The Viability of Blockchain Markets under Discrete Clearing and Paid Priority

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July 8, 2026

ABSTRACT

This paper develops a model to evaluate the viability of blockchain markets as the sole venue for price formation. Blockchains clear at discrete intervals called *block time*, and transactions are executed sequentially according to *priority fees* paid by traders who compete for queue position. We show that these features undermine the viability of markets. Paid-priority ordering induces endogenous selection, where only traders with sufficiently high valuations participate. The participation cutoff rises with competition, which intensifies with lower information costs or higher liquidity demand. This hinders price discovery and biases prices. It also impairs liquidity: the cutoff concentrates trading among aggressive traders and increases adverse selection that liquidity suppliers absorb in a single clearing round. Although longer block times enhance consensus security, they amplify these effects and can cause markets to shut down.

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Acknowledgments: We are grateful to the committees of the *NBER Summer Institute 2026, Financial Market Structure*, the *41st Meeting of the European Economic Association* and *77th European Meeting of the Econometric Society (EEA-ESEM 2026)*, and the *6th Annual CBER Conference 2026* for accepting the paper in their programs. We are grateful to Bruno Biais, Patrick Chang, Thomas Ernst, Zachary Feinstein, Joel Hasbrouck, Sebastian Jaimungal, Olga Klein, Igor Makarov, Katya Malinova, Andreas Park, Fahad Saleh, and Basil Williams for their valuable comments and discussions. We are also thankful to participants of the Columbia CBER CtCe Conference 2025, the Oxford-Harvard Conference on Decentralised Finance, the Stevens Institute of Technology's DeFi Seminar, the SEEM Seminar at the Chinese University of Hong Kong, the 2025 Warwick Business School Workshop on Financial Technology, the session on Blockchain Economics and Decentralized Finance of the INFORMS 2025 annual meeting, and the Oxford-Princeton Workshop for insightful discussions.

A central ambition of blockchain technology is to provide a decentralized infrastructure to organize economic activity at scale.[1] The viability of financial markets within this infrastructure is therefore a fundamental test of that ambition. This paper develops a theoretical framework that models the blockchain as the sole venue for price formation to assess its viability as an infrastructure to support markets. The model endogenizes liquidity supply, trading volumes, and information revealed in equilibrium. It incorporates three defining features of blockchain infrastructure: clearing occurs discretely in a single round within each block; block time determines the length of the round and is necessary to conduct security consensus and preserve decentralization; transactions are ordered through paid-priority discriminatory pricing.

Blockchains operate in discrete time, and information is revealed through an auction with discriminatory pricing. Orders are recorded into *blocks* built at regular intervals, called *slots*, and the duration of a slot is referred to as *block time*. At the end of a slot, a *builder* is selected by the blockchain's *protocol* to build the next block. Once the block is created, the transactions composing the block are executed in order of inclusion. The builder sequences transactions in the block according to *priority fees* paid by traders who compete for queue position. Consequently, traders engage in *priority gas auctions* (PGAs) to optimize their queue positions in the block. Blockchain trading contrasts with traditional markets with continuous trading. In the latter, trading unfolds over multiple short clearing rounds, and in the former, trading unfolds over relatively long clearing rounds with discriminatory prices.

We model the strategic interaction between liquidity suppliers and liquidity takers for a risky asset on a blockchain in three stages. In stage one, traders decide whether to enter the blockchain and acquire information at a cost. In stage two, a liquidity supplier sets the depth of a decentralized exchange (DEX) by balancing revenue from price-sensitive uninformed demand against expected losses to informed traders (see Capponi and Jia (2021); Malinova and Park (2024)).[2] In stage three, informed traders with private valuations compete in the

[1] See Harvey (2016), Cong and He (2019) and Biais, Capponi, Cong, Gaur, and Giesecke (2023).

[2] A DEX operates as a smart contract under the blockchain protocol; see John, Kogan, and Saleh (2023).

PGA to buy or to sell the asset, and price-sensitive uninformed traders submit transactions. In our model, informed traders are either all buyers or all sellers. Block time is long enough for substantial price movements to occur, so most private valuations observed at the end of block time take a definite sign. The remainder of the introduction considers buyers; the seller case is symmetric.

Traders compete for block priority to avoid worse execution prices resulting from the adverse price impact of preceding orders in the block. We propose and solve a special form of multi-prize auction for the PGA in which each trader's payoff depends on the rank of their bid relative to that of others. Specifically, the surplus from bidding a priority fee is the expected price impact that a trader avoids by improving queue position. In the perfect Bayesian equilibrium of the PGA, informed traders determine both their priority fees and their trading volumes. To determine priority fees, they balance profits from better execution prices against the fee paid to the builder. To determine volumes, they balance increased expected profits from larger positions against slippage that increases with order size.

We show that the defining features of blockchains fundamentally determine market outcomes and undermine market viability. Our main findings are threefold. First, competition in paid-priority contests generates endogenous selection, where only traders with sufficiently high valuations participate, which hinders price discovery by truncating information and biasing prices towards extreme values. Second, this selection mechanism raises adverse selection costs for liquidity providers and decreases liquidity in equilibrium, potentially leading to a market shutdown. Third, the very feature that supports decentralization, namely block time for consensus, amplifies these effects and tightens the constraints for viable markets. We elaborate on each of these findings below.

Our first two findings indicate that increased competition between informed traders in blockchains generates adverse effects for both liquidity and price discovery. First, we show

This contract defines the rules governing pricing and liquidity, which differ from those in traditional markets (see Barbon and Ranaldo (2021); Aoyagi and Ito (2021)). In 2025, DEXs supported monthly trading volumes of approximately $420 billion.

that there exists a cutoff for private valuations below which traders choose not to participate in the PGA, so only aggressive traders with high valuations transact in the blockchain. The intuition is as follows. Low valuations correspond to low desired volumes and less aggressiveness in priority fee bidding. This results in worse queue positions within the block and, consequently, higher adverse price impact from traders with better positions in the block and larger volumes. For traders with sufficiently low valuations, the adverse price impact associated with high-valuation traders will discourage participation because expected wealth from trading is negative. Hence, only a small fraction of traders in the blockchain with high enough valuations participate in the PGA.

Two factors exacerbate these negative effects on markets. First, as the number of competitors increases, the participation cutoff rises, so increasingly higher valuations are required to participate in the PGA. Thus, competition limits the amount of information that is disseminated: it narrows the range of private valuations revealed to the market, and skews it towards extreme values. Second, competition also impairs liquidity. Although the fraction of informed traders submitting transactions becomes smaller with competition, trading concentrates among the most aggressive traders, and the resulting adverse selection costs per unit of liquidity supply eventually increase.

These findings contrast with market outcomes in traditional markets where trading unfolds over multiple short clearing rounds. There, greater competition among informed traders accelerates the incorporation of information in the early rounds, and market depth typically improves thereafter; see Holden and Subrahmanyam (1992). The mechanism behind our result is fundamentally different. Blockchain block times are long, so each blockchain round of clearing aggregates the trading activity that, in traditional markets, would unfold over multiple successive rounds. Two consequences follow. First, the liquidity supplier absorbs adverse-selection risk from aggregate informed flow in a single decision, rather than adjusting liquidity across successive rounds. Second, paid-priority induces endogenous selection and only the most aggressive informed traders participate, pushing prices toward extreme values

and increasing adverse-selection costs. As a result, competition decreases liquidity.

Our model shows that a larger mass of uninformed demand and lower information costs increase the equilibrium number of informed traders who enter the blockchain and participate in the PGA. This would improve market efficiency in traditional electronic markets. The effect is reversed under paid-priority pricing. In blockchains, an increased number of informed traders raises the participation cutoff, so information becomes more truncated, and price efficiency deteriorates.

Our third main finding is that block time creates a tradeoff between security and efficiency. Longer blocks increase the dispersion of private valuations and intensify adverse selection, while simultaneously reducing the effective mass of price-sensitive uninformed demand. As a result, with many informed traders, liquidity decreases and there is a critical block time beyond which the market collapses.

Our model implies several stylized facts that we take to the data. First, using historical data from the DEX Uniswap v3 on Ethereum, we study assets whose price forms on the blockchain.[3] For these assets, the sequence of transactions within a block reflects on-chain price discovery, and we find that it follows the pattern predicted by the model: (i) transactions at the start of the block are predominantly in the same direction, (ii) the volume of transactions decreases with queue position, and (iii) the expected net trading volume is close to zero at the end of the block. This supports the equilibrium structure of a block that our model predicts: aggressive traders with high valuations obtain the earliest queue positions, followed by traders with lower valuations who trade in the same direction, and then by noise traders who trade in both directions.

Second, we study assets that are traded significantly both on the blockchain and on a centralized venue, so that price formation occurs on both markets. For these assets, we find that the price change over a single block is significantly more likely to be extreme on the blockchain than on the centralized venue, and that per-transaction volumes on the

[3]That is, assets that are not traded on a major centralized electronic exchange.

blockchain are substantially higher. This supports the model's prediction that competition and priority ordering among informed traders induce endogenous selection and bias prices towards extreme values.

Literature review. The tradeoff faced by informed traders in PGAs is analogous to that faced by political contestants or researchers in R&D races; see Lazear and Rosen (1981); Hillman and Riley (1989); Barut and Kovenock (1998). In such contests, the cost of the effort exerted by contestants corresponds to the priority fee paid by traders, and the payoff linked to achieving a particular rank in the race corresponds to the surplus in the PGA; see also Klose and Kovenock (2015). Multi-prize contests are typically modeled as independent private cost contests, where the cost of effort is private but the prize vector is known ex ante; see Moldovanu and Sela (2001). In contrast, in the PGA, the *prize* from attaining a given position is not fixed but depends on the private valuations and trading volumes of competitors. In the PGA, the value of a given position corresponds to the adverse price impact that a trader avoids by securing that position within the block.

The model of this paper is related to the literature that studies the properties of price and liquidity. Our model is information based, however, it shares features of the multi-stage inventory-based models in Biais (1993); De Frutos and Manzano (2002). We adapt these models to account for information dissemination, DEX algorithmic pricing, and the blockchain protocol whereby traders compete for queue position instead of speed (O'Hara (1998)). Our model is also related to the theory on the costs of information processing such as that in Grossman and Stiglitz (1980), Verrecchia (1982), Kyle (1989), and Baldauf and Mollner (2020).

Some studies examine periodic uniform price auctions for market clearing (Madhavan (1992); Budish, Cramton, and Shim (2015)), and they show that these auctions enhance price efficiency but impose higher information costs on traders. Instead, our model considers discriminatory auctions in which liquidity suppliers do not participate. Several studies

assume an information monopolist (Kyle (1985)). In blockchains, monopolistic information would drive priority fees to zero in equilibrium, which contradicts empirical evidence showing that priority fees increase with the informational content of transactions; see Capponi, Jia, and Yu (2024). We therefore consider competition among multiple informed traders. Models with competition, such as Holden and Subrahmanyam (1992) and Foster and Viswanathan (1996), lead to revealing equilibria where prices reflect private information. In our model, traders submit fully revealing priority fees, however, blockchains operate with periodic clearing and the revealing equilibrium is delayed until the end of block time.

Trading in blockchains resembles trading in preopening sessions of traditional electronic exchanges, where markets clear only at the end of a short period. Unlike preopening sessions, where orders execute at a uniform clearing price that maximizes volume, blockchain orders are priced by priority fees, and volume is not maximized. Moreover, traders in preopening sessions observe partial information about the market, such as liquidity at the best prices or a virtual clearing price; see Van Bommel and Hoffmann (2011).[4]

The microstructure of DEXs has been studied extensively. The economic tradeoffs for liquidity supply are similar to those for market makers in limit order books and dealer markets (Ho and Stoll (1983); Glosten and Milgrom (1985)), and they are studied for DEXs and characterized in Malinova and Park (2024); see also Lehar and Parlour (2025), Hasbrouck, Rivera, and Saleh (2026), Milionis, Moallemi, Roughgarden, and Zhang (2022), and Park (2023) for an analysis of the microstructure of DEXs.[5] In contrast to this literature, we develop a model of a DEX comprising two components: (i) a smart contract and (ii) the

[4]Biais, Hillion, and Spatt (1999) propose several hypotheses regarding the informativeness of preopening prices; our empirical results in Appendix A show that information revelation is delayed in public memory pools, which supports their *pure-noise hypothesis*, under which trading activity before clearing contains no new information. Similarly, Medrano and Vives (2001) find that trading volumes and information revelation accelerate toward the end of preopening sessions.

[5]See also Angeris, Evans, and Chitra (2021); Capponi, Iyengar, Sethuraman, et al. (2023); Drissi, Wu, and Jaimungal (2025) who show that DEXs cause losses to liquidity suppliers. Klein, Kozhan, Viswanath-Natraj, and Wang (2023) study the role of informed liquidity supply in price discovery. Hasbrouck, Rivera, and Saleh (2023) study concentrated liquidity DEXs. Cartea, Drissi, Sánchez-Betancourt, Siska, and Szpruch (2024b) propose AMM designs to mitigate adverse selection.

blockchain infrastructure on which it operates.[6] In particular, the trading function of a DEX can be viewed as a parameterized price schedule in electronic exchanges; see Glosten (1994); Biais, Martimort, and Rochet (2000). As a consequence, the conclusions of our model apply if the blockchain runs other market infrastructures. Finally, He, Yang, and Zhou (2025) study priority fees when traders arbitrage the blockchain against a competing venue. In contrast, this paper studies whether the blockchain itself can serve as the primary venue for price formation.

The role of DEXs is likely to grow with the development of asset tokenization (Heines, Dick, Pohle, and Jung (2021); Cartea, Drissi, and Saleh (2026)), central bank digital currencies (Fung and Halaburda (2016); Auer, Frost, Gambacorta, Monnet, Rice, and Shin (2022)), and cross-border settlement (Harvey (2021); Hub (2023); Cardozo, Fernández, Jiang, and Rojas (2024)).

The remainder of this paper proceeds as follows. In Section I, we present notation, assumptions, and structure of the model. In Section II, we study the priority fee bidding strategies and trading volumes of informed traders. In Section III, we analyze the liquidity supply. In Section IV, we study incentives to acquire information at a cost. In Section V, we study the economic effects of block time. In Appendix A, we describe the features of blockchains that underpin our model. In Appendix B we discuss extensions of our model. Finally, Appendix C collects the proofs.

I. General features of the model

In this section, we introduce the features of our model for the strategic interactions of market participants in blockchain-based markets. A decentralized exchange (DEX) supplies liquidity in a reference asset X (e.g., dollar) and in a risky asset Y.[7] There are three types of

[6] See Capponi et al. (2024) for an empirical study of the influence of gas fees on the informativeness of trades.

[7] See Appendix A.B and Capponi and Jia (2021); Cartea, Drissi, and Monga (2024a); Lehar and Parlour (2025) for more details on the mechanics of DEXs.

agent, a representative liquidity supplier (he), informed traders (she), and noise traders with price-sensitive demand. The entry to blockchain markets, liquidity supply, and the trading process are modeled as a game that proceeds as follows.

- *Stage one*: M traders decide whether to pay a fixed information cost C to enter the blockchain and to observe private information. This choice depends on whether informed trading yields an expected future payoff higher than C.
- *Stage two*: the liquidity supplier sets the liquidity reserves in the DEX by balancing expected losses to informed traders and expected fee revenue from noise traders. The level of reserves determines the cost of liquidity.
- *Stage three*: Informed traders hold private information about the future liquidation value of the asset. Based on valuations, traders compete for queue priority in the next block, and they determine their priority fee bids and their trading volumes. In contrast, noise traders submit transactions with zero priority fees.[8]

After the three stages, a builder constructs the block by sorting transactions according to their priority fees. Specifically, the block executes the transactions of informed traders first, followed by those from noise traders who only pay the base fee.[9]

After the liquidity supplier sets the DEX's liquidity in stage two, we assume for simplicity that he remains passive and does not compete with traders for queue priority in the subsequent block. Although the liquidity supplier does not compete directly, his strategy depends indirectly on the behavior of informed traders: he chooses the cost of liquidity in the DEX based on rational expectations about their best response in the next stage.

At the start of the PGA in stage three, each informed trader observes a private valuation,

[8]Builders are paid *gas fees* by agents to include their transactions in a block. Gas fees consist of two components: the *base fee* and the *priority fee*. The base fee is mandatory for inclusion and is paid by all traders. We assume that noise traders pay the base fee only, which we normalize to zero without loss of generality, because the base fee does not affect ordering within the block. See Appendix A.A for further institutional details on the blockchain protocol.

[9]In blockchains, informed traders do not profitably blend with noise traders to conceal their orders, as they would in Kyle (1985). Specifically, blending would require paying a zero priority fee. Submitting an arbitrarily small positive priority fee is a profitable deviation, because it secures a better queue position and execution price. In equilibrium, informed traders pay priority fees which reveal valuations; see Proposition 4.

drawn from a common and known distribution. Next, they set priority fees and trading volumes by balancing expected profits against (i) the adverse price impact generated by traders with better positions in the block and (ii) slippage in the DEX.

A key assumption of the model is that all informed traders know whether the price innovation is positive or negative. This determines the sign of all valuations and whether traders are buyers or sellers.[10] We motivate this assumption as follows. Informed traders submit their transactions near the end of the blockchain slot and rely on private information observed at that time.[11] Blockchains that host decentralized markets, such as Ethereum, operate with slots of twelve seconds or longer to build blocks securely.[12] Thus, substantial price movements can occur during this period and cause most private valuations to take a definite sign. Our focus is on price discovery and liquidity in settings where the liquidation value of the asset is likely to change significantly in the DEX, so most informed traders are either buyers or sellers, and the PGA serves as the mechanism through which information is incorporated into prices.[13] Appendix B discusses the case in which informed traders are both buyers and sellers.

We solve for a perfect Bayesian equilibrium of this game by backward induction. At stage three (Section II), given a known level of liquidity supply L and a known number M of competing informed traders, the bidding strategies and trading volumes are determined. At stage two (Section III), given a known number M of competing informed traders, the

[10]More precisely, the conditional information structure is as follows. At the beginning of the PGA, a public indicator reveals the direction of the price innovation, after which each informed trader observes a private and independent valuation regarding the magnitude of the innovation. As detailed below, positive valuations are drawn from a distribution with positive support, while negative valuations follow a symmetric distribution with negative support.

[11]Informed traders transact through private memory pools or wait until the end of block time in public memory pools, consistent with the empirical evidence reported in Appendix A.A.

[12]Layer-two blockchains achieve shorter block times by relying on centralized sequencers, and thus do not qualify as decentralized.

[13]In contrast, when the future liquidation value of the asset is close to its initial value, private valuations are more dispersed in direction. In such situations, if an informed buyer and an informed seller both submit transactions within the same block, each has an incentive for the other's trade to be executed first, because this improves their own execution price. Consequently, the expected value of queue priority becomes non-positive for both traders, leading to zero equilibrium bids and limited informational content in the auction outcome.

liquidity supply L is determined based on the supplier's rational expectations of future trading volumes and noise trading activity. At stage one (Section IV), the number M of informed traders who pay the cost of information is determined. The sequence of events is described in more detail in the next sections.

II. Stage three: priority fees and trading volumes

This section studies the priority fee bidding strategies and trading volumes of informed traders who compete for queue priority in stage three. Traders take as given the liquidity supply in the DEX and the number M of competitors. Assume that informed traders know the liquidation value V is positive, so they wish to buy the asset. The case in which informed traders are sellers is symmetric and yields identical equilibrium priority fee bidding strategies, and trading volumes of opposite sign.

A. Assumptions

In stage three, M risk-neutral informed traders compete for queue priority in the next block. We assume that the DEX offers a linear price schedule, and implements a linear price update rule. Let L denote the depth of liquidity in the DEX determined in stage two.[14] An order of size Q is executed with slippage Q/L per unit of the asset, and, after execution, the price updates linearly by $2\,Q/L$ in the direction of the trade. This assumption is a first-order approximation of the pricing mechanism in standard DEXs; see Appendix A.B for details.

Traders compete to avoid potentially worse execution prices resulting from the adverse price impact of preceding orders in the block. Thus, the supply L influences competition outcomes because it determines execution prices and the magnitude of price impact. Consider two traders, 1 and 2, who sequentially buy quantities $Q_1 > 0$ and $Q_2 > 0$ of asset Y. We normalize the DEX's initial price at the start of the blockchain slot to zero, without loss of

[14]The depth L is determined by the reserves deposited in the DEX's liquidity pool, and by the shape of the *bonding curve* implemented in the DEX's smart contract; see Appendix A.B for details.

generality. Thus, the execution price for trader 1, assuming she has queue priority, is Q_1/L, after which the DEX price updates to $2\,Q_1/L$. Consequently, the execution price for trader 2, who trades second in the block, is $Q_2/L + 2\,Q_1/L$.[15]

The PGA among traders is a multi-prize contest in which each competitor's payoff depends on the rank of her priority fee relative to others. As discussed in Appendix A.A, the PGA is *blind* because traders either compete in the private memory pool or submit their transactions to the public memory pool immediately before block creation. Moreover, the PGA is *all-pay* because traders' transactions are all executed and builders collect priority fees regardless of relative ranks within the block.

Before submitting their transactions, traders know whether they are all buyers or all sellers, and they observe private valuations $\{v_1, \ldots, v_M\}$ used to assess the asset's worth. Specifically, from the perspective of trader i, the expected liquidation value is

$$\mathbb{E}_i[V] = v_i\,. \tag{1}$$

Valuations are independent and identically distributed (i.i.d.) with continuous cumulative distribution function F on $[0, \overline{v}]$, admitting a continuous density f. In the perfect Bayesian equilibrium of the PGA, the M risk-neutral traders determine their priority fees $\{\Phi_1, \cdots, \Phi_M\}$ and their trading volumes $\{Q_1, \cdots, Q_M\}$.

B. The priority gas auction

This section derives the expected utility of competing traders in the PGA. The contest is symmetric, and we describe it from the perspective of trader $i \in \{1, \ldots, M\}$. Trader i competes with $M-1$ other traders in the PGA. From her perspective, the $M-1$ valuations of her competitors are i.i.d. draws from the same distribution; likewise, the $M-1$ trading volumes of her competitors are i.i.d. draws from the same distribution. We denote by

[15] See Appendix A.B for more details on execution prices and price impact in DEXs.

$\Phi_{(j)}$, for $j \in \{1, \ldots, M-1\}$, the j-th smallest bid among the $M-1$ competitors, so that $\Phi_{(j)} < \Phi_{(j+1)}$ and $\Phi_{(M-1)}$ is the largest competing priority fee. We denote by $v_{(j)}$ and $Q_{(j)}$ the valuation and trading volume, respectively, of the competitor submitting the priority fee ranked j-th.

If trader i wins priority in the block, i.e., if $\Phi_i > \Phi_{(M-1)}$, her buy order is executed first in the next block at the price $Q_i/L + \pi$ per unit of the asset, where π is a proportional fee paid to the DEX; see (A2).[16] In this case, the trader's terminal wealth depends on the priority fee paid to the builder, the cash paid to the DEX to purchase Q_i units of the asset, the proportional DEX fee π, the information cost C incurred in stage one, and the terminal value of her holdings:

$$W_{i,(M-1)} = \underbrace{-\Phi_i}_{\text{priority fee}} \underbrace{- Q_i \left(\frac{Q_i}{L} + \pi \right)}_{\text{cash paid to DEX}} + \underbrace{Q_i V}_{\text{terminal value of holdings}} - \underbrace{C}_{\text{information cost}} . \tag{2}$$

If trader i's priority fee Φ_i lies between the j-th and $(j+1)$-th smallest priority fees among her competitors, i.e.,

$$\Phi_{(j)} < \Phi_i < \Phi_{(j+1)} ,$$

then exactly $M-1-j$ traders, with trading volumes $\{Q_{(j+1)}, \ldots, Q_{(M-1)}\}$, are executed in the block before trader i's buy order. The price impact in the DEX when trading a volume Q is $2\,Q/L$. Hence, trader i's execution price per unit of the risky asset is

$$\underbrace{\frac{Q_i}{L}}_{\text{slippage}} + \underbrace{\frac{2}{L} \sum_{\ell=j+1}^{M-1} Q_{(\ell)}}_{\text{impact of traders with higher priority fees}} + \underbrace{\pi}_{\text{DEX fee}} .$$

[16] We assume that $\pi < \overline{v} < \infty$ to ensure that the probability of non-zero trading volumes is positive; see Section II.D.

Accordingly, trader i's terminal wealth in this case is

$$W_{i,(j)} = \underbrace{-\Phi_i}_{\text{priority fee}} \underbrace{- Q_i\left(\frac{Q_i}{L} + \frac{2}{L}\Delta_{(j+1:M-1)} + \pi\right)}_{\text{cash paid to DEX}} + \underbrace{Q_i V}_{\text{terminal value of holdings}} - \underbrace{C}_{\text{information cost}}, \quad (3)$$

where, for convenience, we define

$$\Delta_{(l:L)} = \sum_{\ell=l}^{L} Q_{(\ell)}.$$

Finally, if trader i's priority fee is lower than the lowest competing fee, i.e.,

$$\Phi_i < \Phi_{(1)}\,,$$

then her terminal wealth is

$$W_{i,(0)} = -\Phi_i - Q_i\left(\frac{Q_i}{L} + \frac{2}{L}\,\Delta_{(1:M-1)} + \pi\right) + Q_i V - C\,.$$

Using the cases above, the expected utility of trader i can be written as

$$\begin{aligned}\mathbb{E}_i[W_i] &= \sum_{j=0}^{M-1} \mathbb{E}_i\Big[\mathbb{1}_{\Phi_{(j)}<\Phi_i<\Phi_{(j+1)}}\, W_{i,(j)}\Big] \\ &= \sum_{j=0}^{M-1} \mathbb{E}_i\left[\mathbb{1}_{\Phi_{(j)}<\Phi_i<\Phi_{(j+1)}}\left(-\Phi_i - Q_i\left(\frac{Q_i}{L} + \frac{2}{L}\,\Delta_{(j+1:M-1)} + \pi\right) + Q_i V - C\right)\right],\end{aligned}$$

with the conventions

$$\Delta_{(l:L)} = 0 \text{ whenever } l > L, \qquad \Phi_{(M)} = \infty, \qquad \Phi_{(0)} = -\infty.$$

At stage three, trader i's valuation of the asset is v_i, and she knows the DEX supply L, the number of competing traders M, her trading volume Q_i, and her priority fee Φ_i. She understands that her queue position depends on the rank of Φ_i relative to her competitors.

Hence the expected wealth of trader i can be written as

$$\mathbb{E}_i\big[W_i\big] = -\Phi_i + Q_i\Big(v_i - \pi - \frac{Q_i}{L}\Big) - C - \frac{2\,Q_i}{L}\sum_{j=0}^{M-1}\mathbb{E}_i\Big[\mathbb{1}_{\{\Phi_{(j)}<\Phi_i<\Phi_{(j+1)}\}}\,\Delta_{(j+1:M-1)}\Big]\,. \tag{4}$$

The expected wealth (4) consists of (i) the expected profit $Q_i\,v_i$ and (ii) several trading costs. These costs include the priority fee paid to builders, the DEX fee, the information cost, the expected adverse price impact generated by trader i's competitors, and the execution price paid to the DEX.

When submitting a transaction, trader i determines both the priority fee and the volume, thus she solves the problem[17]

$$\sup_{Q_i}\,\sup_{\Phi_i}\mathbb{E}_i\left[W_i\right]\,. \tag{5}$$

Intuitively, traders buy and sell volumes proportional to their private valuations of the asset. In the optimization problem (5), the trading volume Q_i for trader i depends on v_i. Similarly, the priority fee Φ_i depends on the trading volume Q_i. Thus, in equilibrium, both the volume Q_i and the priority fee Φ_i are functions of the private valuation v_i.[18] Section II.C derives the equilibrium priority fees for a fixed distribution of trading volumes, and Section II.D then derives the equilibrium trading volumes given these priority fees.

C. Priority fees

Here, we solve for the equilibrium priority fee under an arbitrary distribution of trading volumes. Let Q_j denote the random variable representing the trading volume of trader $j \neq i$, drawn from the interval $[0, \overline{Q}]$ according to a density function g with finite first and second moments, which may include an atom $p = G(\{0\})$ at zero volume. We denote by G the cumulative distribution function of volumes. At zero volume, traders submit the minimum

[17] The order of the two suprema can be interchanged.

[18] Specifically, note that $\partial_{Q_i}\mathbb{E}_i\left[W_i\right]$ is a function of v_i, i.e., $\partial_{Q_i v_i}\mathbb{E}_i\left[W_i\right] \neq 0$. Thus, the optimal trading volume $\arg\max_{Q_i}\mathbb{E}_i\left[W_i\right]$ is a function of the valuation v_i. Similarly, $\partial_{\Phi_i v_i}\mathbb{E}_i\left[W_i\right] \neq 0$, so the priority fee also depends on the private valuation.

zero priority fee. Equivalently, they do not participate in the PGA, and their expected wealth equals $-C$.[19] The equilibrium distribution of trading volumes is derived in Section II.D.

When solving for the equilibrium at stage three, informed traders take the depth L as fixed and independent of the priority fee Φ_i. Although the priority fee does not directly affect liquidity supply, it exerts an indirect influence. As shown in Section III, the liquidity supplier anticipates the priority fees and trading volumes of informed traders when determining the depth of the DEX's pool.

To better characterize the economic object of competition in the PGA, we rewrite trader i's expected wealth in (4) as

$$\mathbb{E}_i[W_i] = \mathbb{E}_i\big[W_{i,(0)}\big] + \frac{2\,Q_i}{L} \sum_{j=0}^{M-1} \mathbb{E}_i\Big[\mathbb{1}_{\{\Phi_{(j)}<\Phi_i<\Phi_{(j+1)}\}}\,\Delta_{(1:j)}\Big]\,, \tag{6}$$

which has the following economic interpretation. The term $\mathbb{E}_i\big[W_{i,(0)}\big]$ represents trader i's expected wealth if she is executed last in the block. By submitting a positive priority fee Φ_i, she obtains, with positive probability, an additional surplus. This surplus,

$$\frac{2\,Q_i}{L} \sum_{j=0}^{M-1} \mathbb{E}_i\Big[\mathbb{1}_{\{\Phi_{(j)}<\Phi_i<\Phi_{(j+1)}\}}\,\Delta_{(1:j)}\Big]\,, \tag{7}$$

represents the expected price impact that trader i avoids by improving her queue position. The magnitude of this surplus increases with the rank of Φ_i among competitors and with the quantity demanded by the trader.

Trader i expects her competitors to employ a continuous and differentiable priority fee bidding strategy $\Phi(\cdot)$ which is increasing in the trading volume Q. Therefore, the probability of submitting the $j+1$-th largest priority fee is

$$\mathbb{P}_i\left[\Phi_{(j)} < \Phi_i < \Phi_{(j+1)}\right] = \mathbb{P}_i\left[Q_{(j)} < \Phi^{-1}\left(\Phi_i\right) < Q_{(j+1)}\right]\,.$$

[19] In particular, no tie-breaking rule is required for zero volumes. Note also that a zero trading volume generates no adverse price impact on subsequent transactions within the block.

To determine her optimal priority fee, trader i solves the optimization problem

$$\sup_{\Phi_i} \mathbb{E}_i \left[W_i \right] , \tag{8}$$

which is equivalent to solving

$$\sup_{\Phi_i} \left\{ -\Phi_i + \frac{2\,Q_i}{L} \sum_{j=0}^{M-1} \mathbb{E}_i \left[\mathbb{1}_{\Phi_{(j)} < \Phi_i < \Phi_{(j+1)}} \Delta_{(1:j)} \right] \right\} . \tag{9}$$

That is, trader i chooses her priority fee to maximize the sum of (i) the loss from paying the priority fee to the builder and (ii) the gain from the surplus. Trader i therefore faces a tradeoff: lowering the priority fee increases expected wealth but decreases the probability of attaining a higher position in the queue.

To further analyze the optimization problem, the following lemma is useful, because it simplifies trader i's estimation of the expected surplus from the PGA.

LEMMA 1: *Assume $M \geq 2$. The surplus* (7) *is*

$$\frac{2\,Q_i}{L} \sum_{j=0}^{M-1} \mathbb{E}_i \left[\mathbb{1}_{\{\Phi_{(j)} < \Phi_i < \Phi_{(j+1)}\}} \Delta_{(1:j)} \right] = \frac{2\,Q_i}{L} \, (M-1) \int_0^{\Phi^{-1}(\Phi_i)} x \, dG\left(x\right) . \tag{10}$$

Lemma 1 shows that the surplus is obtained by averaging the price impact of transactions with volumes lower than trader i's inverse bid. This result follows from the structure of the PGA. First, it arises from our assumption of additive and linear price impact in the DEX. In practice, nonlinearities exist in the impact of consecutive trades; see Cartea, Drissi, and Monga (2023). However, we model competition within a block whose duration is short enough for our linear approximation (A3) to be accurate. Second, the result of Lemma 1 also relies on the strict ordering of transactions by priority fee within the block. In practice, while builders have reputational incentives to maintain strict ordering, they are not required to do so by the blockchain protocol. Such strategic considerations are beyond the scope of this work.

In a Bayesian-Nash equilibrium, trader i finds it optimal to adopt the same differentiable and increasing strategy Φ, which pins down the equilibrium strategy. The solution is characterized in the following result.

PROPOSITION 1: *The equilibrium priority fee is*

$$\Phi\left(Q_i\right) = \frac{2}{L}\left(M-1\right)\int_0^{Q_i} x^2\, dG\left(x\right) . \tag{11}$$

The priority fee is increasing in the trading volume Q_i, increasing in the number of informed traders M, and decreasing in the liquidity depth L. Finally, trader i's objective (9) *is*

$$\frac{2}{L}\left(M-1\right)\int_0^{Q_i} x\,\left(Q_i - x\right)\, dG\left(x\right) . \tag{12}$$

To set her priority fee, trader i uses the reservation priority fee

$$\frac{2\,Q_i}{L}\left(M-1\right)\int_0^{Q_i} x\, dG(x)$$

as a baseline when computing her optimal fee. This reservation priority fee is the level that makes trader i indifferent between participating in the PGA and abstaining, that is, it sets her objective (12) equal to zero. Trader i then applies a discount to this baseline to capture a surplus. In particular, as trader i's trading volume Q_i increases, the likelihood that her reservation fee exceeds those of other traders also rises. Consequently, trader i applies a larger discount as the value of her private volume increases.

For a fixed arbitrary distribution of trading volumes, equilibrium priority fees increase with the number of competitors. Specifically, as the number of informed traders rises, the expected adverse price impact becomes larger, incentivizing each trader to raise her priority fee. Conversely, equilibrium priority fees decrease with liquidity supply. Specifically, when L is large, price impact is low and the cost of losing queue priority becomes less significant.

As we show below, however, these relationships do not necessarily hold (i) when informed

traders choose their trading volumes strategically as a function of anticipated priority fees, and (ii) when liquidity suppliers set their supply strategically as a function of anticipated trading volumes.

D. Trading volumes and participation cutoff

The section above derived the equilibrium priority fees of informed traders for an arbitrary distribution g of trading volumes with support $\left[0, \overline{Q}\right]$. We now endogenize this distribution by determining the volumes that maximize the informed traders' objective. Substituting the optimal priority fee Φ_i from (11) into the objective function (5), we express trader i's optimization problem as

$$\sup_{Q_i} \left\{ -\frac{2}{L}\,(M-1)\left(\int_0^{Q_i} x^2\, dG(x) + Q_i \int_{Q_i}^{\overline{Q}} x\, dG(x)\right) + Q_i\left(v_i - \pi - \frac{Q_i}{L}\right)\right\}. \qquad (13)$$

The programme (13) is interpreted as follows. In equilibrium, all traders employ the same priority fee bidding strategy, allowing them to estimate, on average, the expected costs of the PGA in the form of expected adverse price impact and priority fees. Additional trading costs incurred by trader i include (i) the slippage $-Q_i^2/L$, (ii) the DEX's fee $-\pi\, Q_i$, and (iii) the cost of information $-C$. Both trading costs and infrastructure costs increase with trading volume, creating an incentive for trader i to reduce her trading volume Q_i. However, trader i's expected trading profits are $Q_i\, v_i$. This provides an incentive for trader i to increase her holdings in the asset.

We look for equilibria in which trading volumes are a weakly monotone function of private valuations and we write $Q_i = Q(v_i)$ for $v_i \in [0, \overline{v}]$. In particular, the minimum and maximum trading volumes satisfy

$$Q(0) = 0 \qquad \text{and} \qquad \overline{Q} = Q(\overline{v})\,.$$

We later verify that the monotonicity property holds in equilibrium. The distribution of

trading volumes, expressed as a function of F, is given by

$$G(x) = F\big(Q^{-1}(x)\big)\,, \tag{14}$$

where $Q^{-1}(\cdot)$ denotes the generalized inverse of the function $Q(\cdot)$.

The adverse price impact of competing traders depends on trader i's private valuation of the asset. Lower valuations correspond to lower volumes and to worse queue positions within the block, and consequently, to higher adverse price impact from traders with better positions. For sufficiently low valuations, the adverse price impact associated with high-valuation traders may discourage trader i from submitting a transaction if doing so results in a negative objective (13). In what follows, we show that there indeed exists a participation cutoff $\underline{v}_M$ for private valuations below which trader i optimally chooses not to submit a transaction.

Using (14), the first-order condition (FOC) derived from the optimization problem (13) yields the following implicit integral equation for trader i's optimal trading volume

$$(v_i - \pi)\, L - 2\, Q(v_i) - 2\,(M-1) \int_{v_i}^{\overline{v}} Q(x)\, dF(x) = 0\,. \tag{15}$$

Next, Lemma 2 characterizes the participation cutoff, and Proposition 2 derives the equilibrium trading volumes and their distribution.

LEMMA 2: *Fix $M \geq 2$. There exists a unique $\underline{v}_M \in (0, \overline{v})$ which satisfies*

$$\underline{v}_M - \pi - \int_{\underline{v}_M}^{\overline{v}} \big(e^{(1-F(u))(M-1)} - 1\big)\, du = 0\,. \tag{16}$$

Moreover, $\underline{v}_M$ is strictly increasing in M and $\lim_{M\to\infty} \underline{v}_M = \overline{v}$.

PROPOSITION 2: *Fix $M \geq 2$. If $v_i < \underline{v}_M$, where $\underline{v}_M$ is defined in (16), then trader i's optimal trading volume is $Q(v_i) = 0$. If $v_i \geq \underline{v}_M$, then the optimal trading volume is*

proportional to the liquidity supply L,

$$Q(v_i) = L\,\tilde{Q}(v_i)\,, \tag{17}$$

where

$$\tilde{Q}(v_i) = \frac{1}{2}\left((\overline{v} - \pi)\, e^{-(M-1)(1-F(v_i))} - \int_{v_i}^{\overline{v}} e^{-(M-1)(F(u)-F(v_i))}\, du \right). \tag{18}$$

Moreover,

$$Q(\underline{v}_M) = 0 \qquad \textit{and} \qquad \overline{Q} = Q(\overline{v}) = L\frac{\overline{v} - \pi}{2}.$$

The trading volume $Q(v_i)$ is increasing in the private valuation v_i, decreasing in the number of informed traders M with limit $\lim_{M\to\infty} Q(v_i) = 0$ for every $v_i < \overline{v}$.

Lemma 2 shows that there is a participation cutoff $\underline{v}_M$ for private valuations: informed traders with valuations below $\underline{v}_M$ find it unprofitable to trade and abstain from submitting a transaction. The cutoff is strictly increasing in the number of competitors M and converges to the upper bound $\overline{v}$ as $M \to \infty$.

When a trader's valuation exceeds the participation cutoff $\underline{v}_M$, Proposition 2 shows that her trading volume is proportional to the liquidity supply L, with proportionality factor $\tilde{Q}(v_i)$. Thus, deeper liquidity reserves allow traders to extract greater profits from private information. In contrast, trading volumes decrease with the number of traders in anticipation of higher expected PGA costs.

Moreover, the factor $\tilde{Q}(v_i)$ increases with the private valuation v_i. This occurs for two reasons. One, a higher valuation strengthens the incentive to trade, and two, it increases the expected surplus from the PGA. Thus, higher private valuations correspond to larger trading volumes, and as shown in Proposition 1, they are also associated with better queue positions.

To test these predictions, Figures 1 and 2 present an empirical analysis of assets whose price forms on Ethereum. For such assets, the sequence of transactions within a block reflects

on-chain price discovery rather than arbitrage against an external market. Figure 1 shows that transactions near the start of the block are predominantly in the same direction as the first transaction: over the first 30% of the block, the probability that a transaction shares the sign of the first transaction is well above 50%. Later in the block, the expected net trading volume is close to zero, consistent with two-sided noise trading. In turn, Figure 2a shows that absolute trading volume decreases with queue position: the large, aggressive trades at the front are followed by progressively smaller ones. These figures lend empirical support to the findings of our model: high-valuation aggressive traders obtain earlier queue positions, followed by lower-valuation traders who trade in the same direction, and by noise traders who trade in both directions. Finally, Figure 2b shows that price impact is larger for transactions at the front of the block.

Proposition 2 also shows that the participation cutoff $\underline{v}_M$ for profitable informed trading increases with M. Therefore, as the number of competitors grows, increasingly higher valuations are required to participate. Because only high-valuation traders ultimately submit transactions in blockchains, higher trading volumes, associated with higher valuations, should be more frequently observed on blockchains. This prediction is consistent with empirical evidence showing that per-transaction trading volumes in blockchain markets are significantly higher than those in traditional electronic limit order books. For instance, between 1 July 2021 and 31 December 2023, the average size of liquidity-taking trades in the most active DEX on Ethereum was approximately \$70,000, compared with about \$1,200 for the same pair of assets on Binance; see Cartea, Drissi, and Monga (2025).

Competition and price efficiency. Proposition 2 shows that the equilibrium distribution of trading volumes is a transformation of the truncated distribution of valuations over $[\underline{v}_M, \overline{v}]$:

$$G\left(\{0\}\right) = F(\underline{v}_M) \qquad \text{and} \qquad G\big(Q(v)\big) = F(v) \quad \text{for } v \in [\underline{v}_M, \overline{v}]\,. \tag{19}$$

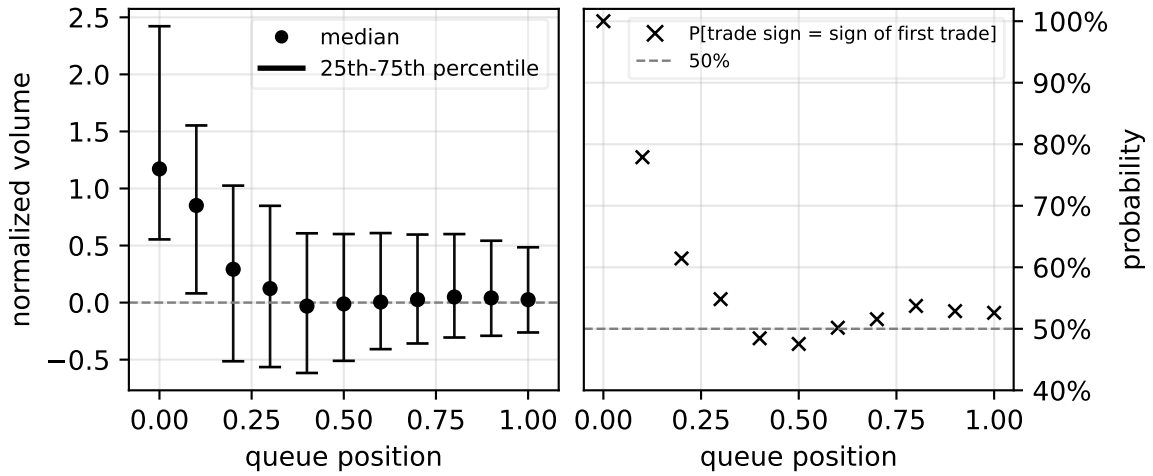


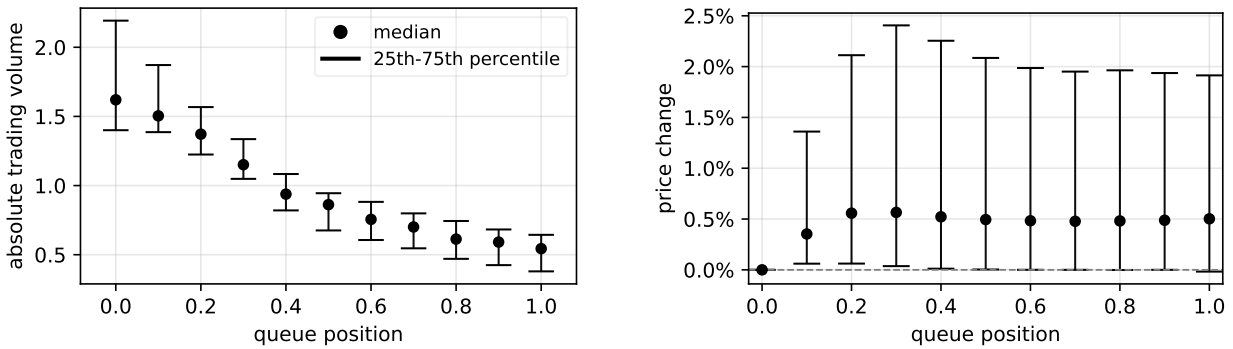
Figure 1. Left panel: median and interquartile range of (signed) trading volumes as a function of queue position within the block (0 denotes the first transaction and 1 the last). Specifically, for each asset and each block, we change the signs of observed volumes so that a positive volume denotes a transaction in the *same* direction as the first transaction of the block and a negative volume the *opposite* direction. We normalize by the block's mean absolute volume. **Right panel**: the probability that a transaction shares the sign of the first transaction of its block, as a function of queue position. The reference level of 50% corresponds to a transaction's direction being unrelated to that of the first transaction. **Data**: the data are all liquidity-taking trades between 19 May 2021 and 30 June 2026 in 75 Uniswap v3 pools on Ethereum whose risky asset is not listed on Binance, which we take to be the main venue where price formation takes place. For each asset, we keep blocks with more than five transactions and assets with more than ten such blocks. This yields 317,901 transactions in 36,692 blocks.

For a given number M of competing traders, the expected number of traders with sufficiently high valuations for the asset to submit non-zero trading volumes is $M\big(1-F(\underline{v}_M)\big)$. We refer to these traders as *active traders*.

In what follows, we assume that the probability density function of valuations f does not exceed the uniform density in a (left) neighborhood of $\overline{v}$.[20] The next result characterizes the behavior of price and volume in blockchain markets as competition intensifies.

PROPOSITION 3: *The expected aggregate trading volume of active informed traders admits*

[20]The upper bound $\overline{v}$ on valuations can be taken arbitrarily large to accommodate extreme valuations and ensure right-tail decay, so the condition holds for most standard distributions on compact support.



(a) Absolute trading volume

(b) DEX price

Figure 2. Median and interquartile range as a function of queue position within the block, rescaled to the unit interval: 0 denotes the first transaction in the block and 1 the last. For each asset, values are averaged across blocks at each queue position. In panel (a) the absolute trading volume is normalized so that a value of one corresponds to the average absolute trading volume; in panel (b) the DEX price is normalized by its value before the block. The data are those of Figure 1.

the closed form

$$L\,M\int_{\underline{v}_M}^{\overline{v}}\tilde{Q}(x)\,dF(x)\;=\;\frac{L\,M\,(\underline{v}_M-\pi)}{2\,(M-1)}\,. \tag{20}$$

The aggregate trading volume admits the limit $L\,\dfrac{\overline{v}-\pi}{2}=L\,\tilde{Q}(\overline{v})$ *as competition intensifies* $(M\to\infty)$*. Moreover, the expected price at the end of the block admits the closed form*

$$\frac{M\,(\underline{v}_M-\pi)}{M-1} \tag{21}$$

and converges to $\overline{v}-\pi$*. Both limits are approached from below.*

Proposition 3 shows that, as competition intensifies, a growing mass of active traders with increasingly high valuations participate in the PGA. For instance, when valuations are uniformly distributed, the participation cutoff admits the form $\underline{v}_M=\overline{v}-(\overline{v}-\pi)\log M/(M-1)$, so the range $[\underline{v}_M,\overline{v}]$ of active traders' valuations shrinks at rate $\log M/M$. Yet the expected number of active traders $M(1-F(\underline{v}_M))=M\log M/(M-1)$, the aggregate trading volume in (20), and the expected price at the end of the block in (21) all increase strictly with M.

In the limit when $M \to \infty$, aggregate volume converges to the volume $L\,\tilde{Q}(\overline{v})$ associated with an informed trader holding the maximal valuation $\overline{v}$. Moreover, the expected price at the end of the block converges to $\overline{v} - \pi$, which corresponds to the upper bound of the valuation support net of fees.

The economic mechanism behind our result is endogenous selection. As M increases, participation requires progressively more aggressive bidding to remain competitive. Traders anticipate both higher expected priority fees and the adverse price impact generated by participants with larger valuations. This raises the cutoff $\underline{v}_M$ and excludes traders with moderate valuations from the market. In equilibrium, only the most aggressive traders remain active and their aggregate trading volume biases prices towards high values.

To test the prediction that competition and priority ordering among informed traders bias prices towards extreme values, Table I compares the dispersion and tails of one-block returns on the blockchain and on Binance, for a set of assets whose prices form both on-chain and off-chain (Capponi, Jia, and Yu (2026)). The table shows that the standard deviation and the 99th percentile of one-block returns are higher on the blockchain than on Binance.

		Blockchain (bp)			Binance (bp)		
Asset	N	std	75%	99%	std	75%	99%
ETH/BTC	148,624	7.72	4.07	30.71	6.00	3.52	23.26
ETH	1,703,611	8.71	3.21	29.86	6.87	4.70	26.10
BTC	24,967	24.94	14.91	89.33	17.83	12.77	69.27
LINK	31,663	27.35	8.70	79.51	13.45	8.33	48.35
UNI	14,606	29.41	9.65	81.29	18.29	6.70	78.74
APE	41,902	36.34	15.28	99.50	28.63	18.92	108.52
MATIC	13,928	43.07	14.95	99.61	18.77	12.21	73.19
1INCH	3,751	84.11	10.64	182.40	34.84	20.14	119.70

Table I. Dispersion and tails of one-block returns on the blockchain and Binance. For each asset, the table reports the standard deviation and the 75th and 99th percentiles of the *absolute* one-block return in basis points on the blockchain (Uniswap v3) and on Binance, between 1 January 2021 and 31 December 2023. Returns are measured over the same interval: Binance prices of an asset are sampled at the timestamps of two consecutive blocks that each contain at least a transaction in the asset. The column N reports the number of one-block returns used for each asset.

These results have direct implications for price efficiency on a blockchain that serves as

the venue for price formation. From the perspective of an uninformed observer, only non-zero priority fees and executed volumes reveal private information. As competition increases, the fraction of the valuation distribution that generates transactions shrinks. Price formation is thus driven by an increasingly thin upper tail of the distribution. Thus, the transaction price becomes systematically biased upward (downward if traders are selling).

As we discuss below, an increase in block time, that is, the time required for a block to be created and markets to clear, may raise the upper bound of possible valuations $\overline{v}$ and amplify the upward price bias. These effects play a role in shaping the equilibrium supply of liquidity, which we characterize in Section III.

E. Equilibrium priority fees

For a fixed arbitrary distribution of trading volumes, Proposition 1 showed that higher competition in the PGA increases priority fees and that deeper liquidity decreases them. However, trading volumes are part of the traders' equilibrium strategy. The next result derives the equilibrium priority fee accounting for strategic trading volumes.

PROPOSITION 4: *The equilibrium priority fee is zero if* $v_i < \underline{v}_M$. *For* $v_i \geq \underline{v}_M$, *the equilibrium priority fee accounting for strategically adjusted trading volumes, is*

$$\Phi\left(v_i\right) = 2\,L\left(M-1\right)\int_{\underline{v}_M}^{v_i} \tilde{Q}\left(x\right)^2\, dF\left(x\right)\,. \tag{22}$$

The equilibrium priority fee is increasing in the depth of liquidity L, *and, for every* $v_i < \overline{v}$, *it admits the limit*

$$\lim_{M\to\infty} \Phi(v_i) = 0\,.$$

Proposition 4 shows that the equilibrium priority fees $\Phi(Q(v))$, accounting for strategically adjusted volumes, converge monotonically to zero with the number of informed traders in the memory pool. The intuition is that increased competition raises anticipated PGA costs and expected adverse price impact, which induces a downward scaling in equilibrium

trading volumes. As $M \to \infty$, both trading volumes and priority fees converge to zero.

Similar arguments to those above show that the equilibrium priority fees and trading volumes derived earlier also apply when traders wish to sell the asset. As a consequence, traders are symmetrically aggressive in equilibrium, i.e., they buy and sell the same volumes for valuations of equal absolute value and opposite signs.

III. Stage two: liquidity supply

A. Assumptions

The level of reserves deposited in the DEX determines the execution costs and the price impact of liquidity taking trades. At stage two, a risk-neutral representative liquidity supplier sets the DEX reserves by balancing losses to informed traders with fee revenue from noise traders.[21] Liquidity supply is competitive and is determined by a zero-profit condition: expected fee revenue from noise traders equals expected losses to informed traders.[22]

For simplicity, we assume that noise traders transact a net volume that sums to zero in expectation, but an absolute expected volume which is price-sensitive. Specifically, the liquidity demanded by buyers is decreasing in the price $1/L$ and its expected volume is

$$\frac{N}{2} \times \frac{1}{1+\theta/L},$$

and the expected liquidity demanded by sellers is symmetric.

Demand on each side is therefore characterized by two parameters: $N/2$, the aggregate positive (resp. negative) liquidity needs over the blockchain slot, and $\theta > 0$, which governs the sensitivity of realized demand to liquidity depth L. When $L \ll \theta$, demand responds

[21] Unlike traditional venues such as limit order books or dealer markets, the permissionless nature of blockchains facilitates entry to liquidity provision, particularly by less sophisticated participants. As a result, strategic liquidity suppliers cannot freely set the price of liquidity because of *noise liquidity suppliers*. This feature of blockchains may explain the losses observed in practice; see Cartea et al. (2024a).

[22] This views the representative liquidity supplier as a continuum of competitive, atomistic, price-taking liquidity suppliers operating under free entry.

approximately linearly to liquidity, with slope proportional to $1/\theta$. As L increases, marginal gains from additional liquidity diminish. Smaller values of θ imply that most of the available demand is captured at relatively modest depth, whereas larger values imply that demand is more sensitive and requires substantial liquidity to materialize. Our specification is bounded, so realized demand does not exceed the available mass N. Liquidity demand follows, in spirit, the reduced-form models of demand in Garman (1976); Ho and Stoll (1981); Hendershott and Menkveld (2014). The liquidity supplier's expected fee revenue is therefore

$$\pi N \frac{L}{L+\theta}. \tag{23}$$

The liquidity supplier does not hold the same information about the future liquidation value V of the asset as that of informed traders. At stage two, he assumes that with probability $1/2$, the liquidation value V of the asset is positive, in which case the informed traders buy the asset and their private valuations are drawn independently from the interval $[0, \overline{v}]$ according to the continuous and differentiable density f. Similarly, with probability $1/2$, the liquidation value of the asset is negative, in which case the informed traders sell the asset and their valuations are drawn independently from the interval $[-\overline{v}, 0]$, according to the symmetric density $f(-x)$.

Recall that only traders who value the asset above the cutoff (16) submit transactions with volumes (17). We denote the total trading volume of informed traders by

$$\Delta_M = \sum_{k=1}^{M} Q(v_k)\,. \tag{24}$$

From the perspective of the supplier, Δ_M is a random variable, whose expected value is zero, and which is assumed to be independent of the noise liquidity demand.

The liquidity supplier balances fee revenue with expected losses to informed traders. Next, we derive the expected adverse selection cost. Let X_0 and Y_0 denote the initial cash and risky asset reserves deposited by the liquidity supplier, so his initial wealth is $X_0 + Y_0\, V_0 = X_0$.

Under the DEX's linear price schedule, the aggregate informed flow Δ_M executes at price Δ_M/L. The liquidity supplier's cash therefore changes by $\Delta_M\,(\Delta_M/L) = \Delta_M^2/L$.[23] The liquidity supplier marks his position at the end of the block, after trading unfolds, at the prevalent DEX price $2\Delta_M/L$.[24]. Thus, his wealth becomes

$$X_0 \;+\; \frac{\Delta_M^2}{L} \;+\; (Y_0 - \Delta_M)\,\frac{2\Delta_M}{L},$$

and the change in wealth attributable to informed trading is

$$\frac{\Delta_M^2}{L} \;+\; (Y_0 - \Delta_M)\,\frac{2\Delta_M}{L} \;=\; -\,\frac{\Delta_M^2}{L} \;+\; \frac{2\,Y_0\,\Delta_M}{L}. \tag{25}$$

The first term in (25) is the adverse selection cost. It is non-positive because the liquidity supplier holds more reserves of the asset whose price has decreased, or less of the asset whose price has increased. The second term in (25) is the change in value of the liquidity supplier's initial inventory. Under the prior $\mathbb{E}[\Delta_M] = 0$, the term has zero expectation. Hence the expected change in the wealth attributable to informed trading at stage three is

$$-\frac{1}{L}\,\mathbb{E}\left[\Delta_M^2\right] = -L\,M\,S_M\,, \tag{26}$$

where we define

$$S_M = \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2\,dF(u) \;+\; \frac{(\underline{v}_M - \pi)^2}{4\,(M-1)}\,, \tag{27}$$

and the volume function $\tilde{Q}$ is defined in (17).[25]

[23]The change is similar whether informed traders buy or sell.

[24]Each infinitesimal liquidity supplier marks wealth at the DEX's price because the DEX is the only venue to unwind inventory. Thus, a cash-out trade executes at the marginal price.

[25]The first term in (27) is the expected squared volume of an active trader. The second term reflects the positive correlation between any two traders' volumes. Equations (26) and (27) are derived in the proof of Proposition 5.

B. *Equilibrium liquidity supply*

The aggregate equilibrium liquidity supply $L^\star$ satisfies a zero-profit condition: expected fee revenue from noise traders equals expected losses to informed traders.

$$\pi\, N\, \frac{L^\star}{L^\star + \theta} = L^\star\, M\, S_M\,. \tag{28}$$

The next proposition derives the equilibrium DEX liquidity supply.

PROPOSITION 5: *In equilibrium, the supply of liquidity is*

$$L^\star(M) = \frac{\pi\, N}{M\, S_M} - \theta\,, \tag{29}$$

where S_M *is defined in* (27)*. Liquidity supply increases in the profitability* $\pi\, N$ *of noise trading flow, and admits the limit*

$$\lim_{M\to\infty} L^\star(M) = \frac{8\,\pi\, N}{3\,(\overline{v} - \pi)^2} - \theta\,, \tag{30}$$

which is approached from above. The condition for markets to remain open is

$$M\, S_M \leq \frac{\pi\, N}{\theta}\,. \tag{31}$$

Trading volumes in stage three are strategically set by informed traders to be proportional to the liquidity depth L. Thus, greater liquidity provision in stage two amplifies, on average, the dollar value of informed trading profits and, consequently, the expected losses (26) of the liquidity supplier. The liquidity supplier anticipates that the dispersion S_M of aggregate trading volumes determines these losses and decreases supply accordingly. Conversely, he anticipates that noise demand is profitable and increases supply in response.

We now discuss how liquidity supply depends on the degree of competition in the PGA. As the number of competitors M increases, the aggregate trading volume (20) and the

expected price (21) at the end of the block both rise toward their limits (Proposition 3). As a consequence, the expected adverse selection cost per unit of supplied liquidity also rises. The liquidity supplier anticipates this and decreases DEX liquidity. In the limit when $M \to \infty$, the price is most biased, liquidity is smallest, and only a small portion of private information is revealed. When valuations are uniformly distributed, liquidity supply admits the closed form

$$L^\star(M) \;=\; \frac{8\pi N(M-1)^3}{M(\overline{v}-\pi)^2\Big[(M-1)(3M-5)-2(2M-3)\log M+2(\log M)^2\Big]} - \theta, \qquad (32)$$

which is strictly decreasing in M.

Our results stand in sharp contrast to the effect of competition among informed traders in traditional markets with continuous trading and multiple clearing rounds. In such markets, as the number of informed traders tends to infinity, prices become fully revealing in early rounds and adverse selection premia vanish later; see Holden and Subrahmanyam (1992). Market depth increases as private information is incorporated through successive rounds of trading.

The mechanism behind our result is fundamentally different. In blockchains, trades are executed in a single discrete clearing round and priced according to priority fees. Traders pay both the cost of market impact and the priority bid required to secure queue position. Because clearing occurs in one round, the liquidity supplier must absorb the full adverse selection risk from aggregate trading volume in a single decision, rather than adjusting liquidity across successive rounds.

C. Market viability

Under the zero-profit condition (28), the equilibrium liquidity supply $L^\star$ is nonnegative only if expected fee revenue from noise traders can cover expected losses to informed traders. This requires the condition (31) for the viability of blockchain markets. Condition (31) is

standard, it states that if the fee revenue from liquidity demand is less than the expected losses to informed traders, liquidity provision is unsustainable. The degree to which this condition must hold depends on the price-sensitivity parameter θ. All else being equal, as demand becomes more sensitive to the price of liquidity, the viability of liquidity provision requires either greater liquidity demand N, higher fee rates π, or reduced variance in informed trading volumes. This condition mirrors that in Glosten and Milgrom (1985) where markets shut down due to liquidity freeze if the valuation of informed traders is too precise relative to the price-sensitivity of liquidity demand.

When the variance of trading volumes is maximal, i.e., when

$$S_M = \frac{\pi\, N}{M\, \theta}\,, \tag{33}$$

then the liquidity depth is $L^\star = 0$.

Our analysis in this section treats the number M of informed traders as exogenous. In the next section, we endogenize entry into blockchains. The equilibrium number of competing traders in the PGA is constrained by the cost of acquiring information and by the limited profitability induced by defensive liquidity supply.

IV. Stage one: information acquisition

Our results in Section III show that, upon observing their private valuations, traders with low valuations submit zero trading volumes, while traders with high valuations participate in the PGA. At stage one, however, traders must decide whether to incur the information cost C to acquire private information before observing their valuations. These costs include expenditures on proprietary blockchain data, centralized exchange data, searcher contract deployment, and blockchain monitoring tools.

Assume that the total number of traders eligible to acquire information is arbitrarily large, and let M denote the subset that chooses to do so. In equilibrium, entry into informed trading

is determined by the comparison between the expected profitability of informed trading and the information cost C. At stage one, the equilibrium number of informed traders M is the largest integer value such that the marginal trader's expected profit is at least the information cost. We characterize this equilibrium number in the following result.

PROPOSITION 6: *The equilibrium number of informed traders is the largest integer M such that*

$$C \;\leq\; H(M)\,, \qquad H(M) \;:=\; L^{\star}(M)\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v)^2\big[1-2(M-1)(1-F(v))\big]\,dF(v), \tag{34}$$

where $\underline{v}_M$ and $\tilde{Q}$ are defined in (16) *and* (18)*, respectively. The function $H(M)$ is the ex-ante trading profit per informed trader, net of execution costs and priority fees, and satisfies* $\limsup_{M\to\infty} H(M) \leq 0$. *If $C > 0$ and $H(2) > C$, then an equilibrium number $M^{\star} \geq 2$ of informed traders exists and is given by the largest integer M satisfying* (34)*. Moreover, $M^{\star}$ is non-decreasing in the noise-trading mass N, and non-increasing in the information cost C.*

In the equilibrium condition (34), the integrand on the right-hand side represents the expected profit from participating in the PGA when a trader observes a valuation $v > \underline{v}_M$ and liquidity supply is set at its equilibrium level (29). These expected profits are weighted by the likelihood $dF(v)$ of observing valuation v in stage three. Proposition 6 also shows that the mass of informed traders decreases with the cost of information and increases with the size of uninformed demand.

In markets, price efficiency is directly related to the number of traders who incur the cost of acquiring information. Each revealed valuation reduces the conditional variance of the fundamental price from the perspective of an uninformed observer. Thus, lower information costs C and greater noise trading improve price efficiency. However, under paid-priority discriminatory pricing of blockchains, price efficiency is also related to the participation cutoff (16) below which traders abstain from the PGA. An increase in entry raises the

participation cutoff, so that only increasingly high valuations are revealed. Information becomes more truncated, and price efficiency deteriorates.

V. Block time

Our model endogenizes trading volumes, entry into the blockchain, participation in the PGA, liquidity supply, and the amount of information in the market. The primitives are the price-sensitivity and total mass of noise trading flow, the distribution of private valuations, and the cost of acquiring information. An additional primitive specific to blockchains is the length of the slot, i.e., block time.

Block time is the delay traders must wait before the market clears, and it is necessary to secure the blockchain. It therefore shapes both the distribution of private valuations at clearing and the intensity of uninformed trading within a block. Specifically, longer blocks increase the likelihood of large innovations in prices and widen the dispersion of private valuations, and they also deteriorate execution quality for uninformed traders within the block.

Let T denote block time, which is common knowledge to all competitive agents. We make the following assumptions to formalize the effect of block time on the primitives of our model.

ASSUMPTION 1: *(i) The distribution $F(\cdot\,;T)$ of private valuations has support $[0, \overline{v}(T)]$ where $\overline{v}(T)$ is strictly increasing in block time T, with $\lim_{T\to\infty} \overline{v}(T) = \infty$. For any $T' > T$, $F(\cdot\,;T')$ strictly first-order stochastically dominates $F(\cdot\,;T)$ on $(0, \overline{v}(T)]$, i.e., $F(v;T') < F(v;T)$ for all $v \in (0, \overline{v}(T)]$.*

(ii) The mass of noise trading flow $N(T)$ is decreasing in T and nonnegative.

Assumption 1(i) states that longer block times widen the support of private valuations and make extreme valuations more likely. Assumption 1(ii) states that longer block times reduce the mass of noise trading flow. This reflects greater uncertainty about execution

prices within longer blocks. The following corollary presents the comparative statics implied by these assumptions and the results derived in the previous sections.

COROLLARY 1: *Fix $M \geq 2$ and let Assumption 1 hold. The participation cutoff $\underline{v}_M(T)$ in* (16) *is increasing in T. With many informed traders ($M \to \infty$), the DEX price $\overline{v}(T) - \pi$ at the end of the block is increasing in T, the equilibrium liquidity $\dfrac{8\,\pi\,N(T)}{3\,(\overline{v}(T)-\pi)^2} - \theta$ is decreasing in T, and markets shut down for sufficiently large T.*

Corollary 1 shows that longer block times discourage participation in informed trading and push prices to more extreme levels, which impairs price discovery. The result also shows that, when many traders compete, longer blocks reduce liquidity, and beyond a critical block time, the market collapses.

Longer block times reduce uninformed demand, by Assumption 1(ii). Holding the valuation distribution fixed, this channel lowers DEX liquidity for any fixed number of informed traders, tightens the market viability condition (31), and reduces the number of informed traders $M^\star$.

In traditional markets with continuous trading, transactions that would be aggregated within a single blockchain slot of duration T instead unfold over multiple short clearing rounds. Greater competition among informed traders in such markets accelerates the incorporation of information in early rounds, and market depth typically improves thereafter; see Holden and Subrahmanyam (1992). By contrast, blockchain markets aggregate the entire interval T into a single trading round with a priority gas auction. Our results show that longer block times, although they enhance security, decrease liquidity, deter entry, and impair price efficiency.

VI. Conclusions

The stated ambition of blockchains is to provide a decentralized alternative to intermediaries and to organize economic activity at scale. Financial markets are a central component

of that ambition. We proposed a theoretical model of price formation and liquidity in a blockchain market with discriminatory pricing based on paid-priority queues and discrete clearing. The model endogenized trading volumes, entry into informed trading, participation in the priority gas auction, liquidity supply, and payment for information. We showed that market outcomes are governed by three key primitives: the distribution of private valuations, the mass of uninformed trading flow, and the length of the blockchain slot.

Our analysis showed that the very features that secure decentralization, most notably block time to conduct consensus and priority fees to compensate block builders, can undermine market viability. In general, under these design features, blockchains are not viable for price discovery. If blockchains are to become a credible infrastructure for price discovery, protocol design must carefully address how transactions are organized and prioritized within each block.

Appendix A. Institutional details

The microstructure of DEXs differs fundamentally from that of traditional financial markets due to the unique infrastructure on which they operate. In this section, we outline some institutional features of blockchains that underpin the framework of our model.

Appendix A. Ethereum, memory pools, and priority gas auctions

The Ethereum blockchain is a distributed and public digital ledger stored by *nodes*. Blocks of transactions are sequentially added to the ledger at regular intervals called block time. Block time must be long enough to allow for secure confirmation of blocks because this process requires aggregating a large number of cryptographic signatures in multiple rounds of network communications. Shortening block time excludes slower participants and concentrates rewards among those with superior connectivity, which would undermine decentralization. For example, block time on Ethereum is deterministic and fixed at twelve second.

When an agent submits a transaction, it is not immediately included in a block. Instead, the pending transaction is stored in a memory pool until the end of block time. For a pending transaction to be executed, it must be included in a block created by a builder. Builders are paid gas fees by agents. Gas fees consist of a mandatory base fee and an optional priority fee. The priority fee incentivizes quick inclusion and priority in the block. Thus, agents compete in PGAs for better execution prices or to exploit arbitrage opportunities.

Accordingly, there are three stages in the lifecycle of a transaction: (i) *submission*, where an agent specifies the transaction details and sets a gas fee; (ii) *storage in the memory pool*, where the pending transaction awaits selection by a builder; and (iii) *inclusion in a block*, which corresponds to the execution of the transaction. Transaction submission may occur at any time within the blockchain slot, and it is executed provided the transaction reaches the builder's memory pool before block creation.[26]

[26]In practice, if there are too many transactions in the memory pool, only a fraction of all transactions is

Memory pools and PGAs. There are two types of memory pools: public and private. Pending transactions in the public memory pool are visible prior to execution, so agents operating on the Ethereum blockchain are exposed to arbitrage and predatory attacks. Private memory pools have recently emerged in the blockchain ecosystem to protect users; see Capponi (2024); Wang, Huang, Zhang, Huang, Wang, and Tang (2025).[27] Agents in these private channels send their transactions directly to builders to conceal transaction details and avoid attacks. At present, the vast majority of trading flow in Ethereum DEXs passes through private memory pools.[28] For additional details on blockchain protocols, see John, Monnot, Mueller, Saleh, and Schwarz-Schilling (2025).

Next, we argue that our model is suitable for PGAs among informed traders in both types of memory pools when the blockchain is the sole venue for price formation.

PGAs differ across public and private memory pools. In private memory pools, traders do not observe each other's bids before block creation, so the PGA is sealed-bid as described in our model above. In contrast, in public memory pools, bids are visible prior to execution, and traders compete in an online auction throughout the blockchain slot.[29]

In public memory pools, informed traders benefit from waiting until the end of block time to submit their transactions for three reasons. First, early bids reveal information to competitors, second, early bids set a minimum fee due to the *account nonce*;[30] and third, late bidding allows users to incorporate the most up-to-date information. As a result, late bidding has emerged as the dominant strategy in public memory pools. We study the distribution of transaction submission time in the public memory pool of Ethereum in Figure 3 to support this claim empirically. Therefore, our model is suitable to model PGAs in public memory

executed.

[27] www.flashbots.net

[28] See www.dune.com/queries/5184076/8532375.

[29] Another difference between both types of memory pools is that in public memory pools, failed transactions are paid regardless of execution, whereas in private memory pools, transactions that are not executed do not pay priority fees.

[30] A *nonce* tracks the number of transactions and it is assigned to each user to prevent replay and double-spending attacks; see Vujičić, Jagodić, and Ranđić (2018). Users can only modify pending transactions by submitting a new one with the same nonce and a higher gas fee.

pools.

At present, PGAs are mainly between specialized users (searchers or bots) who compete

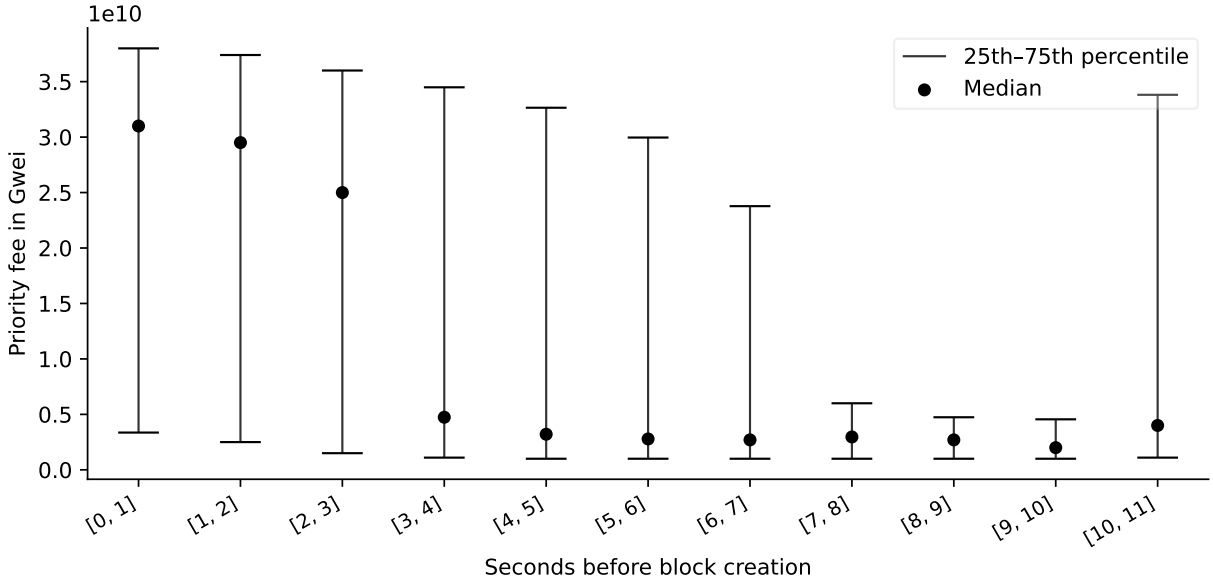


Figure 3. Distribution of priority fees as a function of timing within the blockchain slot. Informed traders are typically associated with higher priority fees, as shown empirically in Capponi et al. (2026) and theoretically in our model. The figure shows that they tend to submit their transactions very close to the end of the blockchain slot. The data is from *EthPandaOps* and it includes 10^7 transactions observed in the public memory pool of Ethereum between 20 March 2024, 00:00, and 21 March 2024, 17:08. This data corresponds to a period when the public memory pool accounted for approximately 60% of DEX trading volumes. At present (November 2025), this share is about 16%. The SQL data tables and other details are here. See Liu et al. (2022); Mizrach and Yoshida (2025) for a more detailed empirical analysis.

to exploit the discrete-time structure of blockchains through two types of strategies: attacks on transactions in public memory pools,[31] and arbitrage opportunities across DEXs or between a DEX and a competing centralized venue such as Binance; see Heimbach, Pahari, and Schertenleib (2024). Effectively, this type of PGA is a first-price sealed-bid auction in which the value of the item is public and known to all competitors. As predicted by standard theory and as observed empirically, the majority of the revenue from such PGAs is ultimately paid back to builders in priority fees. The objective of this paper is not to study

[31] These include frontrunning, backrunning, and sandwich attacks.

PGAs for arbitrage. Instead, we focus on market outcomes when PGAs are the means for price formation and private information is incomplete.

Sequential market clearing. In our model, we make the simplifying assumption that builders strictly sort transactions in the block only by priority fee. In practice, they are not required by the blockchain protocol to do so. However, failing to do so harms reputation and weakens agents' incentive to pay priority fees. Moreover, the Ethereum Foundation is actively improving the blockchain protocol to impose rules for the behavior of builders to reduce censorship and rent extraction; see Thiery, D'Amato, Ma, Monnot, Tsao, Kaufmann, and Song (2024); Wadhwa, Ma, Thiery, Monnot, Zanolini, Zhang, and Nayak (2025).

Appendix B. Automated market makers

In this section, we show how the market frictions assumed in our model above apply to automated market makers (AMMs). In AMMs, algorithmic rules specify how liquidity supply, in the form of aggregated reserves in a liquidity pool, determines execution prices and price impact; see Lehar and Parlour (2025), Capponi and Jia (2021), and Cartea et al. (2025).

Assume an AMM that supplies liquidity x in the reference asset X and y in the risky asset Y. A convex trading function Γ defines the combinations of reserves $\{x = \Gamma(y), y\}$ that make LPs indifferent, i.e., an iso-liquidity curve. Let $Q > 0$ denote a quantity of Y that a trader wishes to buy (resp. sell). The trader pays (resp. receives) $\Gamma(y - Q) - \Gamma(y)$ (resp. $\Gamma(y + Q) - \Gamma(y)$) in asset X. Thus, execution prices per unit of asset Y are

$$\text{price to sell } Q: \quad \frac{\Gamma(y) - \Gamma(y+Q)}{Q}, \qquad \text{price to buy } Q: \quad \frac{\Gamma(y-Q) - \Gamma(y)}{Q}. \tag{A1}$$

Moreover, execution prices for an infinitesimal volume $Q \to 0$ converge to $V = -\Gamma'(y)$, which is referred to as the *marginal price*. The difference between execution and marginal prices are execution costs, and they are determined by the reserves y. The reserves also determine

the impact $-\Gamma'(y \pm Q) - V$ of a trade on the marginal price.

Our model assumes a linear price schedule and a linear price update rule in the DEX. These are nonlinear in an AMM. Consider the following approximations of execution prices:

$$\frac{\Gamma(y) - \Gamma(y+Q)}{Q} \approx V - \frac{Q\,\Gamma''(y)}{2}\,, \qquad \frac{\Gamma(y-Q) - \Gamma(y)}{Q} \approx V + \frac{Q\,\Gamma''(y)}{2}\,, \tag{A2}$$

and price impact:

$$-\Gamma'(y+Q) - V \approx -Q\,\Gamma''(y)\,, \qquad -\Gamma'(y-Q) - V \approx Q\,\Gamma''(y)\,. \tag{A3}$$

The depth L of the DEX in our model depends on the convexity $\Gamma''(y)$ of the AMM's trading function in (A2) and (A3):[32]

$$L = 2/\Gamma''(y). \tag{A4}$$

The convexity of trading functions is a key determinant of liquidity; see Milionis et al. (2022); Cartea et al. (2023). Akin to traditional electronic markets, market frictions in AMMs increase with the traded volume Q and decrease with the depth L. Figure 4 uses DEX data from the Ethereum blockchain to show that approximating the AMM's pricing rule with a linear schedule is accurate in practice because trading volumes represent a small fraction of total liquidity supply.

[32]For example, the trading function for constant product markets like Uniswap, which are the most popular DEXs, is $\Gamma(y) = L^2/y$, where $L = \sqrt{x\,y}$ is the pool's liquidity parameter, so $\Gamma''(y) = 2\,V^{3/2}/L$, and by (A4) the model's depth is $L = 2/\Gamma''(y) = L/V^{3/2} = y^2/x$.

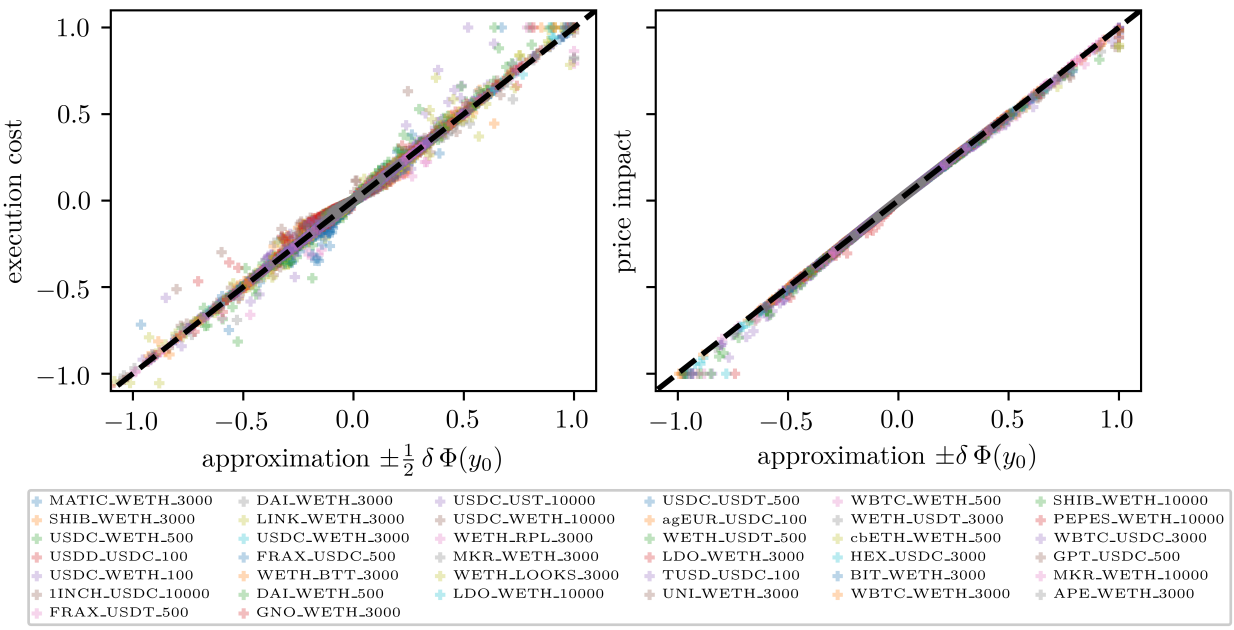


Figure 4. Scatter plots of the slippage and the price impact of 2.622 million LT transactions against the approximations (A2) and (A3). The transactions are between 1 January 2023 and 31 December 2023 in 38 different Uniswap v3 pools. For each pool, the slippages and price impacts are scaled between $[0, 1]$ for buy orders and $[-1, 0]$ for sell orders.

Appendix B. Two-sided trading

In the model of Sections I and II, every informed trader buys: a positive innovation makes all valuations positive, and all traders take the same side. A trader with a low valuation might nonetheless prefer to sell. Traders with high valuations trade large volumes and pay high priority fees, so they execute at the top of the block and move the price up substantially. A trader with a low valuation, anticipating this, may earn more by selling the asset at the resulting high price than by buying it: once the price has risen above her valuation, selling is profitable. We argue in this appendix that no configuration in which contrarians sell behind the buyers constitutes an equilibrium in pure strategies.

Assume, as in the main text, that the price innovation is positive; the negative case is symmetric. Selling is then contrarian: an informed seller profits only if she executes after the buyers have pushed the price above her valuation. We therefore examine configurations in which buyers execute at the front of the block and sellers execute at the back.

Two configurations fail. First, suppose the (contrarian) sellers pay priority fees and execute behind the buyers. This is not an equilibrium: the buyer with the lowest fee deviates to a fee below the sellers', and thus she executes her order after those of the sellers and obtains a strictly better price. Second, suppose instead that the sellers pay no fees, so that they execute at the back in random order. This is not an equilibrium either: the price falls as the net-selling group executes, so a single seller profits by paying an arbitrarily small fee, jumping ahead of the other sellers, and selling at the price the buyers have pushed up.

One configuration remains: the contrarian sellers do not pay priority fees and are mixed in a group with noise traders and with informed buyers whose valuations are too low to pay for priority. Because all the transactions in the group pay the same zero fee, they execute in random order. Whether this is an equilibrium depends on the average direction of the group. If the group sells more than it buys on average, the price drifts down while the group executes; in this case, a seller finds it profitable to pay a small fee and sell first. If the group buys more than it sells, the price drifts up, and a buyer in the group gains by paying a small fee to buy first. An equilibrium therefore requires zero net volume in the group: buying and selling must cancel on average, so that deviations do not improve expected execution prices. However, an order in the group is placed at random among hundreds of transactions, so its execution price is uncertain. In practice, traders dislike this execution risk and account for it in their objective. By paying a small fee, a trader can significantly reduce the uncertainty in her execution price.

We conclude that contrarian selling admits no equilibrium in pure strategies in which sellers execute behind buyers. Other equilibria, in mixed strategies or with buy and sell orders interleaved, may exist, but we do not pursue them as we do not find them in the data: volume within blocks is concentrated at the front, is in the direction of the block's first trade, and decays to zero toward the back with no reversal (Figures 1 and 2a).

Appendix C. Proofs

Appendix A. Proof of Lemma 1

Fix trader i. Since G is continuous on $(0, \overline{Q}]$, the events $\{Q_{(j)} < \Phi^{-1}(\Phi_i) < Q_{(j+1)}\}$ for $j = 0, \ldots, M-1$ form an almost-sure partition of the sample space, with the boundary cases understood as $\{\Phi^{-1}(\Phi_i) < Q_{(1)}\}$ for $j = 0$ and $\{Q_{(M-1)} < \Phi^{-1}(\Phi_i)\}$ for $j = M-1$.

Whenever $Q_{(j)} < \Phi^{-1}(\Phi_i) < Q_{(j+1)}$, exactly j of the $M-1$ competitor volumes fall below $\Phi^{-1}(\Phi_i)$, and these are precisely the volumes entering the lower partial sum $\Delta_{(1:j)}$. Therefore, on this event,

$$\Delta_{(1:j)} = \sum_{k=1}^{M-1} Q_k \, \mathbb{1}_{\{Q_k < \Phi^{-1}(\Phi_i)\}},$$

and the right-hand side does not depend on j. Multiplying by the corresponding indicator and summing over j, the partition property collapses the left-hand side:

$$\sum_{j=0}^{M-1} \mathbb{1}_{\{Q_{(j)} < \Phi^{-1}(\Phi_i) < Q_{(j+1)}\}} \Delta_{(1:j)} = \sum_{k=1}^{M-1} Q_k \, \mathbb{1}_{\{Q_k < \Phi^{-1}(\Phi_i)\}}.$$

Taking expectations and using that $Q_1, \ldots, Q_{M-1}$ are i.i.d. with distribution G, we obtain

$$\begin{aligned}\sum_{j=0}^{M-1} \mathbb{E}_i \left[\mathbb{1}_{\Phi_{(j)} < \Phi_i < \Phi_{(j+1)}} \Delta_{(1:j)} \right] &= (M-1) \, \mathbb{E}\left[Q \, \mathbb{1}_{\{Q < \Phi^{-1}(\Phi_i)\}} \right] \\ &= (M-1) \int_0^{\Phi^{-1}(\Phi_i)} x \, dG(x).\end{aligned}$$

□

Appendix B. Proof of Proposition 1

First, consider the function

$$\mathbb{E}[Q \mid Q > x] = \tau(x),$$

for the random variable Q with continuous distribution g. Write

$$\tau(x) = \frac{\int_x^{\overline{Q}} u\, g(u)\, du}{1 - G(x)},$$

to obtain

$$\begin{aligned}\tau'(x) =& \frac{-x\, g(x)}{1 - G(x)} + g(x) \frac{\int_x^{\overline{Q}} u\, g(u)\, du}{(1 - G(x))^2} \\ =& \frac{g(x)}{1 - G(x)} (\tau(x) - x).\end{aligned}$$

Thus, the FOC derived from the optimization problem in (9) is

$$\begin{aligned}\Phi'\left(\Phi^{-1}(\Phi_i)\right) =& \left(2\, Q_i \Big/ L\right) (M-1)\, g\left(\Phi^{-1}(\Phi_i)\right) \tau\left(\Phi^{-1}(\Phi_i)\right) \\ & - \left(2\, Q_i \Big/ L\right) (M-1) \left(1 - G\left(\Phi^{-1}(\Phi_i)\right)\right) \tau'\left(\Phi^{-1}(\Phi_i)\right) \\ =& \frac{2\, Q_i}{L} (M-1)\, g\left(\Phi^{-1}(\Phi_i)\right) \mathbb{E}\left[Q \mid Q > \Phi^{-1}(\Phi_i)\right] \\ & - \frac{2\, Q_i}{L} (M-1)\, g\left(\Phi^{-1}(\Phi_i)\right) \left(\mathbb{E}\left[Q \mid Q > \Phi^{-1}(\Phi_i)\right] - \Phi^{-1}(\Phi_i)\right) \\ =& \frac{2\, Q_i}{L} (M-1)\, \Phi^{-1}(\Phi_i)\, g\left(\Phi^{-1}(\Phi_i)\right).\end{aligned}$$

In equilibrium, trader i finds it optimal to adopt the same strategy Φ, so $\Phi^{-1}(\Phi_i) = Q_i$, so the FOC becomes

$$\Phi'(Q_i) = \frac{2}{L} (M-1)\, Q_i^2\, g(Q_i),$$

with boundary condition $\Phi(0) = 0$, which establishes (11). Substituting $\Phi_i = \Phi(Q_i)$ into (9) and applying Lemma 1 with $\Phi^{-1}(\Phi_i) = Q_i$ yields

$$-\Phi(Q_i) + \frac{2\, Q_i}{L}(M-1) \int_0^{Q_i} x\, dG(x) = \frac{2}{L}(M-1) \int_0^{Q_i} x(Q_i - x)\, dG(x),$$

which is (12).

It remains to verify global optimality. Reparametrizing the objective (9) in the bid $x^\star =$

$\Phi^{-1}(\Phi_i)$ gives $U(x^\star) = -\Phi(x^\star) + \frac{2Q_i}{L}(M-1)\int_0^{x^\star} x\, dG(x)$. Using the closed form $\Phi'(y) = (2/L)(M-1)\, y^2\, g(y)$ just derived,

$$U'(x^\star) \;=\; -\Phi'(x^\star) + \frac{2Q_i}{L}(M-1)\, x^\star g(x^\star) \;=\; \frac{2(M-1)}{L}\, x^\star\, g(x^\star)\,(Q_i - x^\star)\,,$$

which is strictly positive on $(0, Q_i)$ and strictly negative on $(Q_i, \overline{Q}]$ whenever $g > 0$. Bidding $\Phi_i > \Phi(\overline{Q})$ wins against all competitors with probability one and yields payoff $-\Phi_i + \frac{2Q_i}{L}(M-1)\int_0^{\overline{Q}} x\, dG(x)$, strictly decreasing in Φ_i, so it is dominated by $\Phi_i = \Phi(\overline{Q})$. Hence $x^\star = Q_i$ is the unique global maximizer and the FOC's solution characterizes the global optimum. □

Appendix C. Proof of Lemma 2

For $M \geq 2$ and $v \in [0, \overline{v}]$, define the function

$$h_M(v) = v - \pi - \int_v^{\overline{v}} \left(e^{(1-F(u))(M-1)} - 1\right) du, \qquad v \in [0, \overline{v}]. \tag{C1}$$

First, we show that the function h_M is increasing in v. Note that the integrand $e^{(1-F(u))(M-1)} - 1$ is continuous and nonnegative. Thus, h_M is continuous and differentiable on $(0, \overline{v})$ with derivative

$$h_M'(v) = e^{(1-F(v))(M-1)} > 1.$$

Thus h_M is strictly increasing.

Next we show the existence and uniqueness of the root. Because h_M is strictly increasing, it can have at most one root. Use the endpoint conditions

$$h_M(0) < 0 \qquad \text{and} \qquad h_M(\overline{v}) = \overline{v} - \pi > 0\,.$$

By continuity of h_M, we obtain existence of a unique $\underline{v}_M \in (0, \overline{v})$ satisfying $h_M(\underline{v}_M) = 0$. Since $h_M(\overline{v}) > 0$, the root cannot equal $\overline{v}$ and thus $\underline{v}_M < \overline{v}$.

Next, we show that the root, i.e., the valuation cutoff, is increasing in the number of informed traders M that paid the cost of acquiring information in stage one. For fixed v, differentiate $h_M(v)$ with respect to M to obtain:

$$\partial_M h_M(v) = -\int_v^{\overline{v}} (1 - F(u))\, e^{(1-F(u))(M-1)}\, du < 0.$$

Thus for every v, the function $M \mapsto h_M(v)$ is strictly decreasing. Use the identity $h_M(\underline{v}_M) = 0$ and the implicit function theorem[33] to write

$$\partial_M \underline{v}_M = -\frac{\partial_M h_M(\underline{v}_M)}{\partial_v h_M(\underline{v}_M)} > 0,$$

because $\partial_M h_M(\underline{v}_M) < 0$ and $h'_M(\underline{v}_M) > 0$. Therefore, the cutoff $\underline{v}_M$ is strictly increasing in M.

Finally, we show that $\lim_{M\to\infty} \underline{v}_M = \overline{v}$. First, we use (C1) to obtain that for all $v < \overline{v}$, $\lim_{M\to\infty} h_M(v) = -\infty$.[34] Thus, for each $\epsilon > 0$, there exists a large enough $M(\epsilon)$ such that for all $M > M(\epsilon)$, $h_M(\overline{v} - \epsilon) < 0$. Use that (i) $h_M(\cdot)$ is increasing, (ii) $h_M(\overline{v} - \epsilon) < 0$, and (iii) the definition of the cutoff $h_M(\underline{v}_M) = 0$, to obtain that for all $\epsilon > 0$ and $M > M(\epsilon)$, $\overline{v} - \epsilon \leq \underline{v}_M$. Next, we showed earlier that for all M, $\underline{v}_M \leq \overline{v}$. Thus, for all $M > M(\epsilon)$,

$$\overline{v} - \epsilon \leq \underline{v}_M \leq \overline{v},$$

and we conclude that $\lim_{M\to\infty} \underline{v}_M = \overline{v}$.

□

[33] Although M takes integer values, $h_M(v)$ is well-defined for any real $M \geq 2$, so the implicit function theorem applies. Equivalently, for integer M, $h_{M+1}(\underline{v}_M) < h_M(\underline{v}_M) = 0$ because the integrand in (C1) is strictly increasing in M on the set where $F < 1$; combined with strict increasingness of h_{M+1} in v, this yields $\underline{v}_{M+1} > \underline{v}_M$.

[34] For $u \in [v, \overline{v})$, $1 - F(u) > 0$, so $e^{(1-F(u))(M-1)} \to +\infty$ pointwise and the integrand in (C1) diverges to $+\infty$ on a set of positive Lebesgue measure. By monotone convergence, $\int_v^{\overline{v}} \left(e^{(1-F(u))(M-1)} - 1\right) du \to +\infty$ as $M \to \infty$, hence $h_M(v) \to -\infty$.

Appendix D. Proof of Proposition 2

Use the optimal priority fee (11) in the objective (13) to write the expected wealth of trader i as

$$\mathbb{E}_i\left[W_i\right] = -\frac{2}{L}\left(M-1\right)\left(\int_0^{Q_i} x^2\, dG\left(x\right) + Q_i \int_{Q_i}^{\overline{Q}} x\, dG\left(x\right)\right) + Q_i\left(v_i - \pi - \frac{Q_i}{L}\right) - C\,.$$

The optimal trading volume is the solution of $\partial_{Q_i}\mathbb{E}\left[W_i\right] = 0$ or

$$0 = \left(v_i - \pi\right) L - 2\, Q_i - 2\,\left(M-1\right)\int_{Q_i}^{\overline{Q}} x\, dG\left(x\right)\,. \tag{C2}$$

Differentiating (C2) in Q_i yields the second-order condition

$$\partial^2_{Q_i}\mathbb{E}_i\left[W_i\right] \;=\; \frac{2}{L}\big[\left(M-1\right) Q_i\, g(Q_i) - 1\big]\,,$$

where the $Q_i^2 g(Q_i)$ contributions from the two integrals in the objective cancel. Under the equilibrium relation $G(Q(v)) = F(v)$, the strategy $Q : [\underline{v}_M, \overline{v}] \to [0, \overline{Q}]$ is a strict bijection (established below), so every $Q_i \in (0, \overline{Q}]$ admits a unique $v = Q^{-1}(Q_i)$. Differentiation then gives $g(Q_i) = f(v)/Q'(v)$, and the ODE established below implies

$$\left(M-1\right) Q_i\, g(Q_i) \;=\; \frac{\left(M-1\right) Q(v)\, f(v)}{L/2 + \left(M-1\right) Q(v)\, f(v)} \;<\; 1\,,$$

so $\partial^2_{Q_i}\mathbb{E}_i\left[W_i\right] < 0$ for every $Q_i \in (0, \overline{Q}]$, and also at $Q_i = 0$ since the factor $Q_i g(Q_i)$ vanishes there. Hence the objective is strictly concave on $[0, \overline{Q}]$. For $Q_i > \overline{Q}$, g vanishes and $\partial_{Q_i}\mathbb{E}_i\left[W_i\right] = v_i - \pi - 2Q_i/L \le v_i - \overline{v} \le 0$, so the objective is strictly decreasing on $[\overline{Q}, \infty)$. Combining, the FOC's solution is the unique global maximizer.

Recall that, in equilibrium, G is the distribution of trading volumes pinned down by the

equilibrium increasing trading volume function Q, so

$$G\left(Q_i\right) = F\left(v_i\right) \ .$$

Rearranging (C2) one obtains the boundary condition

$$\overline{Q} = L\frac{\overline{v} - \pi}{2}$$

and differentiating we find that the trading volumes solve the ODE

$$Q'\left(v_i\right) = \frac{L}{2} + \left(M-1\right) Q\left(v_i\right)\ f\left(v_i\right) \ ,$$

whose solution is in the statement of the result. The solution is increasing in v, and trader i's optimization problem is over nonnegative volumes. Thus the boundary condition is at the lowest valuation $\underline{v}_M$ for which the trader optimally chooses a nonnegative volume. This cutoff is characterized in Lemma 2 and corresponds to when the FOC (C2) is satisfied at $\underline{v}_M$ with $Q(\underline{v}_M) = 0$. For $v_i < \underline{v}_M$, evaluating the partial derivative of the objective at $Q_i = 0$ yields

$$\partial_{Q_i}\mathbb{E}_i\left[W_i\right]\Big|_{Q_i=0} = \left(v_i - \pi\right)L - 2\left(M-1\right)\int_0^{\overline{Q}} x\, dG\left(x\right) = \left(v_i - \underline{v}_M\right)L < 0\,,$$

where the second equality uses (16) rewritten as the FOC at $Q_i = 0$, $v_i = \underline{v}_M$. By strict concavity of the objective on $[0, \overline{Q}]$, the constrained maximum on $Q_i \geq 0$ is at $Q_i = 0$, hence $Q(v_i) = 0$. To obtain the form in Lemma 2, set $\tilde{Q}(\underline{v}_M) = 0$ in (18), which yields

$$\left(\overline{v} - \pi\right)e^{-(M-1)(1-F(\underline{v}_M))} \ = \ \int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(F(u)-F(\underline{v}_M))}\, du\,.$$

Multiplying both sides by $e^{(M-1)(1-F(\underline{v}_M))}$ gives

$$\overline{v} - \pi \;=\; \int_{\underline{v}_M}^{\overline{v}} e^{(M-1)(1-F(u))}\, du\,,$$

which, after adding and subtracting $\overline{v} - \underline{v}_M$, is equivalent to (16).

It remains to establish the monotonicity and limit properties in the statement. From the ODE, $Q'(v_i) = L/2 + (M-1)Q(v_i)\, f(v_i) \geq L/2 > 0$ on $[\underline{v}_M, \overline{v}]$, so Q is strictly increasing in v_i. Next, (18) rewrites as

$$\tilde{Q}(v_i) = \frac{e^{-(M-1)(1-F(v_i))}}{2}\left[(\overline{v} - \pi) - \int_{v_i}^{\overline{v}} e^{(M-1)(1-F(u))}\, du\right],$$

where the prefactor is positive and decreasing in M since $1 - F(v_i) \geq 0$. The bracket is decreasing in M since its integrand increases in M, and nonnegative on $[\underline{v}_M, \overline{v}]$ since it vanishes at $v_i = \underline{v}_M$ by (16) and is increasing in v_i (its integrand is positive). Hence $Q(v_i) = L\,\tilde{Q}(v_i)$ is decreasing in M. Finally, bounding the bracket above by $\overline{v} - \pi$ yields

$$\tilde{Q}(v_i) \;\leq\; \frac{\overline{v} - \pi}{2}\, e^{-(M-1)(1-F(v_i))},$$

which converges to zero as $M \to \infty$ for every $v_i < \overline{v}$. □

Appendix E. Proof of Proposition 4

Trader i uses the priority fee (11) for an arbitrary distribution of volumes with cumulative distribution function G:

$$\Phi\left(Q_i\right) = \frac{2}{L}\left(M-1\right)\int_0^{Q_i} u^2\, dG\left(u\right)\,. \tag{C3}$$

The optimal volumes of PGA competitors are distributed according to the distribution G

described in (19):

$$G\left(\{0\}\right) = F(\underline{v}_M) \qquad \text{and} \qquad G\big(Q(v)\big) = F(v) \quad \text{for } v \in [\underline{v}_M, \overline{v}]\,, \tag{C4}$$

The priority fee is trivially zero for $Q_i = 0$, i.e., when $v_i \leq \underline{v}_M$. Next, fix $v_i \in [\underline{v}_M, \overline{v}]$. Note that the atom at zero causes no problem because the integrand u^2 evaluated at zero is zero. Thus, the mass $G(\{0\})$ contributes zero to the Stieltjes integral, and we write

$$\int_0^{Q_i} u^2\, dG(u) = 0\, G(\{0\}) + \int_{(0,Q_i]} u^2\, dG(u) = \int_{\underline{v}_M}^{v_i} Q(x)^2\, dF(x)\,. \tag{C5}$$

where we used that $Q : [\underline{v}_M, \overline{v}] \mapsto [0, Q(\overline{v})]$, defined in (17), is increasing and continuous, hence it is invertible on its image and $G(Q(v)) = F(v)$ for $v \geq \underline{v}_M$. Substituting $Q(x) = L\,\tilde{Q}(x)$, so that $Q(x)^2 = L^2\,\tilde{Q}(x)^2$, and combining with the prefactor $2/L$ from (11), we obtain (22).

Since $\tilde{Q}$ in (18) does not depend on L, $\Phi(v_i)$ is linear in L by (22), hence increasing in L.

Next, we show that for all $v_i < \overline{v}$, the priority fee tends to zero when the number of competitors M tends to infinity. For $v_i \leq \underline{v}_M$, $\Phi(v_i) = 0$ by the first part of the proposition. We therefore consider $v_i \in (\underline{v}_M, \overline{v})$ in what follows. Consider the strategic volumes (18):

$$\tilde{Q}(x) = \frac{1}{2}\Big((\overline{v} - \pi)e^{-(M-1)(1-F(x))} - \int_x^{\overline{v}} e^{-(M-1)(F(u)-F(x))}\, du\Big) \quad \text{if } x \geq \underline{v}_M,$$

and zero otherwise. By Proposition 2, $\tilde{Q}(x) \geq 0$ on $[\underline{v}_M, \overline{v}]$, and the second term in $\tilde{Q}(x)$ is nonnegative, so

$$0 \leq \tilde{Q}(x) \leq \frac{\overline{v} - \pi}{2}\, e^{-(M-1)(1-F(x))} \implies \tilde{Q}(x)^2 \leq \frac{(\overline{v} - \pi)^2}{4} e^{-2(M-1)(1-F(x))}.$$

Fix $v_i < \overline{v}$. Since F is nondecreasing, for all $x \leq v_i$ we have $F(x) \leq F(v_i)$ and therefore

$$1 - F(x) \geq 1 - F(v_i) > 0.$$

Thus,

$$\tilde{Q}(x)^2 \leq \frac{(\overline{v}-\pi)^2}{4} e^{-2(M-1)(1-F(v_i))} \quad \text{for all } x \in [\underline{v}_M, v_i].$$

It follows from the definition of the equilibrium priority fee in (22), accounting for strategic volumes, that

$$\Phi(v_i) = 2L(M-1)\int_{\underline{v}_M}^{v_i} \tilde{Q}(x)^2\, dF(x) \leq 2L(M-1)(F(v_i)-F(\underline{v}_M))\frac{(\overline{v}-\pi)^2}{4} e^{-2(M-1)(1-F(v_i))}. \tag{C6}$$

Since $F(v_i) - F(\underline{v}_M) \leq 1$, we obtain

$$0 \leq \Phi(v_i) \leq \frac{L(\overline{v}-\pi)^2}{2}(M-1)e^{-2(M-1)(1-F(v_i))}.$$

Because $1 - F(v_i) > 0$ for all $v_i < \overline{v}$, we conclude that, for all $v_i < \overline{v}$,

$$\lim_{M\to\infty} \Phi(v_i) = 0.$$

□

Appendix F. Proof of Proposition 3

We first establish the closed form (20). The first-order condition (C2) characterising the optimal trading volume reads

$$0 \;=\; (v_i - \pi)\, L - 2\, Q_i - 2\,(M-1)\int_{Q_i}^{\overline{Q}} x\, dG(x).$$

Evaluating this condition at $v_i = \underline{v}_M$, and using $Q(\underline{v}_M) = 0$ from Proposition 2, yields

$$(\underline{v}_M - \pi)\, L \;=\; 2\,(M-1)\int_{0}^{\overline{Q}} x\, dG(x).$$

By (19) and (17), the atom $G(\{0\}) = F(\underline{v}_M)$ contributes zero to the Stieltjes integral (the integrand x vanishes at $x = 0$), and the change of variable $x = Q(v) = L\,\tilde{Q}(v)$ on $[\underline{v}_M, \overline{v}]$ gives

$$\int_0^{\overline{Q}} x\, dG(x) \;=\; \int_{\underline{v}_M}^{\overline{v}} Q(v)\, dF(v) \;=\; L \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v)\, dF(v).$$

Combining the two displays,

$$(\underline{v}_M - \pi)\, L \;=\; 2\,(M-1)\, L \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v)\, dF(v),$$

and multiplying by $M/(2(M-1))$ yields (20). The limit $L(\overline{v}-\pi)/2$ then follows directly from (20) and Lemma 2, which gives $\lim_{M\to\infty} \underline{v}_M = \overline{v}$. We present below an alternative direct derivation of this limit, which also establishes the auxiliary result $\lim_{M\to\infty}(M-1)(1 - F(\underline{v}_M)) = \infty$ used in the proof of Proposition 5.

Recall that for $v_i \geq \underline{v}_M$,

$$\tilde{Q}(v_i) = \frac{1}{2}\left((\overline{v} - \pi) e^{-(M-1)(1-F(v_i))} - \int_{v_i}^{\overline{v}} e^{-(M-1)(F(u)-F(v_i))}\, du \right).$$

Factoring out $e^{-(M-1)(1-F(v_i))}$ yields

$$\tilde{Q}(v_i) = \frac{1}{2} e^{-(M-1)(1-F(v_i))} \left(\overline{v} - \pi - \int_{v_i}^{\overline{v}} e^{(M-1)(1-F(u))}\, du \right).$$

Hence, the expected total trading volume of informed traders is

$$M \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(x)\, dF(x) = \frac{M(\overline{v} - \pi)}{2} \int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(1-F(x))}\, dF(x) \tag{C7}$$

$$- \frac{M}{2} \int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(1-F(x))} \left[\int_x^{\overline{v}} e^{(M-1)(1-F(u))}\, du \right] dF(x). \tag{C8}$$

We first evaluate (C7). Using the change of variable $z = 1 - F(x)$,

$$\frac{M(\overline{v}-\pi)}{2}\int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(1-F(x))}\,dF(x) = \frac{M(\overline{v}-\pi)}{2}\int_0^{1-F(\underline{v}_M)} e^{-(M-1)z}\,dz$$
$$= \frac{M(\overline{v}-\pi)}{2(M-1)}\left(1 - e^{-(M-1)(1-F(\underline{v}_M))}\right). \qquad \text{(C9)}$$

We now show that

$$\lim_{M\to\infty}(M-1)\big(1-F(\underline{v}_M)\big) = \infty.$$

Suppose instead that this sequence is bounded. Then there exists $C > 0$ such that

$$(M-1)\big(1-F(\underline{v}_M)\big) < C \qquad \text{for all } M.$$

Using the definition of $\underline{v}_M$ in (16),

$$\underline{v}_M - \pi = \int_{\underline{v}_M}^{\overline{v}} \big(e^{(M-1)(1-F(u))} - 1\big)\,du,$$

and the bound $1 - F(u) \leq 1 - F(\underline{v}_M)$, we obtain

$$0 \leq \underline{v}_M - \pi \leq \big(e^{(M-1)(1-F(\underline{v}_M))} - 1\big)(\overline{v} - \underline{v}_M) \leq \big(e^{C} - 1\big)(\overline{v} - \underline{v}_M).$$

By Lemma 2, $\underline{v}_M \to \overline{v}$ as $M \to \infty$. The inequality above would then imply $\underline{v}_M \to \pi$, which contradicts Lemma 2. Hence,

$$(M-1)\big(1-F(\underline{v}_M)\big) \to \infty.$$

Combining this result with (C9) gives

$$\lim_{M\to\infty}\frac{M(\overline{v}-\pi)}{2}\int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(1-F(x))}\,dF(x) = \frac{\overline{v}-\pi}{2}.$$

We now turn to (C8). Define

$$I_2 = \frac{M}{2} \int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(1-F(x))} \left[\int_x^{\overline{v}} e^{(M-1)(1-F(u))}\, du \right] dF(x).$$

Reversing the order of integration,

$$I_2 = \frac{M}{2} \int_{\underline{v}_M}^{\overline{v}} e^{(M-1)(1-F(u))} \left[\int_{\underline{v}_M}^{u} e^{-(M-1)(1-F(x))}\, dF(x) \right] du.$$

With the change of variable $z = 1 - F(x)$,

$$\begin{aligned} \int_{\underline{v}_M}^{u} e^{-(M-1)(1-F(x))}\, dF(x) &= \int_{1-F(u)}^{1-F(\underline{v}_M)} e^{-(M-1)z}\, dz \\ &= \frac{1}{M-1} \left(e^{-(M-1)(1-F(u))} - e^{-(M-1)(1-F(\underline{v}_M))} \right). \end{aligned}$$

Substituting back,

$$I_2 = \frac{M}{2(M-1)} \int_{\underline{v}_M}^{\overline{v}} \left(1 - e^{-(M-1)(1-F(\underline{v}_M))} e^{(M-1)(1-F(u))} \right) du.$$

Hence,

$$I_2 = \frac{M}{2(M-1)} \left[(\overline{v} - \underline{v}_M) - e^{-(M-1)(1-F(\underline{v}_M))} \int_{\underline{v}_M}^{\overline{v}} e^{(M-1)(1-F(u))}\, du \right].$$

Rearranging the cutoff equation (16) yields the exact identity

$$\int_{\underline{v}_M}^{\overline{v}} e^{(M-1)(1-F(u))}\, du \;=\; \overline{v} - \pi.$$

Since $(M-1)(1-F(\underline{v}_M)) \to \infty$, the exponential term vanishes, and therefore $I_2 \to 0$ as $M \to \infty$.

Combining the limits of (C7) and (C8), we conclude that

$$\lim_{M\to\infty} M\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)\,dF(u) = \frac{\overline{v}-\pi}{2}.$$

Next, we show that the aggregate trading volume approaches its limit from below; that is,

$$L\,M\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(x)\,dF(x) \;<\; L\,\frac{\overline{v}-\pi}{2} \tag{C10}$$

for all M sufficiently large. By our standing assumption on F, there exists $\eta > 0$ such that $f(u) \le 1/(\overline{v}-\pi)$ for all $u \in [\overline{v}-\eta, \overline{v}]$. We establish (C10) by comparison with the uniform distribution on $[\pi, \overline{v}]$.

Let F_U denote the uniform CDF on $[\pi, \overline{v}]$, $F_U(u) = (u-\pi)/(\overline{v}-\pi)$, and let $\underline{v}_M^U$ denote the corresponding cutoff defined by (16) with F replaced by F_U.

We first compute the uniform cutoff and the corresponding uniform aggregate volume. Substituting F_U in (16) and using the change of variable $s = (\overline{v}-u)/(\overline{v}-\pi)$,

$$\underline{v}_M^U - \pi \;=\; \int_{\underline{v}_M^U}^{\overline{v}} \big(e^{(M-1)(\overline{v}-u)/(\overline{v}-\pi)} - 1\big)\,du \;=\; \frac{\overline{v}-\pi}{M-1}\big(e^{(M-1)(\overline{v}-\underline{v}_M^U)/(\overline{v}-\pi)} - 1\big) - (\overline{v}-\underline{v}_M^U),$$

which simplifies to $e^{(M-1)(\overline{v}-\underline{v}_M^U)/(\overline{v}-\pi)} = M$, i.e.,

$$\underline{v}_M^U \;=\; \overline{v} - (\overline{v}-\pi)\,\frac{\log M}{M-1}. \tag{C11}$$

Substituting (C11) into the closed form (20) applied to F_U,

$$L\,M\int_{\underline{v}_M^U}^{\overline{v}} \tilde{Q}(x)\,dF_U(x) \;=\; L\,\frac{\overline{v}-\pi}{2}\cdot\frac{M\big(M-1-\log M\big)}{(M-1)^2}. \tag{C12}$$

The standard inequality $\log M > 1 - 1/M$ for $M > 1$ is equivalent to $M(M-1-\log M) <$

$(M-1)^2$. Hence, for all $M > 1$,

$$L\,M\int_{\underline{v}_M^U}^{\overline{v}} \tilde{Q}(x)\,dF_U(x) \;<\; L\,\frac{\overline{v}-\pi}{2}. \tag{C13}$$

Next, we establish tail dominance of F over F_U. Assume M is large enough that $(\overline{v}-\pi)\log M/(M-1) < \eta$, equivalently $\underline{v}_M^U > \overline{v}-\eta$ by (C11). For any $u \in [\underline{v}_M^U, \overline{v}] \subset [\overline{v}-\eta, \overline{v}]$, integrating the hypothesis $f(u) \le 1/(\overline{v}-\pi)$ yields

$$1-F(u) \;=\; \int_u^{\overline{v}} f(s)\,ds \;\le\; \frac{\overline{v}-u}{\overline{v}-\pi} \;=\; 1-F_U(u). \tag{C14}$$

We now compare the cutoffs $\underline{v}_M$ and $\underline{v}_M^U$. For any continuous CDF G on $[\pi,\overline{v}]$ and $v \in [\pi,\overline{v}]$, define

$$\mathcal{I}(v;G) \;:=\; \int_v^{\overline{v}} \left(e^{(M-1)(1-G(u))}-1\right) du.$$

By (16), $\underline{v}_M$ is the unique root in $[\pi,\overline{v})$ of $v \mapsto \mathcal{I}(v;F)-(v-\pi)$. This map is strictly decreasing, since its derivative equals $-e^{(M-1)(1-F(v))} < 0$. Evaluating at $v = \underline{v}_M^U$ and using (C14) together with the monotonicity of $x \mapsto e^{(M-1)x}$,

$$\mathcal{I}(\underline{v}_M^U;F) \;\le\; \mathcal{I}(\underline{v}_M^U;F_U) \;=\; \underline{v}_M^U-\pi,$$

where the last equality is (16) applied to F_U at its own cutoff. Thus $\mathcal{I}(\underline{v}_M^U;F)-(\underline{v}_M^U-\pi) \le 0$, and the strict monotonicity yields

$$\underline{v}_M \;\le\; \underline{v}_M^U. \tag{C15}$$

We now conclude. Using the closed form (20), (C15), and (C13),

$$L\,M\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(x)\,dF(x) \;=\; \frac{L\,M\,(\underline{v}_M-\pi)}{2\,(M-1)} \;\le\; \frac{L\,M\,(\underline{v}_M^U-\pi)}{2\,(M-1)} \;<\; L\,\frac{\overline{v}-\pi}{2},$$

which establishes (C10) for every M satisfying $(\overline{v}-\pi)\log M/(M-1) < \eta$.

We finally establish convergence of the expected end-of-block price. Each unit of volume executed in the block moves the DEX price by $2/L$; see (A3). Since the initial price is normalized to zero, the expected end-of-block price is

$$\frac{2}{L}\,M\int_{\underline{v}_M}^{\overline{v}} Q(v)\,dF(v) \;=\; 2\,M\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v)\,dF(v) \;=\; \frac{M(\underline{v}_M-\pi)}{M-1},$$

where the last equality uses the closed form (20). By Lemma 2, $\underline{v}_M \to \overline{v}$, so the expected end-of-block price converges to $\overline{v}-\pi$ as $M\to\infty$. Since the expected end-of-block price equals $2/L$ times the expected aggregate trading volume, (C10) yields $M(\underline{v}_M-\pi)/(M-1) < \overline{v}-\pi$ for all M sufficiently large; hence the price limit is also approached from below.

□

Appendix G. Proof of Proposition 5

We first derive $\mathbb{V}[\Delta_M]$. Recall the LP's stage-two prior stated in Section III: with probability $1/2$, the liquidation value satisfies $V>0$ and the informed traders' valuations $v_1,\ldots,v_M$ are i.i.d. from F on $[0,\overline{v}]$ (each trader buys); with probability $1/2$, $V<0$ and valuations are i.i.d. from the symmetric density $f(-\cdot)$ on $[-\overline{v},0]$ (each trader sells). Equilibrium volumes are $Q(v_k)=L\,\tilde{Q}(v_k)$ on $V>0$ by Proposition 2, and $-Q(|v_k|)$ on $V<0$ by the buy/sell symmetry recorded after Proposition 4.

By construction, the conditional distribution of $Q(v_k)$ on $\{V<0\}$ equals the negative of its conditional distribution on $\{V>0\}$, so

$$\mathbb{E}[Q(v_k)] \;=\; \tfrac{1}{2}\,\mathbb{E}[Q(v_k)\mid V>0] + \tfrac{1}{2}\,\mathbb{E}[Q(v_k)\mid V<0] \;=\; 0,$$

hence $\mathbb{E}[\Delta_M]=0$ and $\mathbb{V}[\Delta_M]=\mathbb{E}[\Delta_M^2]$. Conditional on the sign of V, the v_k are i.i.d., so the $Q(v_k)$ are conditionally i.i.d. as well. Expanding the square,

$$\mathbb{E}[\Delta_M^2] \;=\; M\,\mathbb{E}[Q(v_k)^2] \;+\; M(M-1)\,\mathbb{E}[Q(v_k)\,Q(v_l)] \qquad (k\neq l). \tag{C16}$$

For the diagonal term, using $Q(v_k) = L\,\tilde{Q}(v_k)$ on $\{v_k \geq \underline{v}_M\}$, $Q(v_k) = 0$ on $\{v_k < \underline{v}_M\}$ (Proposition 2), and the symmetry of the prior across signs,

$$\mathbb{E}[Q(v_k)^2] \;=\; \mathbb{E}[Q(v_k)^2 \mid V > 0] \;=\; L^2 \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2 \, dF(u). \tag{C17}$$

For the cross term, with $k \neq l$, conditional independence gives, on each side of the prior,

$$\mathbb{E}[Q(v_k)\,Q(v_l) \mid V > 0] \;=\; \big(\mathbb{E}[Q(v_k) \mid V > 0]\big)^2 \;=\; \Big(L \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)\, dF(u)\Big)^2,$$

and by the symmetric structure $\mathbb{E}[Q(v_k)\,Q(v_l) \mid V < 0] = (-1)^2\big(\mathbb{E}[Q(v_k) \mid V > 0]\big)^2$ equals the same value. Combining and applying the closed form (20), $\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)\, dF(u) = (\underline{v}_M - \pi)/(2(M-1))$, yields

$$\mathbb{E}[Q(v_k)\,Q(v_l)] \;=\; L^2\,\frac{(\underline{v}_M - \pi)^2}{4\,(M-1)^2}. \tag{C18}$$

Substituting (C17)–(C18) into (C16),

$$\mathbb{V}[\Delta_M] \;=\; L^2\,M \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2\, dF(u) \;+\; L^2\,\frac{M\,(\underline{v}_M - \pi)^2}{4\,(M-1)} \;=\; L^2\,M\,S_M, \tag{C19}$$

where the last equality uses the definition (27). Combined with $\mathbb{E}[\Delta_M] = 0$, this gives the rightmost equality in (26).

Next, we derive the zero-profit closed form. Multiplying the zero-profit condition (28) by $(L^\star + \theta)/L^\star$ (with $L^\star > 0$, addressed below) gives

$$\pi\,N \;=\; (L^\star + \theta)\,M\,S_M,$$

which rearranges to the closed form (29): $L^\star(M) = \pi\,N/(M\,S_M) - \theta$. The supply increases in $\pi\,N$, since S_M is independent of $\pi\,N$.

We next establish the viability condition. Non-negativity of (29) requires $\pi\,N/(M\,S_M) \geq$

θ, equivalent to (31): $M\,S_M \le \pi\,N/\theta$.

We now derive the asymptotic limit. By (27),

$$M\,S_M \;=\; M\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2\,dF(u) \;+\; \frac{M\,(\underline{v}_M-\pi)^2}{4\,(M-1)}. \tag{C20}$$

The cross-term contribution converges to $(\overline{v}-\pi)^2/4$ since, by Lemma 2, $\underline{v}_M \to \overline{v}$ and $M/(M-1)\to 1$. For the integral, we now show $\lim_{M\to\infty} M\int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2\,dF(u) = (\overline{v}-\pi)^2/8$, which combined with the cross-term limit gives $\lim_{M\to\infty} M\,S_M = 3\,(\overline{v}-\pi)^2/8$, hence by (29),

$$\lim_{M\to\infty} L^\star(M) \;=\; \frac{8\,\pi\,N}{3\,(\overline{v}-\pi)^2} - \theta,$$

which is (30). To distinguish the two contributions to $M\,S_M$, denote

$$\widehat{S}_M \;:=\; \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2\,dF(u), \qquad \text{so that} \qquad S_M \;=\; \widehat{S}_M \;+\; \frac{(\underline{v}_M-\pi)^2}{4\,(M-1)}. \tag{C21}$$

It remains to show that $\lim_{M\to\infty} M\,\widehat{S}_M = (\overline{v}-\pi)^2/8$. Using the factored form of $\tilde{Q}$ from the proof of Proposition 3,

$$\tilde{Q}(x) = \frac{1}{2}\,e^{-(M-1)(1-F(x))}\,((\overline{v}-\pi)-B(x))\,, \qquad B(x)\equiv\int_x^{\overline{v}} e^{(M-1)(1-F(u))}\,du,$$

so that

$$M\,\widehat{S}_M = \frac{M}{4}\int_{\underline{v}_M}^{\overline{v}} e^{-2(M-1)(1-F(x))}\,((\overline{v}-\pi)-B(x))^2\,dF(x) = T_1+T_2+T_3,$$

where

$$T_1 = \frac{M(\overline{v}-\pi)^2}{4}\int_{\underline{v}_M}^{\overline{v}} e^{-2(M-1)(1-F(x))}\,dF(x),$$
$$T_2 = -\frac{M(\overline{v}-\pi)}{2}\int_{\underline{v}_M}^{\overline{v}} e^{-2(M-1)(1-F(x))}\,B(x)\,dF(x),$$
$$T_3 = \frac{M}{4}\int_{\underline{v}_M}^{\overline{v}} e^{-2(M-1)(1-F(x))}\,B(x)^2\,dF(x).$$

For T_1, the change of variable $z = 1 - F(x)$ gives

$$T_1 = \frac{M(\overline{v}-\pi)^2}{4}\int_0^{1-F(\underline{v}_M)} e^{-2(M-1)z}\,dz = \frac{M(\overline{v}-\pi)^2}{8(M-1)}\left(1 - e^{-2(M-1)(1-F(\underline{v}_M))}\right).$$

Since $(M-1)(1-F(\underline{v}_M)) \to \infty$ (established in the proof of Proposition 3), the exponential vanishes and $M/(M-1) \to 1$, so $T_1 \to \frac{(\overline{v}-\pi)^2}{8}$.

For T_2, reversing the order of integration between x and u,

$$\int_{\underline{v}_M}^{\overline{v}} e^{-2(M-1)(1-F(x))}B(x)\,dF(x) = \int_{\underline{v}_M}^{\overline{v}} e^{(M-1)(1-F(u))}\left[\int_{\underline{v}_M}^{u} e^{-2(M-1)(1-F(x))}\,dF(x)\right]du.$$

The inner integral evaluates, via $z = 1 - F(x)$, to

$$\int_{\underline{v}_M}^{u} e^{-2(M-1)(1-F(x))}\,dF(x) = \frac{1}{2(M-1)}\left(e^{-2(M-1)(1-F(u))} - e^{-2(M-1)(1-F(\underline{v}_M))}\right).$$

Substituting back and using the cutoff definition (16), which gives $\int_{\underline{v}_M}^{\overline{v}} e^{(M-1)(1-F(u))}\,du = \overline{v} - \pi$,

$$T_2 = -\frac{M(\overline{v}-\pi)}{4(M-1)}\left[\int_{\underline{v}_M}^{\overline{v}} e^{-(M-1)(1-F(u))}\,du \;-\; (\overline{v}-\pi)\,e^{-2(M-1)(1-F(\underline{v}_M))}\right].$$

The first term in brackets is bounded by $\overline{v} - \underline{v}_M \to 0$; the second vanishes since $(M-1)(1-F(\underline{v}_M)) \to \infty$. Hence $T_2 \to 0$.

For T_3, since B is decreasing in x, we have $B(x) \leq B(\underline{v}_M) = \overline{v} - \pi$ for all $x \in [\underline{v}_M, \overline{v}]$, so

$$0 \leq T_3 \leq \frac{(\overline{v} - \pi)}{4} \cdot M \int_{\underline{v}_M}^{\overline{v}} e^{-2(M-1)(1-F(x))} B(x)\, dF(x) \to 0,$$

where the last limit follows from the computation for T_2.

Combining the three limits gives $\lim_{M\to\infty} M\, \widehat{S}_M = \frac{(\overline{v}-\pi)^2}{8}$, which together with the cross-term limit $\lim_{M\to\infty} M\, (\underline{v}_M - \pi)^2/(4(M-1)) = (\overline{v} - \pi)^2/4$ established above completes Step 4.

Finally, we establish convergence from above by showing that

$$M\, S_M \;<\; \frac{3\,(\overline{v} - \pi)^2}{8} \tag{C22}$$

for all M sufficiently large, which by (29) is equivalent to $L^\star(M) > \lim_{M\to\infty} L^\star(M)$. By (C20), it suffices to prove the two strict inequalities

$$M\, \widehat{S}_M \;<\; \frac{(\overline{v} - \pi)^2}{8}, \tag{C23}$$

$$\frac{M\,(\underline{v}_M - \pi)^2}{4\,(M-1)} \;<\; \frac{(\overline{v} - \pi)^2}{4}. \tag{C24}$$

We first prove (C23). Applying the change of variable $z = 1 - F(x)$ to the expression for $M\, \widehat{S}_M$ recalled above,

$$M\, \widehat{S}_M \;=\; \frac{M}{4} \int_0^{1-F(\underline{v}_M)} e^{-2(M-1)z} \big((\overline{v} - \pi) - B(x)\big)^2\, dz, \tag{C25}$$

with $x = F^{-1}(1-z)$; recall $B(\overline{v}) = 0$ and, by (16), $B(\underline{v}_M) = \overline{v} - \pi$. By the standing assumption, there exists $\eta > 0$ such that $f \leq 1/(\overline{v} - \pi)$ on $[\overline{v} - \eta, \overline{v}]$; since $\underline{v}_M \to \overline{v}$ (proof of Proposition 3), we assume M large enough that $\underline{v}_M \geq \overline{v} - \eta$, so that $1/f(u) \geq \overline{v} - \pi$ for all $u \in [\underline{v}_M, \overline{v}]$.

We first derive a lower bound on B. For $z \in [0, 1 - F(\underline{v}_M)]$ and $x = F^{-1}(1-z)$, the change

of variable $s = 1 - F(u)$ in $B(x) = \int_x^{\overline{v}} e^{(M-1)(1-F(u))}\,du$ gives

$$B(x) \;=\; \int_0^z \frac{e^{(M-1)s}}{f(u)}\,ds \;\geq\; (\overline{v}-\pi)\int_0^z e^{(M-1)s}\,ds \;=\; \frac{\overline{v}-\pi}{M-1}\big(e^{(M-1)z}-1\big),$$

where the inequality uses $1/f(u) \geq \overline{v}-\pi$ on $[\underline{v}_M, \overline{v}]$, the range over which u varies as s ranges over $[0, z]$.

Evaluating the lower bound just derived at $z = 1 - F(\underline{v}_M)$ (so $x = \underline{v}_M$) and using $B(\underline{v}_M) = \overline{v} - \pi$ yields $\overline{v} - \pi \geq (\overline{v}-\pi)\big(e^{(M-1)(1-F(\underline{v}_M))}-1\big)/(M-1)$, which rearranges to

$$1 - F(\underline{v}_M) \;\leq\; \frac{\log M}{M-1}. \tag{C26}$$

Rearranging the lower bound,

$$(\overline{v}-\pi) - B(x) \;\leq\; (\overline{v}-\pi) - \frac{\overline{v}-\pi}{M-1}\big(e^{(M-1)z}-1\big) \;=\; \frac{(\overline{v}-\pi)\big(M - e^{(M-1)z}\big)}{M-1}.$$

The left-hand side is nonnegative because $B(x) \leq B(\underline{v}_M) = \overline{v} - \pi$ (as B is decreasing in x), and the right-hand side is nonnegative by (C26). Squaring preserves the inequality:

$$\big((\overline{v}-\pi) - B(x)\big)^2 \;\leq\; \frac{(\overline{v}-\pi)^2}{(M-1)^2}\big(M - e^{(M-1)z}\big)^2 \qquad \text{on } [0, 1-F(\underline{v}_M)]. \tag{C27}$$

Inserting (C27) into (C25) and extending the integration range from $[0, 1 - F(\underline{v}_M)]$ to $[0, \log M/(M-1)]$ (valid by (C26), since the integrand is nonnegative),

$$M\,\widehat{S}_M \;\leq\; \frac{M(\overline{v}-\pi)^2}{4(M-1)^2}\int_0^{\log M/(M-1)} e^{-2(M-1)z}\big(M - e^{(M-1)z}\big)^2\,dz.$$

Direct evaluation of the integral gives

$$M\,\widehat{S}_M \;\leq\; \frac{(\overline{v}-\pi)^2}{8}\left[\frac{M(M-3)}{(M-1)^2} + \frac{2\,M\,\log M}{(M-1)^3}\right]. \tag{C28}$$

It remains to verify the strict inequality. Setting $\nu := M-1 \geq 1$ and $g(\nu) := \nu(\nu+2) - 2(\nu+1)\log(\nu+1)$, the bracketed expression in (C28) is strictly less than 1 if and only if $g(\nu) > 0$. One has $g'(\nu) = 2\nu - 2\log(\nu+1)$ with $g'(0) = 0$, and $g''(\nu) = 2\nu/(\nu+1) \geq 0$; hence g is non-decreasing on $[0,\infty)$. Since $g(1) = 3 - 4\log 2 > 0$, monotonicity yields $g(\nu) \geq g(1) > 0$ for all $\nu \geq 1$. Combined with (C28), this establishes (C23) for every M with $\underline{v}_M \geq \overline{v} - \eta$.

We now prove (C24). Working under the same standing assumption $\underline{v}_M \geq \overline{v} - \eta$, we use (C26) together with the cutoff identity (16) to bound $\overline{v} - \underline{v}_M$ from below. For $u \in [\underline{v}_M, \overline{v}]$, $F(u) \geq F(\underline{v}_M)$, hence $(M-1)(1-F(u)) \leq (M-1)(1-F(\underline{v}_M)) \leq \log M$ by (C26), so $e^{(M-1)(1-F(u))} - 1 \leq M-1$. Substituting into (16),

$$\underline{v}_M - \pi \;=\; \int_{\underline{v}_M}^{\overline{v}} \left(e^{(M-1)(1-F(u))} - 1\right) du \;\leq\; (M-1)\,(\overline{v} - \underline{v}_M),$$

which rearranges to

$$\overline{v} - \underline{v}_M \;\geq\; \frac{\underline{v}_M - \pi}{M-1}. \tag{C29}$$

Setting $\gamma := (\underline{v}_M - \pi)/(\overline{v} - \pi) \in (0,1]$, inequality (C29) divided by $\overline{v} - \pi$ reads $1 - \gamma \geq \gamma/(M-1)$, equivalently $(M-1)(1-\gamma) \geq \gamma$, i.e., $M \geq M\gamma + 1 \geq M\gamma$. Hence $\gamma \leq (M-1)/M < 1$, so

$$\frac{M\,(\underline{v}_M - \pi)^2}{4\,(M-1)} \;=\; \frac{M\,\gamma^2\,(\overline{v} - \pi)^2}{4\,(M-1)} \;\leq\; \frac{M\,(M-1)^2/M^2\,(\overline{v} - \pi)^2}{4\,(M-1)} \;=\; \frac{(M-1)\,(\overline{v} - \pi)^2}{4\,M} \;<\; \frac{(\overline{v} - \pi)^2}{4},$$

which is (C24). Combining (C23) and (C24) via (C20) yields (C22) for every M with $\underline{v}_M \geq \overline{v} - \eta$, hence $L^\star(M)$ is approached from above as $M \to \infty$. □

Appendix H. Proof of Proposition 6

Use the expected wealth of trader i, conditional on observing a signal v_i, in (4),

$$\mathbb{E}_i\big[W_i\big] = -\Phi_i + Q_i\Big(v_i - \pi - \frac{Q_i}{L}\Big) - C - \frac{2\,Q_i}{L}\sum_{j=0}^{M-1} \mathbb{E}_i\Big[\mathbb{1}_{\{\Phi_{(j)} < \Phi_i < \Phi_{(j+1)}\}}\,\Delta_{(j+1:M-1)}\Big],$$

together with the equilibrium priority fees (Proposition 4), trading volumes (Proposition 2), and liquidity (Proposition 5), to obtain for each $i \in \{1, \dots, M\}$:

$$\begin{aligned}\mathbb{E}\big[W_i \mid v_i\big] = &- \frac{2}{L^\star}\,(M-1)\left(\int_0^{Q^\star(v_i)} x^2\,dG(x) + Q^\star(v_i)\int_{Q^\star(v_i)}^{\overline{Q}} x\,dG(x)\right)\\ &+ Q^\star(v_i)\left(v_i - \pi - \frac{Q^\star(v_i)}{L^\star}\right) - C.\end{aligned}$$

Using that $Q^\star(v_i) = 0$ for $v_i < \underline{v}_M$ and $Q^\star(v_i) = L^\star\tilde{Q}(v_i)$ for $v_i \geq \underline{v}_M$, this can be written as

$$\begin{aligned}\mathbb{E}\big[W_i \mid v_i\big] = L^\star\Bigg[&\tilde{Q}(v_i)\big(v_i - \pi - \tilde{Q}(v_i)\big)\\ &- 2\,(M-1)\left(\int_0^{v_i}\tilde{Q}(u)^2\,dF(u) + \tilde{Q}(v_i)\int_{v_i}^{\overline{v}}\tilde{Q}(u)\,dF(u)\right)\Bigg] - C.\end{aligned}$$

At stage one, signals have not yet been realized and traders are ex ante symmetric. If $v_i < \underline{v}_M$, then $Q^\star(v_i) = 0$ and $\Phi_i = 0$, so the payoff is $-C$. Combining with the case $v_i \geq \underline{v}_M$, the expected wealth is

$$\begin{aligned}\mathbb{E}[W_i] = &- C + L^\star\int_{\underline{v}_M}^{\overline{v}}\tilde{Q}(v)\big(v - \pi - \tilde{Q}(v)\big)\,dF(v)\\ &- 2\,L^\star(M-1)\int_{\underline{v}_M}^{\overline{v}}\left[\int_{\underline{v}_M}^{v}\tilde{Q}(u)^2\,dF(u) + \tilde{Q}(v)\int_{v}^{\overline{v}}\tilde{Q}(u)\,dF(u)\right]dF(v).\end{aligned}$$

We now show that $\mathbb{E}[W_i]$ converges to a finite negative limit as $M \to \infty$. First, by Proposition 5, $L^\star$ converges to a finite constant as $M \to \infty$.

Consider

$$(M-1)\int_{\underline{v}_M}^{\overline{v}}\int_{\underline{v}_M}^{v}\tilde{Q}(u)^2\,dF(u)\,dF(v).$$

Interchanging the order of integration yields

$$\begin{aligned}\int_{\underline{v}_M}^{\overline{v}} \int_{\underline{v}_M}^{v} \tilde{Q}(u)^2 \, dF(u) \, dF(v) &= \int_{\underline{v}_M}^{\overline{v}} \int_{u}^{\overline{v}} \tilde{Q}(u)^2 \, dF(v) \, dF(u) \\ &= \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(u)^2 \big(1 - F(u)\big) \, dF(u).\end{aligned}$$

Since $1 - F(u) \leq 1$, the limit derived in the proof of Proposition 5 implies

$$0 \leq \limsup_{M \to \infty} (M-1) \int_{\underline{v}_M}^{\overline{v}} \int_{\underline{v}_M}^{v} \tilde{Q}(u)^2 \, dF(u) \, dF(v) \leq \frac{(\overline{v} - \pi)^2}{8}.$$

Next, consider

$$(M-1) \int_{\underline{v}_M}^{\overline{v}} \int_{v}^{\overline{v}} \tilde{Q}(v) \tilde{Q}(u) \, dF(u) \, dF(v).$$

Using the bound $\tilde{Q}(u) \leq \tilde{Q}(\overline{v}) = \frac{\overline{v} - \pi}{2}$,

$$\begin{aligned}\int_{\underline{v}_M}^{\overline{v}} \int_{v}^{\overline{v}} \tilde{Q}(v) \tilde{Q}(u) \, dF(u) \, dF(v) &\leq \frac{\overline{v} - \pi}{2} \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v) \left(1 - F(v)\right) dF(v) \\ &\leq \frac{\overline{v} - \pi}{2} \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v) \, dF(v).\end{aligned}$$

By the limit derived in Proposition 3,

$$0 \leq \limsup_{M \to \infty} (M-1) \int_{\underline{v}_M}^{\overline{v}} \int_{v}^{\overline{v}} \tilde{Q}(v) \tilde{Q}(u) \, dF(u) \, dF(v) \leq \frac{(\overline{v} - \pi)^2}{4}.$$

Collecting terms, the indifference condition $\mathbb{E}[W_i] = 0$ rearranges to

$$\begin{aligned}C =& L^\star \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v) \big(v - \pi - \tilde{Q}(v)\big) \, dF(v) \\ &- 2 \, L^\star (M-1) \int_{\underline{v}_M}^{\overline{v}} (1 - F(u)) \tilde{Q}(u)^2 \, dF(u) \\ &- 2 \, L^\star (M-1) \int_{\underline{v}_M}^{\overline{v}} \int_{v}^{\overline{v}} \tilde{Q}(v) \tilde{Q}(u) \, dF(u) \, dF(v).\end{aligned}$$

The two $(M-1)$ terms remain bounded as $M \to \infty$, while the first integral term converges to zero. Hence,

$$\limsup_{M\to\infty} \mathbb{E}[W_i] < 0.$$

Therefore, if $\mathbb{E}[W_i] > 0$ for $M = 2$, there exists a finite equilibrium number of informed traders, defined as the largest integer M such that $\mathbb{E}[W_i] \geq 0$.

Simplification of $H(M)$. The volume FOC (15), after substituting $Q = L^\star \tilde{Q}$ and multiplying by $\tilde{Q}(v)$, yields the identity

$$\tilde{Q}(v)\big(v - \pi - \tilde{Q}(v)\big) \;=\; \tilde{Q}(v)^2 \;+\; 2(M-1)\,\tilde{Q}(v)\int_v^{\overline{v}} \tilde{Q}(u)\,dF(u), \qquad v \in [\underline{v}_M, \overline{v}].$$

Substituting into the first integral of the indifference condition above, the $\tilde{Q}(v)\tilde{Q}(u)$ cross term cancels exactly with the third integral, leaving

$$C \;=\; L^\star \int_{\underline{v}_M}^{\overline{v}} \tilde{Q}(v)^2\big[1 - 2(M-1)(1-F(v))\big]\,dF(v) \;=\; H(M),$$

the form in (34).

We now establish the comparative statics. Decreasing C weakly enlarges the set $\{M \geq 2 : C \leq H(M)\}$, so $M^\star$ is weakly decreasing in C. By Proposition 5, $L^\star(M)$ is increasing in N (with π fixed), while the bracketed integrand in (34) does not depend on N. At any M with $H(M) \geq C \geq 0$ and $L^\star(M) > 0$, the integral over that bracket is nonnegative, so raising N weakly raises $H(M)$ and thus weakly raises $M^\star$. □

Appendix I. Proof of Corollary 1

Throughout, $F(\cdot\,;T)$ denotes the distribution of private valuations with support $[0, \overline{v}(T)]$ and $N(T)$ the mass of noise-trading flow.

We first show that the participation cutoff $\underline{v}_M(T)$ is strictly increasing in T. Define

$$G(v;T) \;:=\; v-\pi-\int_v^{\overline{v}(T)}\Big(e^{(1-F(u;T))(M-1)}-1\Big)\,du,$$

so that the cutoff $\underline{v}_M(T)$ satisfies $G(\underline{v}_M(T);T)=0$ by (16). Differentiating in v,

$$\partial_v G(v;T) \;=\; 1+\Big(e^{(1-F(v;T))(M-1)}-1\Big) \;=\; e^{(1-F(v;T))(M-1)} \;>\; 0.$$

For $T'>T$, the FOSD ordering in Assumption 1(i) yields $F(u;T')<F(u;T)$ on $[0,\overline{v}(T)]$, so

$$e^{(1-F(u;T'))(M-1)}-1 \;>\; e^{(1-F(u;T))(M-1)}-1 \qquad \text{for } u\in(0,\overline{v}(T)].$$

Moreover, on $(\overline{v}(T),\overline{v}(T')]$ one has $F(u;T')<1$, hence $e^{(1-F(u;T'))(M-1)}-1>0$. Combining,

$$\int_v^{\overline{v}(T')}\Big(e^{(1-F(u;T'))(M-1)}-1\Big)\,du \;>\; \int_v^{\overline{v}(T)}\Big(e^{(1-F(u;T))(M-1)}-1\Big)\,du,$$

so $G(v;T')<G(v;T)$ for every $v\in[0,\overline{v}(T)]$. Since $\partial_v G>0$, the unique solution of $G(\cdot;T')=0$ satisfies $\underline{v}_M(T')>\underline{v}_M(T)$.

We now show that the end-of-block price is strictly increasing in T in the regime with many informed traders. From Proposition 3, as $M\to\infty$ the end-of-block price converges to $\overline{v}-\pi$. With $\overline{v}=\overline{v}(T)$, the limit equals $\overline{v}(T)-\pi$, which is strictly increasing in T by Assumption 1(i).

Next, we show that the equilibrium liquidity $L^\infty(T)$ is decreasing in T. From (30) in Proposition 5,

$$L^\infty(T) \;=\; \frac{8\,\pi\,N(T)}{3\,(\overline{v}(T)-\pi)^2}-\theta.$$

By Assumption 1(i), $\overline{v}(T)-\pi$ is strictly increasing in T, so the denominator $3\,(\overline{v}(T)-\pi)^2$ is strictly increasing; by Assumption 1(ii), the numerator $8\,\pi\,N(T)$ is decreasing in T. Hence $L^\infty(T)$ is strictly decreasing in T.

Finally, we show that markets shut down for sufficiently large T. Since $N(T) \geq 0$ is decreasing, $8\,\pi\,N(T) \leq 8\,\pi\,N(0)$ is bounded. Since $\overline{v}(T) - \pi \to \infty$ by Assumption 1(i), $3\,(\overline{v}(T) - \pi)^2 \to \infty$, so the first term in $L^{\infty}(T)$ tends to zero, hence $L^{\infty}(T) \to -\theta < 0$. Hence there exists $\overline{T} < \infty$ such that $L^{\infty}(T) \leq 0$ for all $T \geq \overline{T}$. □

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