) [7]; $1 million cost snapshots from Castle Labs (September 2026) [10], Alea Research (8 October 2026) [2] and Castle Labs' March tick reconstruction [11]; and one $5 million observation from 0xArchive [1]. These differ in date, session, side convention and fee treatment, and none substitutes for a multi-day capture. We label each with its source, date and basis, and never pool them with our own walks.

3.4 Estimands, Fee Basis and the Crossover Size

At qualified timestamp t with best bid B_t and best ask $A_t > B_t$, the midquote M_t, quoted spread QS_t (bps) and one-sided displayed depth $D_{b,t}$ within $b \in \{2, 5, 10, 25, 50\}$ bps (with contract multiplier C) are

$$M_t = \frac{A_t + B_t}{2}, \qquad QS_t = 10^4 \times \frac{A_t - B_t}{M_t}, \tag{1}$$

$$D_{b,t}^{\text{buy}} = \sum_{i:\, P_{i,t}^{\text{ask}} \le M_t(1+b\cdot 10^{-4})} P_{i,t}^{\text{ask}}\, Q_{i,t}^{\text{ask}}\, C, \tag{2}$$

with $D_{b,t}^{\text{sell}}$ defined symmetrically over bids at or above $M_t(1 - b \cdot 10^{-4})$. For target notional $V \in \{\$10\text{K}, \$100\text{K}, \$1\text{M}, \$5\text{M}\}$, let $Q(V) = \lceil V/(M_t C) \rceil$ on listed venues and V/M_t on-chain. A walk is complete ($\mathbb{I}_t(V) = 1$) if and only if $\sum_{i=1}^{L} Q_{i,t} \ge Q(V)$, and its static buy cost and the full-walk rate are

$$S_t^{\text{buy}}(V) = 10^4 \times \frac{P_t^{\text{VWAP}}(V) - M_t}{M_t}, \qquad F(V) = T^{-1} \sum_{t=1}^{T} \mathbb{I}_t(V). \tag{3}$$

Incomplete walks are never costed on partial fills.

All costs in this paper are one-way, in bps of mid, and before fees unless marked. Where a source reports round trips we halve them, and where it includes fees we say so. A ratio "$r\times$ home" divides an on-chain cost by the home-venue cost for the same side when both are ours, and by the home midpoint otherwise; equity ratios use the single-venue Nasdaq cost.

To avoid choosing a size after the fact, we define the *crossover size* V^* as the smallest notional at which either (i) a venue's firm execution cost exceeds ten times the home venue's, or (ii) its full-walk rate $F(V)$ falls below 50% while the home venue's remains at 100%. This paper does not estimate V^*; the capture in Sect. 7 is designed to.

Table 4. Measurement choices and their effect on the on-chain/home cost ratio.

Choice	Effect on measured quantities	Effect on ratio
Whole-contract rounding at CME	A nominal $1M walk executes $1.0–1.5M in `CL`/`ES`/`NQ`.	Home cost overstated; ratio understated.
Single-venue Nasdaq walks	`XNAS` carries 19.0% of Tape C volume (Sect. 4.2).	Home cost overstated; ratio understated.
Outright-only CME MBO	Omits implied spread liquidity and iceberg reserve.	Home depth understated; ratio understated.
Costs before fees	Excludes CME's per-contract fees and on-chain taker fees (up to 1.25 bps per side on the venues walked; Table 1).	On-chain cost understated where fees apply; ratio understated.
Cancel priority on-chain	Displayed depth can be withdrawn before a taker arrives.	Firm on-chain depth overstated; ratio understated.
Indicative RFQ quotes	Omit the last-look cost ΔC (Eq. (4)) and capacity limits.	RFQ cost understated; ratio understated.
Truncated 1 October ladders	20-level cap censors trade.xyz depth.	Reported as n.m.; no ratio computed.
Lighter RFQ leg not captured	Unlocked RFQ quotes are absent from our snapshots.	Lighter cost may be overstated; ratio may be overstated.
Static walk vs. slicing	Ignores replenishment, which is unmeasured on-chain (Sect. 6).	Unknown sign.
Third-party snapshots	Differ in date, session, side convention and fees.	Unknown sign; reported separately.
Benchmark asset selection	Mega-caps and index futures rather than `SNDK`, `MU`, `SPCX`, `SKHY`.	Unknown for the market as a whole.

3.5 Direction of Bias

Table 4 lists each measurement choice and its effect on the on-chain/home cost ratio. Most choices make our ratios conservative. Two may overstate the gap (the uncaptured Lighter RFQ leg and the choice of benchmark assets), and two have unknown sign (order slicing and heterogeneous third-party snapshots).

4 Results by Execution Channel

4.1 Home Benchmarks: CME Globex Futures

CME Globex sets the institutional benchmark (Table 5). In `NQZ6`, the median regular-session quoted spread is 0.21 bps, depth within 10 bps is $305.7 million / $297.8 million (buy / sell), and every $1 million walk completes, at 0.12 bps. In `ESZ6`, the spread is one tick (0.32 bps), depth is $615.6 million / $636.0 million, and $1 million completes in every minute at 0.16 bps. In crude oil, `CLX6` and `CLZ6` hold $6.02–6.91 million per side within 10 bps and complete every $1 million walk at 1.45–1.69 bps.

Median 10-bps depth exceeds $5 million per side in all three contracts—by 60–125 times in `NQ` and `ES`, and narrowly in `CL`—so in the median regular-session minute a $5 million order fits within 10 bps of mid; we have not yet tabulated $5 million completion rates. CME's own 2025 study adds a dynamic view: on a

calm cash open (17 March 2025), ES absorbed $39.9 million per second at 1.8 bps, $58.75 million at 2.1 bps and $66.98 million at 2.3 bps; during the 7 April 2025 tariff shock, when top-three displayed depth fell 68% and volume reached 2.33 million contracts ($590.6 billion), it still absorbed $58.75 million per second at 5.4 bps [15]. These are CME's figures, not ours.

Our gold minutes are quarantined (Sect. 3.2). CME reports top-of-book depth of 15–24 lots in COMEX gold even in Asian hours [14], about $6.1–9.7 million at $4,037 an ounce [25], at a one-tick spread ($0.10 an ounce, about 0.25 bps). A $1 million order would then cost about half a tick, roughly 0.12 bps; we use this only as an estimate (Sect. 4.5). CME has also extended round-the-clock trading to its 1-Ounce Gold (from late July 2026) and 10-Barrel WTI (from 30 August 2026) futures [16].

4.2 U.S. Equities: Single-Venue Walks and Market Share

On Nasdaq (XNAS.ITCH) alone, regular-session spreads run 0.90–1.86 bps across AAPL, MSFT, NVDA and TSLA, 10-bps depth runs $0.50–1.35 million per side, and every $1 million walk completes, at 3.60–11.25 bps (Table 5). NYSE Arca also completes every walk (6.27–22.53 bps), whereas the non-primary NYSE (XNYS) books show fragmentation even in regulated equities (3.6–88.2% sell completion). Overnight on Blue Ocean ATS (20:00–04:00 ET), spreads widen to 2.41–5.27 bps, yet $1 million walks still complete in 96.4–99.1% of minutes, at 21.18–96.45 bps.

A Nasdaq-only walk is a conservative home benchmark. Over the 10 days to 23 November 2026, XNAS executed only 19.0% of Tape C volume (about 39.0% of lit volume) [44]. The three exchange feeds we license together carried 31.7% (XNAS 19.0%, ARCX 11.3%, XNYS 1.4%; about 65.1% of lit volume), other lit venues 17.0%, and 51.3% executed off-exchange, of which Cboe attributes 18.7% to dark pools and 81.3% to wholesalers [13]. A smart order router would therefore pay less than our single-venue walk. We have not yet merged the three exchange books (Sect. 7), so every equity ratio in this paper uses the Nasdaq-only cost.

4.3 Firm On-Chain Order Books

Table 6 sets our 1 October captures beside dated third-party snapshots, and Fig. 2 plots every $1 million cost against its home benchmark.

Our 1 October captures. No measurable on-chain book completed a $1 million walk in AAPL or MSFT. In NVDA, Lighter completed at 16.61 / 17.79 bps (buy / sell), 4.4–4.9 times the Nasdaq-only walk, while Aster completed only sells, at 177.64 bps (49 times). In TSLA, Lighter cost 47.42 / 79.43 bps (5.4–8.6 times). In the S&P 500, Lighter held $697.5 thousand / $651.7 thousand within 10 bps, about 0.1% of ESZ6's depth, and cost 11.79 / 12.97 bps (74–81 times CME). In WTI, Lighter and Aster cost 6.4–7.6 and 9.2–10.9 times CME.

Dated third-party snapshots. Full-depth data lift trade.xyz's S&P 500 depth within 10 bps from our truncated lower bound of $250–375 thousand to $964 thousand (Hydromancer, July), still about 640 times shallower than ESZ6, and put its Nasdaq-100 depth at $2.6 million, about 115 times shallower than NQZ6 [34].

Table 5. Regulated home and overnight venues: quoted spread, 10-bps depth and $1 million static walk cost.

Underlying	Venue (session)	Spread (bps)	Depth ≤10 bps (buy / sell)	$1M cost (bps, b / s)	Full walk (%, b / s)
Nasdaq-100	CME NQZ6 (RTH)	0.21	$305.7M / $297.8M	0.12 / 0.12	100 / 100
S&P 500	CME ESZ6 (RTH)	0.32	$615.6M / $636.0M	0.16 / 0.16	100 / 100
WTI	CME CLX6 (1–20 Oct)	1.12	$6.02M / $6.04M	1.69 / 1.68	100 / 100
WTI	CME CLZ6 (21 Oct–10 Nov)	1.10	$6.91M / $6.84M	1.46 / 1.45	100 / 100
AAPL	Nasdaq XNAS (19.0% Tape C)	0.90	$1.07M / $949.0K	5.44 / 5.57	100 / 100
	NYSE Arca ARCX (11.3%)	1.16	$516.2K / $507.1K	10.65 / 12.27	100 / 100
	NYSE XNYS (1.4%)	4.11	$67.2K / $68.6K	184.49 / 98.73	32.6 / 3.6
	Blue Ocean (overnight)	3.75	$71.6K / $74.6K	43.83 / 48.29	96.4 / 98.2
MSFT	Nasdaq XNAS	1.53	$524.9K / $501.0K	10.22 / 11.25	100 / 100
	NYSE Arca ARCX	1.83	$480.0K / $445.9K	11.28 / 12.75	100 / 100
	NYSE XNYS	4.72	$56.7K / $55.5K	301.68 / 1,252.94	90.3 / 5.2
	Blue Ocean (overnight)	5.27	$57.2K / $63.9K	81.33 / 96.45	97.0 / 97.4
NVDA	Nasdaq XNAS	0.92	$1.33M / $1.35M	3.75 / 3.60	100 / 100
	NYSE Arca ARCX	0.92	$784.3K / $798.1K	6.62 / 6.27	100 / 100
	NYSE XNYS	2.31	$132.4K / $109.2K	343.80 / 177.94	97.7 / 88.2
	Blue Ocean (overnight)	2.41	$169.2K / $151.1K	21.18 / 22.29	99.0 / 99.1
TSLA	Nasdaq XNAS	1.86	$553.9K / $550.3K	8.72 / 9.22	100 / 100
	NYSE Arca ARCX	2.51	$190.6K / $179.4K	19.41 / 22.53	100 / 100
	NYSE XNYS	7.27	$16.2K / $17.0K	355.69 / 268.20	79.2 / 7.3
	Blue Ocean (overnight)	4.05	$188.6K / $219.5K	27.12 / 25.17	99.1 / 99.1

Medians of trading-day medians over qualified minutes. Equity rows are single-venue static walks, which overstate the cost of routing across venues (Sect. 4.2). Tape C shares are 10-day averages to 23 November 2026 [44].

Cost snapshots vary with date and method. In September, Castle Labs measured $1 million on trade.xyz at 5.84 bps in the S&P 500 and 5.74 bps in the Nasdaq-100, with fees included (37 and 48 times CME), and on Lighter, which charges no fee, at about 3.95 and 9.94 bps (25 and 83 times) [10]. On 8 October, Alea Research's six snapshots, taken between 15:14 and 18:36 ET and before fees, put trade.xyz at 1.20 and 1.02 bps one-way (7.5 and 8.5 times CME) [2]. trade.xyz's taker fee on index markets, 0.9 bps per side, is of the same order as these before-fee costs, whereas CME's fees are a fixed charge per contract that our home costs also exclude. In `NVDA`, 0xArchive reports a $5 million buy on trade.xyz at 21 bps in U.S. regular hours and 123 bps at the weekend [1].

Depth beyond the flagship markets and its firmness. Across the top 25 trade.xyz markets, Blockworks Intel's June–July L4 checkpoints put median two-sided 10-bps depth at $211,380, 41% of which remained at weekends; `xyz:SKHX` held $454 thousand within 25 bps [7]. Displayed depth is also not unconditionally firm under cancel priority: HyperCore-wide L4 logs from 3 November 2026 show about 99 cancels per fill (a 0.08% fill rate and a 541 ms median order life) [23]. That figure covers all HyperCore books, not RWA books alone.

Summary. In equity-index products, the seven $1 million observations on firm books span 7.5–83 times CME; five exceed 20 times, and the two below 10 times are Alea's before-fee snapshot. In single stocks, firm books mostly could not fill $1 million, and where they did they cost 4.4–8.6 times a single-venue Nasdaq walk. In crude oil, firm books cost 2.1–10.9 times CME in October.

4.4 Non-Firm Channels: Variational, Lighter's RFQ Leg and Ostium

Large orders need not sweep a book; they can be routed to a dealer or a vault. Table 7 reports what is known about these channels at $1 million.

Variational swaps. Swaps quote tightly during U.S. hours. Castle Labs (September) and Alea (8 October) put $1 million at 0.44–0.47 bps in the Nasdaq-100 (3.7–3.9 times `NQZ6`) and 0.79–0.94 bps in the S&P 500 (4.9–5.9 times `ESZ6`); Alea's 5.96 bps in WTI is close to the 5.5 bps in our November quotes (3.3–3.5 times `CLX6`) [10,2]. These are the closest on-chain quotes to the home venue that we find, but four documented features separate them from firm liquidity at size. (i) *Firmness.* Prices shown while browsing are informational. On submission, OLP issues a firm quote, which may differ, and a last look checks the trade against eleven documented risk checks—caps on the user's notional and positions, on OLP's value at risk and position size, open-interest and skew caps, and a pricing check—whose thresholds, quote validity and rejection rates are not published [60,57,58]. Neither Castle Labs nor Alea executed a trade, so their figures, like ours, are indicative. (ii) *Capacity.* Swap open-interest caps started at $10 million and were raised to $50 million for the Nasdaq-100 and gold on 2 September [2], and Variational's $110 million Series B (18 November) was raised partly to increase open-interest limits [54]. Variational's public statistics API reports quotes at $1 thousand, $100 thousand and $1 million only [55,3], so no published quote exists at $5 million. (iii) *Hours.* As of November 2026, swaps follow the underlying market's hours: they close at weekends, carry is charged

Table 6. Firm on-chain order books at $1 million: our 1 October 2026 captures and dated third-party snapshots, against the home venue.

Venue	Source, date, basis	Depth ≤10 bps (buy / sell)	$1M cost, bps (buy / sell)	Full walk (%)	× home
S&P 500 — home: CME `ESZ6`, 0.16 bps					
Lighter	Ours, 1 Oct, $N = 26$	$697.5K / $651.7K	11.79 / 12.97	100 / 100	74–81
Lighter	Castle Labs, Sep (no fee)	—	≈3.95	—	25
trade.xyz	Ours, 1 Oct (truncated)	≥$250.1K / ≥$374.8K	n.m.	n.m.	—
trade.xyz	Hydromancer, Jul (full L4)	$964.0K	—	—	—
trade.xyz	Castle Labs, Sep (fees incl.)	—	5.84	—	37
trade.xyz	Alea, 8 Oct (before fees)	—	1.20	—	7.5
Nasdaq-100 — home: CME `NQZ6`, 0.12 bps					
trade.xyz	Hydromancer, Jul (full L4)	$2.60M	—	—	—
trade.xyz	Castle Labs, Sep (fees incl.)	—	5.74	—	48
trade.xyz	Alea, 8 Oct (before fees)	—	1.02	—	8.5
Lighter	Castle Labs, Sep (no fee)	—	9.94	—	83
WTI crude oil — home: CME `CLX6`, 1.69 / 1.68 bps					
Lighter	Ours, 1 Oct, $N = 22$	$360.0K / $380.1K	12.81 / 10.67	100 / 100	6.4–7.6
Aster	Ours, 1 Oct, $N = 6$	$328.0K / $361.8K	18.47 / 15.50	100 / 100	9.2–10.9
trade.xyz	Ours, 1 Oct (truncated)	≥$62.8K / ≥$37.0K	n.m.	n.m.	—
trade.xyz	Alea, 8 Oct (before fees)	—	3.47	—	2.1
trade.xyz	Castle Labs, March tick reconstruction	$152K within ±2 bps	15.4	—	≈20[a]
NVDA — home: Nasdaq `XNAS` only, 3.75 / 3.60 bps					
Lighter	Ours, 1 Oct, $N = 26$	$353.0K / $423.9K	16.61 / 17.79	84.6 / 100	4.4–4.9
Aster	Ours, 1 Oct, $N = 6$	$136.1K / $138.9K	— / 177.64	0 / 100	49 (sell)
trade.xyz	Ours, 1 Oct (truncated)	≥$149.3K / ≥$158.8K	n.m.	n.m.	—
trade.xyz	0xArchive, Nov, $5M buy	—	21 at $5M; 123 at weekend	—	—
TSLA — home: Nasdaq `XNAS` only, 8.72 / 9.22 bps					
Lighter	Ours, 1 Oct, $N = 26$	$258.7K / $209.3K	47.42 / 79.43	96.2 / 100	5.4–8.6
Aster	Ours, 1 Oct	$31K–$109K	—	0	—
trade.xyz	Ours, 1 Oct (truncated)	≥$26K–$34K	n.m.	n.m.	—
AAPL, MSFT — home: Nasdaq `XNAS` only, 5.44–11.25 bps					
All three	Ours, 1 Oct	$15K–$271K	—	0 or n.m.	—

One-way costs in bps of mid. "Ours": 1 October regular-session snapshots, before fees (N snapshots per side). Castle Labs [10] averages long and short positions and includes trade.xyz's fees (Lighter charges none); its S&P 500 figures do not state the order size, which we read as $1 million from context. Alea [2]: medians of six snapshots, 15:14–18:36 ET on 8 October, round trips halved, before fees. "× home" uses our regular-session medians in Table 5, same side where both are ours; equity ratios use the single-venue Nasdaq cost. [a]Against CME `CLJ6` at 0.79 bps in the same March reconstruction [11]. n.m.: not measurable (ladder truncated at 20 levels).

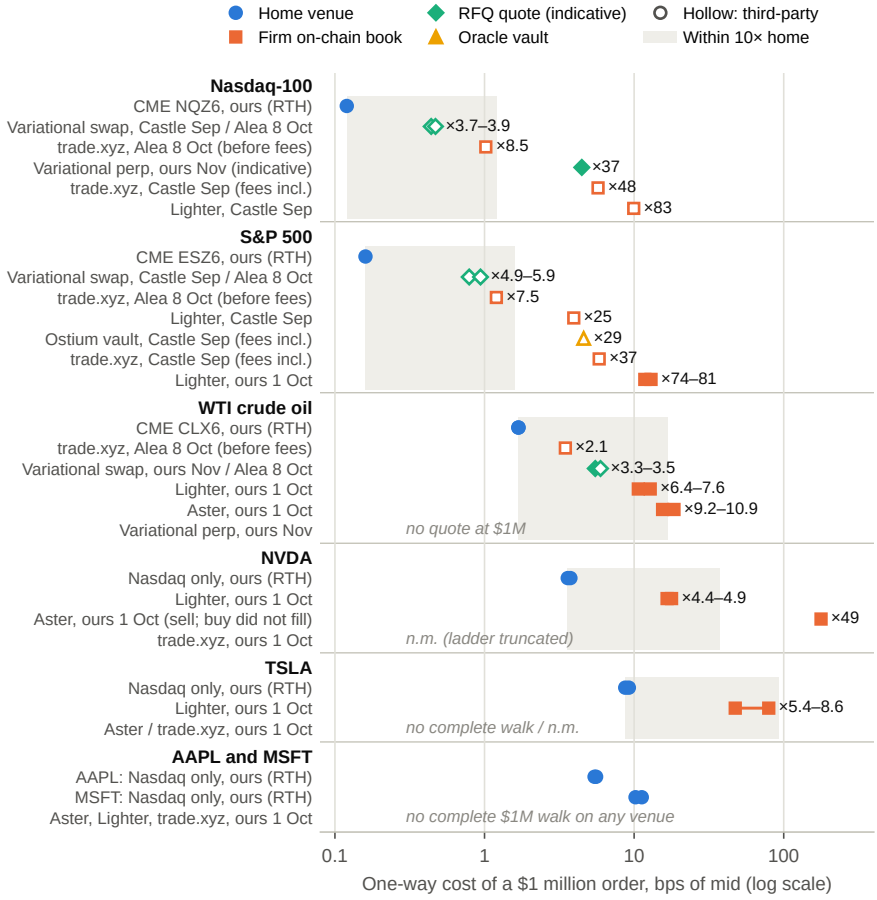


Fig. 2. One-way cost of a $1 million order by underlying and channel (bps of mid, log scale). Shading spans one to ten times the home-venue cost. Filled markers are our data (regulated venues: regular-session medians of day medians, 1 October–12 November 2026; on-chain books: 1 October 2026 snapshots; Variational: indicative quotes, November 2026). Hollow markers are dated third-party snapshots: Castle Labs (September 2026) [10] and Alea Research (8 October 2026, round trips halved) [2]. Ratios are as in Table 6. Equity home costs are single-venue Nasdaq walks, which overstate consolidated cost. Alea's trade.xyz figures exclude its 0.9 bps taker fee; Castle Labs' include it.

at the 5 p.m. ET close and liquidations wait for the reopen [59]. Variational's roadmap for the rest of 2026 includes 24/7 swaps and a trading API [61], so this constraint may not last. (iv) *Product.* Variational's 24/7 perpetuals, which draw liquidity from crypto venues, quoted about 4.47 bps at $1 million in the Nasdaq-100 in our November quotes (about ten times the swap; 37 times `NQZ6`) and returned no quote at $1 million in WTI.

Variational charges no trading fee, and the protocol keeps 20% of the spread that OLP earns [56,5]. Alea estimates that traders paid 2.35 bps of volume as spread in the third quarter across all markets ($26.8 million on $114.2 billion), falling to 2.09 bps in September and 1.64 bps over 1–14 October as swaps reached 50.3% of volume [2]. Long positions in swaps carry 4.6–5.7% a year and shorts receive about 2.4% [10]. In silver, Castle Labs found the swap costlier than Lighter's book: 5.14 against 4.31 bps at $500 thousand, and about 7.87 against 6.56 bps at $1 million [10].

Lighter's RFQ leg and Ostium. Lighter's RFQ leg (used at $500 thousand and above, when the book cannot fill, or above 10 bps of expected slippage beyond $10 thousand; 1 bp fee) hides trade direction when it requests quotes from whitelisted makers, but the quotes it injects into the book are not locked: makers can amend or cancel them during an execution window of up to two minutes [39,40], and standard accounts face a 300 ms taker delay against 0 ms maker cancels [38]. We have no execution data for this leg. Ostium's vault priced $1 million at 4.60 bps in the S&P 500 and 4.63 bps in gold in Castle Labs' September test, fees included (29 times `ESZ6`) [10]. It is closed at weekends and closes leveraged stock positions above the overnight cap at 15:45 ET [48]. On 15 July 2026 an attacker who had compromised Ostium's off-chain price-reporting infrastructure drained 23.75 million USDC from its vault; trading later resumed [53]. DefiLlama reported vault TVL of $1.77–1.82 million on 23 November 2026 [20].

4.5 The trade.xyz Cross-Section and a Centralized-Exchange Benchmark

A synchronous U.S.-hours pass over all 122 live trade.xyz markets on 11 November 2026 shows how thin the long tail is. The top 10 markets carry 66.7% of volume and the top 30 carry 93.0%; the median market holds $95,000 within 10 bps of mid; 79 markets (64.8%) hold under $250,000, and 17 (13.9%) hold nothing. Depth within 10 bps across all 122 markets sums to $73.0 million, against $4.0 billion of open interest. A $100,000 order costs 2.4 bps in a top-10 market and 21.5 bps outside the top 30, where a third of books cannot fill $100,000 at any price (spread–volume correlation -0.73). Order-level data across 73 markets show concentrated maker capital: a single maker wallet ranked in the top five in 47 markets (64.4%) and first in 22 (30.1%), and the number of active makers correlates with spreads at -0.72 [34].

Does a centralized exchange do better? Blockworks Intel's one-hour average gold books from 17 March 2026 (Table 8) show Binance holding $3.3 million within 10 bps, 3.6 times Hyperliquid's $925 thousand, and charging 7.5 bps for a $1 million round trip (3.75 bps one-way) against 16.4 bps on Hyperliquid and

Table 7. Non-firm on-chain channels at $1 million.

Venue, product	Asset	$1M cost, bps (source)	× home	Firmness, capacity and hours
Variational swap	US100	0.47 (Castle, Sep); 0.44 (Alea, 8 Oct)	3.7–3.9	Indicative; last look; OI cap $50M from 2 Sep; market hours only (Nov 2026)
Variational swap	US500	0.79 (Castle); 0.94 (Alea)	4.9–5.9	As above
Variational swap	WTI	5.5 (ours, Nov); 5.96 (Alea)	3.3–3.5	As above
Variational swap	XAU	1.66 (Castle); 1.82 (Alea)	13–15[a]	OI cap $50M; closes one hour each day
Variational swap	XAG	7.87 (Castle); 5.09 (Alea)	—	Costlier than Lighter's book in Castle's test ($500K and $1M)
Variational perp	US100	≈4.47 (ours, Nov)	37	24/7; crypto-sourced liquidity
Variational perp	WTI	No quote (ours, Nov)	—	24/7
Lighter RFQ leg	All	No execution data	—	Injected quotes not locked; window up to 2 min; 1 bp fee
Ostium vault	US500, XAU	4.60; 4.63 (Castle, fees incl.)	29 (US500)	Closed weekends; 15:45 ET auto-close; 23.75M USDC exploit, 15 Jul

One-way costs; Alea's round trips are halved. All Variational figures are indicative quotes; no source reports executed fills. Ratios use NQZ6 0.12, ESZ6 0.16 and CLX6 1.68–1.69 bps. [a] Against the COMEX estimate of about 0.12 bps (Sect. 4.1). Sources: [10,2,58,59,40,48,53].

44.5 bps on edgeX [6]. Binance is thus about twice as cheap as the best DEX in this snapshot, but about 30 times our rough COMEX estimate. One asset in one hour cannot show whether the gap is specific to on-chain venues; in this snapshot the CEX book was also more than an order of magnitude behind the home futures market.

4.6 Retail Size and What Is Not Yet Measured

At $100 thousand, Castle Labs' comparison across seven traditional assets (medians, 23 September 2026) put all-in opening costs at 1.04 bps on Lighter (no fee)

Table 8. Gold order books, CEX versus DEX perpetuals: one-hour averages, 17 March 2026.

Venue	Type	Depth within 1 / 5 / 10 bps	$100K round trip	$1M round trip	$1M one-way (× estimate)
Binance	CEX	$253K / $1.80M / $3.30M	2.7	7.5	3.75 (≈30)
Bybit	CEX	$114K / — / —	3.6	—	—
Hyperliquid	DEX	$174K / $462K / $925K	6.8	16.4	8.2 (≈66)
edgeX	DEX	$169K / $403K / $617K	3.2	44.5	22.25 (≈180)
COMEX GC (estimate)	Futures	$6.1–9.7M at the top of book	—	—	≈0.12 (1)

Costs in bps; RT: round trip, as reported by Blockworks Intel [6]. The COMEX row is an estimate, not a measurement: one tick ($0.10 an ounce, about 0.25 bps) and 15–24 lots at the top of book in Asian hours [14], valued at $4,037 an ounce [25]. Ratios in parentheses divide by this estimate.

and 2.90 bps on trade.xyz (2.06 bps average fee), against 2.82 bps (indicative) on Variational [12]. Small orders are therefore cheap on-chain; the gap opens with size. We have not yet located where. Estimating the crossover size V^* (Sect. 3.4) requires $100 thousand, $1 million and $5 million walks on both venues from the same minutes, which our 1 October captures do not provide; the only $5 million observation, trade.xyz `NVDA` at 21 bps in regular hours, is third-party.

5 Off-Hours Trading and Price Discovery

5.1 Regulated Overnight Benchmarks

Overnight equity trading on Blue Ocean ATS (20:00–04:00 ET) shows the adverse-selection regime that applies when primary markets are closed [24]. Order imbalance triples (0.15–0.16 against 0.05 in regular hours); odd-lot effective spreads widen to 8.63–8.72 bps, yet 5-minute price impact reaches 11.25–11.42 bps, so 5-minute realized spreads turn negative (-2.62 to -2.75 bps). Overnight returns in individual stocks reverse by 54% (20:00–24:00 ET) and 46% (00:00–04:00 ET) the next day, whereas ETFs anchored to 24-hour CME index futures contribute 17.4% of daily price discovery overnight, against 4.5% for single stocks. Where no lit reference market is open, specialized intermediaries can earn large rents: German retail market makers earn an annualized gross Sharpe ratio of 17.85 and make roughly half of their profits outside regular Xetra hours, on 15% of volume [32].

5.2 On-Chain Off-Hours Trading and Price Discovery

On-chain RWA venues stay open at weekends, but activity falls to 4.8% of weekly volume; weekend daily intensity is 4.6% of weekdays for stocks, 5.4% for indices, 9.7% for commodities and 17.9% for currencies [17]. trade.xyz displayed depth drops to 37% of regular-session levels at weekends, while holding at 116% on weekday nights [34]. During macro shocks, on-chain books can impound news early: across 199 asset-weekends, Hyperliquid's last weekend price was closer to Monday's open than Friday's close in 78.4% of cases, cutting the median reopening error from 92.8 to 38.4 bps [33]. Off-hours pricing can also fail. On 18 August 2026, an anomalous pre-market print on Korea's NXT venue fed into Hyperliquid's `xyz:SKHYNIX` oracle, cutting the mark price by 17.9% and triggering $57.4 million of liquidations across 960 accounts [17].

In regulated markets, price discovery concentrates where firm liquidity is deepest: `ES` carries 85–88% of the Hasbrouck information share against about 4% for `SPY`, and `NQ` 84–85% against about 9% for `QQQ` [29], while COMEX gold carries 94–99% against London over-the-counter spot [30]. A paired test on 1-second mid-prices—information shares [28], component shares [27], the metrics compared by Putniņš [49], and variance ratios [41] to detect smoothing by moving-average marks—is part of the capture in Sect. 7.

6 Mechanisms Behind the Gap

This section summarizes mechanisms from the literature that bear on the results; it does not test them.

RFQ and last look. In a single-dealer RFQ with last look, the dealer can reject a request after seeing it, so statistics computed from fills alone omit the cost of rejections [46]. Suppose the price change over a last-look window Δt is $\mathcal{N}(0, \sigma^2 \Delta t)$ and the dealer rejects a buy request whenever the price rises above a threshold, so that a fraction p of requests is rejected. Relative to a firm quote at half-spread s, the taker's expected extra cost is

$$\Delta C = \phi(z)\, \sigma \sqrt{\Delta t} + p\,(s_{\text{retry}} - s), \qquad z = \Phi^{-1}(1 - p), \tag{4}$$

where ϕ and Φ are the standard normal density and distribution function and s_{retry} is the cost of re-executing a rejected order elsewhere. Variational publishes neither Δt nor p, so quoted costs, including all those in Table 7, omit ΔC. Principle 17 of the FX Global Code sets disclosure expectations for last look in currency markets [26]. Multi-dealer RFQs face a different trade-off: customers typically query only a few dealers, balancing competition against information leakage [50].

Cancel priority and latency arbitrage. In a continuous book, fast traders race to pick off stale quotes. Aquilina, Budish and O'Neill estimate that such races impose a tax of about 0.42 bps of traded value in U.K. equities (0.53 bps on non-race volume) and account for roughly a third of the effective spread [4]. Processing cancellations ahead of takers, as Hyperliquid and Lighter do [35,38], shields makers from these races, but displayed depth can then be withdrawn before a taker arrives, so the taker bears the cost as a lower chance of filling rather than as a visible spread. Frequent batch auctions, as on Helix, remove races within a block at the cost of execution delay [8].

Collateral and maker capacity. If each resting order must be collateralized within an isolated market, a maker with capital K and leverage L quoting N markets can display at most about LK/N in each. This is consistent with the concentration of depth in a few markets and a few maker wallets (Sect. 4.5), though our data do not show that it causes it.

Order slicing and resilience. Desks rarely sweep $1 million in one order; they slice it. Slicing lowers cost only insofar as the book refills between child orders, and in Obizhaeva and Wang's model the gain is governed by the book's resilience [45]. Empirically, Large finds that in over 60% of cases a limit order book does not replenish reliably after a large trade, although when it does the half-life is about 20 seconds [37]; Lo and Hall find resiliency consistently high in large stocks, consistent with competition among algorithmic liquidity providers, and more variable elsewhere [42]. CME's study shows `ES` absorbing tens of millions of dollars per second (Sect. 4.1); no comparable measurement exists for on-chain RWA books. Blockworks Intel reports realized fill costs of about 1–4 bps across 3.59 million trade.xyz orders, but the median external order was $471 and unfilled IOC orders are not observed [7], so these figures say little about $1 million. Slicing

therefore does not by itself overturn the static comparison; the capture in Sect. 7 measures replenishment directly.

7 Limitations and Planned Verification

Seven limitations bound the evidence. (1) Our on-chain book sample is one Thursday, 1 October 2026; captures from 1 and 13 November are not yet integrated. (2) Third-party snapshots differ in date, session, side convention and fees, and for the same market they range widely (trade.xyz Nasdaq-100 at $1 million: 1.02 bps on 8 October against 5.74 bps in September). (3) All Variational figures are indicative: firm execution prices, rejection rates and the largest fillable size are not observed, and the 100 RFQ quotes in our register are not yet reported by ticker and size. (4) Equity home walks are single-venue; we have not merged the three exchange books we license. (5) The top on-chain tickers (`SNDK`, `MU`, `SPCX`, `SKHY`) and active-month COMEX gold (`GCZ6`) are not in the paired grid, and our gold benchmark is an estimate. (6) We have not measured RFQ rejection rates, book replenishment after large trades, or V^*. (7) Costs exclude fees, except where third-party sources include them.

We plan three steps.

1. *Repairs with data in hand.* Merge `XNAS`, `ARCX` and `XNYS` into a consolidated three-exchange equity book; report all 100 RFQ quotes by ticker, size and no-quote rate; add the 1 and 13 November captures day by day; and publish $100 thousand and $5 million tiers alongside $1 million.
2. *A 20-trading-day capture, to be pre-registered.* Synchronized 60-second grids over 20 trading days, flagging Thanksgiving, the mid-December index rolls and late-December sessions, covering: (a) untruncated 100-level and L4 Hyperliquid streams; (b) Variational's indicative quotes, back-filled from an hourly archive for 1 October–12 November [3] and polled every minute from the public statistics API, each costed against Variational's own mid and the home-venue mid; (c) firm RFQ tests through an eligible entity (Omni excludes U.S. and Canadian residents [5]): at least 100 small round trips ($10–50 thousand) across sessions, logging indicative quote, firm quote, fill, rejection code and latency, to estimate firm-minus-indicative slippage and p in Eq. (4), plus quote requests at $1, $5 and $10 million to map capacity; (d) `SNDK`, `MU`, `SPCX`, `SKHY` and active-month `GC`; (e) Binance, OKX and Bybit RWA books; (f) Ostium position caps; and (g) realized large-trade slippage and millisecond replenishment from L4 differences. The outputs are V^* and $F(V)$ by asset and session, and the share of time each venue is within ten times the home venue.
3. *Credibility safeguards.* Register the plan, including the definition of V^* and the tenfold test, before capture begins; engage an independent academic reviewer; send measured tables to each venue for right of reply before publication; and release analysis code and derived data under a permanent DOI.

8 Conclusion

Splitting the evidence by execution channel separates three findings. First, in equity-index products, firm on-chain books are an order of magnitude or more costlier than CME at $1 million in five of the seven observations we have, and in mega-cap single stocks they usually cannot fill $1 million at all. Second, the gap is not uniform: crude-oil books were within about 2–11 times CME in October, and one third-party snapshot put trade.xyz's index costs at 7.5–8.5 times CME before fees. Third, the on-chain quotes closest to the home venue—Variational's swaps, at 3–6 times CME—are indicative, capped, subject to last look and available only in market hours, and no published source has measured what a firm $1 million order on them actually costs. The remaining questions are empirical: firm RFQ costs and rejection rates, book replenishment after large trades, and the crossover size V^* by asset and session. The capture in Sect. 7 is designed to answer them.

Disclosure of Interests. The authors are affiliated with Fermi Labs, which develops an on-chain perpetual futures exchange (https://app.fermi.trade/) that competes with the on-chain venues studied here.

Data availability. Listed-market inputs are identified by manifest SHA-256 hash `20b8a51a79bf4bd6b356c89dbe362ef725e4f64a68a82577212addf0af0ae7f8` and analyzer commit `7dcf10b0c51dee6f9d83c0f66b51eac9531287f8`. Raw MBO data are licensed from Databento. The audited on-chain register, the primary-source reconciliation package and the analysis code are available from the authors.

References

1. 0xArchive: Hyperliquid stocks: market data guide (2026), https://0xarchive.io/resources/market-data-guides/hyperliquid-stocks
2. Alea Research: Variational climbs to fourth (2026), https://alearesearch.substack.com/p/variational-climbs-to-fourth, 27 October 2026
3. Allium: Market metrics: Variational Omni (Arbitrum perpetuals) (2026), https://docs.allium.so/historical-data/supported-blockchains/evm/arbitrum/perpetuals/market-metrics
4. Aquilina, M., Budish, E., O'Neill, P.: Quantifying the high-frequency trading "arms race". Quarterly Journal of Economics **137**(1), 493–564 (2022)
5. Bankless: Variational's broker bet goes public (2026), https://www.bankless.com/read/variationals-broker-bet-goes-public, 12 November 2026
6. Blockworks Intel: State of edgeX Q1 2026 (2026), https://app.blockworks.com/report/state-of-edgex-q1-2026, 4 May 2026
7. Blockworks Intel: Weekend trading: evidence of price discovery in Hyperliquid's weekend markets (2026), https://app.blockworks.com/report/weekend-trading-evidence-of-price-discovery-in-hyperliquid-s-weekend-markets, 3 August 2026
8. Budish, E., Cramton, P., Shim, J.: The high-frequency trading arms race: frequent batch auctions as a market design response. Quarterly Journal of Economics **130**(4), 1547–1621 (2015)
9. Buildix: Hyperliquid xyz:SNDK market page (2026), https://www.buildix.trade/hyperliquid/xyz-SNDK

10. Castle Labs: The evolution of RWA trading onchain (2026), https://castlelabs.io/research/the-evolution-of-rwa-trading-onchain, 10 September 2026
11. Castle Labs: Hyperliquid's crude oil liquidity is less than 1% of CME's. Reported by KuCoin News (2026), https://www.kucoin.com/news/flash/hyperliquid-s-crude-oil-liquidity-is-less-than-1-of-cme-s-but-its-price-discovery-capability-improved-over-the-weekend, 5 April 2026
12. Castle Labs: Mapping the perpetual trading ecosystem (2026), https://castlelabs.io/research/reports/mapping-the-perpetual-trading-ecosystem
13. Cboe Global Markets: 2025 U.S. equities year in review (Jan 2026), https://www.cboe.com/insights/posts/2025-u-s-equities-year-in-review/
14. CME Group: Liquidity of COMEX gold and silver is excellent during Asia hours (2018), https://www.cmegroup.com/education/articles-and-reports/liquidity-of-comex-gold-and-silver-is-excellent-during-asia-hours
15. CME Group: Reassessing liquidity: beyond order book depth (Dec 2025), https://www.cmegroup.com/articles/2025/reassessing-liquidity-beyond-order-book-depth.html
16. CME Group: 24/7 trading for 1-ounce gold and 10-barrel WTI crude oil futures (Globex notice) (2026), https://www.cmegroup.com/notices/electronic-trading/2026/06/20260629.html, 29 June 2026
17. CoinMarketCap Research: RWA perpetuals: State of the market, August 2026 (2026), https://s3.coinmarketcap.com/uploads/CMC_RWA_Perps_Quarterly_Report_Aug_2026.pdf
18. Databento: CME Globex MDP 3.0 dataset documentation (2026), https://databento.com/docs/datasets/glbx-mdp3
19. Databento: Symbology: standards and conventions (2026), https://databento.com/docs/standards-and-conventions/symbology
20. DefiLlama: Ostium: protocol TVL (2026), https://defillama.com/protocol/ostium
21. DefiLlama: RWA perpetuals dashboard (2026), https://defillama.com/rwa/perps
22. DefiLlama Research: Spotlight: Variational Swaps (Sep 2026), https://defillama.com/research/spotlight/variational-swaps
23. Dwellir: Hyperliquid order book data: L1 to L4 explained (2026), https://www.dwellir.com/blog/hyperliquid-order-book-data, 3 November 2026
24. Eaton, G.W., Shkilko, A., Werner, I.M.: Nocturnal trading. Working paper (2026), https://www.hillsdaleinv.com/uploads/Nocturnal_Trading_-_Full_Research_Paper.pdf
25. edgeX: Spot gold vs. gold futures: why prices differ (2026), https://pro.edgex.exchange/en-US/news/article/spot-gold-vs-gold-futures-prices-differ
26. Global Foreign Exchange Committee: FX Global Code (2021), https://www.globalfxc.org/docs/fx_global.pdf
27. Gonzalo, J., Granger, C.: Estimation of common long-memory components in cointegrated systems. Journal of Business & Economic Statistics **13**(1), 27–35 (1995)
28. Hasbrouck, J.: One security, many markets: determining the contributions to price discovery. Journal of Finance **50**(4), 1175–1199 (1995)
29. Hasbrouck, J.: Intraday price formation in U.S. equity index markets. Journal of Finance **58**(6) (2003)
30. Hauptfleisch, M., Putniņš, T.J., Lucey, B.: Who sets the price of gold? London or New York. Journal of Futures Markets **36**(6) (2016)
31. HeyGotrade: SpaceX (SPCX) stock news, 24 November 2026 (2026), https://www.heygotrade.com/en/news/spacex-spcx-stock-news-november-24-2026/

32. Hoffmann, P., Jank, S.: What is the value of retail order flow? Discussion Paper 33/2024, Deutsche Bundesbank (2024), https://www.bundesbank.de/resource/blob/938418/aaf5f60cd95bc56ebe7f5ac9aa40dec6/mL/2024-08-20-dkp-33-data.pdf
33. HTX Ventures: RWA perps: a new frontier in the on-chain expansion of global financial markets (2026), https://square.htx.com/htx-ventures-latest-report-rwa-perps-a-new-frontier-in-the-on-chain-expansion-of-global-financial-markets/
34. Hydromancer: trade.xyz builds 92 markets and 98% of HIP-3 volume on Hyperliquid in 8 months. Reported by KuCoin News (2026), https://www.kucoin.com/news/flash/trade-xyz-builds-92-markets-and-98-hip-3-volume-on-hyperliquid-in-8-months, 15 July 2026
35. Hyperliquid: Order book (HyperCore documentation) (2026), https://hyperliquid.gitbook.io/hyperliquid-docs/hypercore/order-book
36. Injective: Injective exchange API documentation (2026), https://api.injective.exchange/
37. Large, J.: Measuring the resiliency of an electronic limit order book. Journal of Financial Markets **10**(1), 1–25 (2007). https://doi.org/10.1016/j.finmar.2006.09.001
38. Lighter: Account types (developer reference) (2026), https://docs.lighter.xyz/developers/reference/account-types
39. Lighter: RFQ (trading documentation) (2026), https://docs.lighter.xyz/trading/rfq
40. Lighter: rfq_create (API reference) (2026), https://docs.lighter.xyz/api/guilds/rfq/rfq_create
41. Lo, A.W., MacKinlay, A.C.: Stock market prices do not follow random walks: evidence from a simple specification test. Review of Financial Studies **1**(1), 41–66 (1988)
42. Lo, D.K., Hall, A.D.: Resiliency of the limit order book. Journal of Economic Dynamics and Control **61**, 222–244 (2015)
43. MarketChameleon: Micron technology (MU) volume summary (2026), https://marketchameleon.com/Overview/MU
44. Nasdaq Trader: Full market share summary (10-day moving average ending 23 November 2026) (2026), https://www.nasdaqtrader.com/trader.aspx?id=FullVolumeSummary
45. Obizhaeva, A.A., Wang, J.: Optimal trading strategy and supply/demand dynamics. Journal of Financial Markets **16**(1), 1–32 (2013)
46. Oomen, R.: Last look. Quantitative Finance **17**(7) (2017)
47. Ostium: How Ostium works (protocol documentation) (2026), https://docs.ostium.com/protocol/how-ostium-works
48. Ostium: Stocks: day trading (trader documentation) (2026), https://docs.ostium.com/traders/trading/stocks-day-trading
49. Putniņš, T.J.: What do price discovery metrics really measure? Journal of Empirical Finance **23**, 68–83 (2013)
50. Riggs, L., Onur, E., Reiffen, D., Zhu, H.: Swap trading after Dodd-Frank: evidence from index CDS. Journal of Financial Economics (2020)
51. SK hynix: SK hynix lists ADRs on NASDAQ, elevating global status at the heart of capital markets. Press release (PR Newswire) (2026), https://news.skhynix.com/en/skhynix-lists-adrs-on-nasdaq/, 10 July 2026
52. TechCrunch: SpaceX officially prices shares at $135 in the largest IPO ever (2026), https://techcrunch.com/2026/06/11/spacex-officially-prices-shares-at-135-in-the-largest-ipo-ever/, 11 June 2026
53. The Block: Ostium blames off-chain breach for $24 million exploit, rules out smart contract flaw (2026), https://www.theblock.co/post/410122/ostium-post-mortem-exploit, 30 July 2026

54. The Block: Variational raises $110 million at $1.5 billion valuation to expand onchain derivatives trading (2026), https://theblock.co/news/deals/2026-11-18-variational-raises-110-million-at-1-5-billion-valuation-to-expand-onchain-derivatives-trading-443445, 18 November 2026
55. Variational: API reference (technical documentation) (2026), https://docs.variational.io/technical-documentation/api
56. Variational: Fees (Omni documentation) (2026), https://docs.variational.io/omni/trading/fees
57. Variational: Quoted, index and mark prices (Omni documentation) (2026), https://docs.variational.io/omni/trading/quoted-index-and-mark-prices
58. Variational: Risk limits and rate limits (Omni documentation) (2026), https://docs.variational.io/omni/trading/risk-limits-rate-limits
59. Variational: Swaps (Omni documentation) (2026), https://docs.variational.io/omni/trading/swaps
60. Variational: Trading via RFQ (protocol documentation) (2026), https://docs.variational.io/variational-protocol/key-concepts/trading-via-rfq
61. Variational: Variational raises $110M Series B at $1.5B valuation to scale on-chain access to global markets. Press release (Business Wire) (2026), https://www.businesswire.com/news/home/20261116481769/en/, 18 November 2026

A Likely Objections and the Status of the Evidence

Table 9 lists six objections a reader is likely to raise against an order-of-magnitude claim, the evidence this paper offers on each, and what remains open.

Table 9. Likely objections, evidence and status.

Objection	Evidence in this paper	Status
1. Large orders route to RFQ or vaults, not books.	Sect. 4.4, Table 7: Variational swaps quote 3.3–5.9× CME at $1M (indicative; last look; caps; market hours only); Ostium 29× `ESZ6` with fees.	Partly addressed: firm RFQ costs and rejection rates unmeasured; no Lighter RFQ data.
2. Hyperliquid's API truncates trade.xyz books at 20 levels.	Sects. 3.3 and 4.3: dated third-party full-depth and cost snapshots; truncated walks reported as n.m.	Partly addressed: no untruncated capture of our own; third-party figures range from 1.02 to 5.74 bps for the same market.
3. One day of on-chain data; no $100K or $5M tiers.	Castle Labs' $100K comparison and one $5M observation (Sect. 4.6).	Open: multi-day capture and V^* pending.
4. Benchmarks omit the top on-chain tickers.	Sect. 2.1: all four have U.S. home markets; trade.xyz volume is 0.6–2.2% of consolidated turnover.	Open: no paired book data for `SNDK`, `MU`, `SPCX`, `SKHY`.
5. Desks slice large orders.	Sect. 6: slicing gains depend on resilience, documented for CME but not on-chain.	Open: replenishment from L4 differences pending.
6. CEX books, not on-chain design, explain the gap.	Sect. 4.5, Table 8: Binance about 2× cheaper than the best DEX in gold but about 30× the COMEX estimate.	Inconclusive: one asset, one hour, estimated home cost.