Market Microstructure in Digital Finance

L06: AMMs, Order Books, and Price Discovery

Economics of Digital Finance

BSc Course

Lesson Overview

Connection to L05: In Lesson 5 we studied how platforms compete and tokens create incentives. Today we look inside the trading mechanisms—how do prices form, and who provides liquidity?

Market microstructure is the study of how trading works at the detailed level: how orders are matched, how prices form, and who provides liquidity.

Today's Topics

1. Traditional vs. DeFi market structure
2. Automated Market Makers (AMMs)
3. Order book mechanics and depth
4. Price discovery in fragmented markets
5. Impermanent loss for liquidity providers
6. MEV (Maximal Extractable Value—profit from reordering transactions) and front-running economics

Learning Objectives

- Compare order book and AMM mechanisms
- Analyze liquidity provision economics
- Understand price discovery in crypto markets
- Evaluate MEV extraction strategies
- Apply microstructure theory to DeFi

This lesson applies market microstructure theory to understand digital asset trading

Traditional vs. DeFi Market Structure

Centralized Exchanges (CEXs)

Characteristics

- CLOB (Central Limit Order Book—matches buy/sell orders by price)
- Custodial trading (the exchange holds your assets on your behalf)
- Professional market makers (firms that continuously offer to buy and sell, providing liquidity)
- High-frequency trading (automated trading at microsecond speeds) infrastructure

Examples

- Binance, Coinbase, Kraken
- NYSE, Nasdaq (traditional)

Decentralized Exchanges (DEXs)

Characteristics

- Automated market makers (AMMs)
- Non-custodial trading (you keep control of your own assets)
- Permissionless liquidity provision
- On-chain settlement (transactions recorded directly on the blockchain)

Examples

- Uniswap, Curve, Balancer
- PancakeSwap, SushiSwap

Economic question: Which structure provides better price discovery and lower transaction costs?

Order Book Mechanics and Liquidity

Order Book Structure

Key Components

- Bid side (buy orders)
- Ask side (sell orders)
- Spread: ask price - bid price
- Depth: volume at each price level

Example If you buy 100 ETH and the order book is thin, you might pay \$1800 for first 50 and \$1850 for next 50.

Price Formation

- Limit orders provide liquidity
- Market orders consume liquidity
- Spread compensates market makers

Economic Theory

Adverse selection: informed traders profit at uninformed traders' expense, forcing market makers to widen spreads.

Kyle (1985) model:

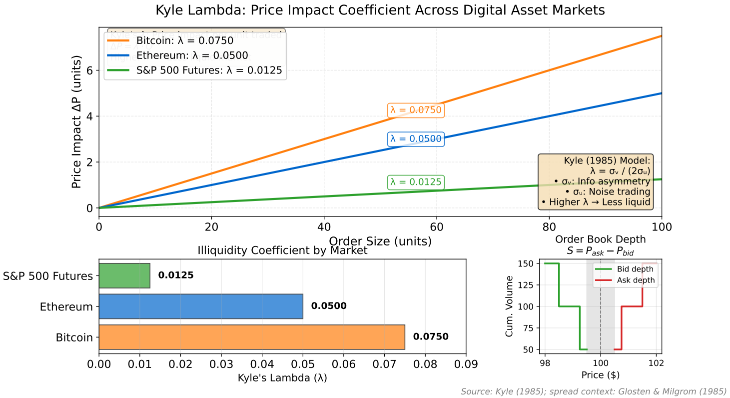
- Price impact: $\lambda = \frac{\sigma_v}{2\sigma_u}$ (higher λ = bigger price move per trade)
- Informed trading intensity: the more insider information exists, the worse the price impact for everyone

Example: For Bitcoin, if $\sigma_v = 0.15$ (high information asymmetry) and $\sigma_u = 0.10$ (moderate noise trading), then $\lambda = 0.15/(2 \times 0.10) = 0.75$. For S&P 500, $\lambda = 0.05/(2 \times 0.20) = 0.125$—meaning Bitcoin trades move prices $6\times$ more per unit traded.

Glosten-Milgrom (1985):

- Bid-ask spread reflects asymmetry
- Sequential trade learning (market makers update beliefs about asset value after each trade)

Traditional microstructure assumes informed vs. uninformed traders; crypto markets add MEV extractors



Kyle's λ measures price impact per unit traded; deeper order books reduce λ. Compare Bitcoin ($\lambda \approx 0.75$) vs. S&P 500 ($\lambda \approx 0.125$)

Automated Market Makers: The Constant Product Formula

How AMMs Work

Constant Product Formula

$$x \cdot y = k$$

where:

- x: reserve of token A
- y: reserve of token B
- k: constant (invariant)

This formula sets prices automatically: as traders buy token A, x decreases, so y must increase (keeping k constant), which raises the price $P = \frac{y}{x}$.

Price Determination

$$P = \frac{y}{x}$$

Example: In a pool with 100 ETH and 180,000 USDC, the price is $\frac{180{,}000}{100} = 1800$ USDC/ETH.

Economic Properties

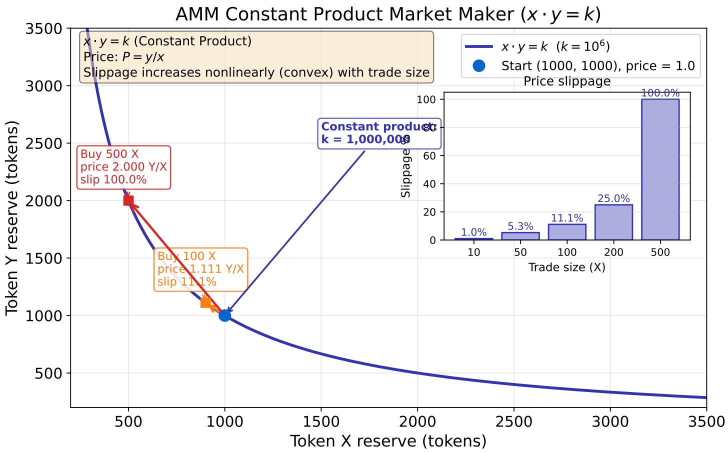
Advantages

- Always provides liquidity
- Permissionless participation
- No order matching needed
- Transparent pricing

Disadvantages

- Slippage (price change between order and execution) on large trades
- Impermanent loss for LPs (Liquidity Providers—people who deposit tokens)
- Capital inefficiency (much of the deposited money sits idle at extreme prices)
- MEV vulnerability

Uniswap pioneered constant product AMM; now the dominant DeFi trading mechanism



Larger trades move farther along the curve, experiencing greater price impact (slippage)

Economics of Liquidity Provision

LP Revenue Streams

Fee Income

- Uniswap v2: 0.3% per trade
- Uniswap v3: 0.05%, 0.3%, 1% tiers
- Proportional to pool share

Incentive Programs

- Liquidity mining rewards (free tokens given to LPs as incentive)
- Protocol token emissions (new tokens created and distributed as rewards)
- Governance rights

LP Costs and Risks

Impermanent Loss

- Loss from price divergence
- Compared to holding assets
- Amplified by volatility

IL formula: $IL = \frac{2\sqrt{r}}{1+r} - 1$ where $r = P_{\text{final}}/P_{\text{initial}}$.

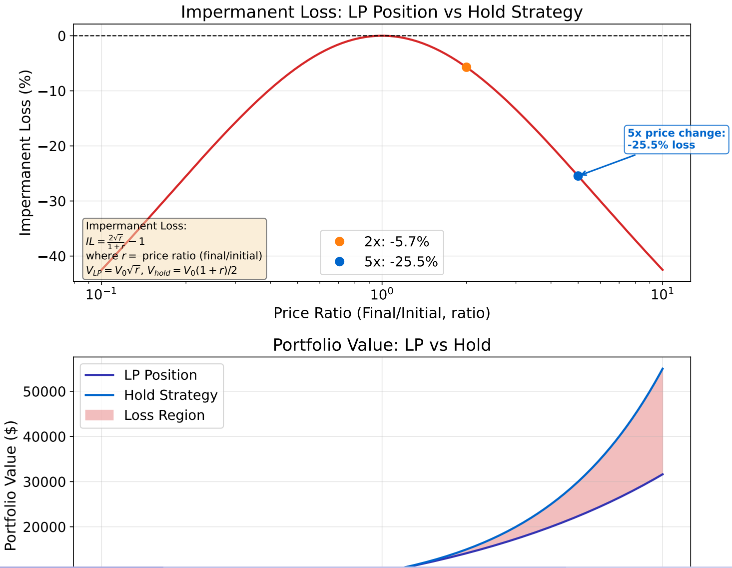
Example: If you provide ETH/USDC liquidity and ETH doubles in price ($r = 2$), $IL = \frac{2\sqrt{2}}{3} - 1 = -5.7\%$ vs just holding ETH and USDC.

Other Risks

- Smart contract (self-executing code on the blockchain) risk
- Gas costs for rebalancing
- MEV extraction

LPs face a trade-off: fee income vs. impermanent loss; only profitable if fees exceed IL

Impermanent Loss Analysis



Price Discovery in Fragmented Markets

Market Fragmentation

Sources of Fragmentation

- Multiple DEXs (Uniswap, Curve, etc.)
- Multiple CEXs (Binance, Coinbase, etc.)
- Cross-chain markets (trading across different blockchains, e.g., Ethereum and Solana)
- Different trading pairs

Arbitrage (profiting from price differences) Mechanism

- Arbitrageurs exploit price differences
- Drive convergence across venues
- Extract value from inefficiencies

Information Share

Hasbrouck (1995) information share (measures how much each venue contributes to price discovery—finding the "true" price):

$$IS_i = \frac{\text{Variance contribution of venue } i}{\text{Total price discovery variance}}$$

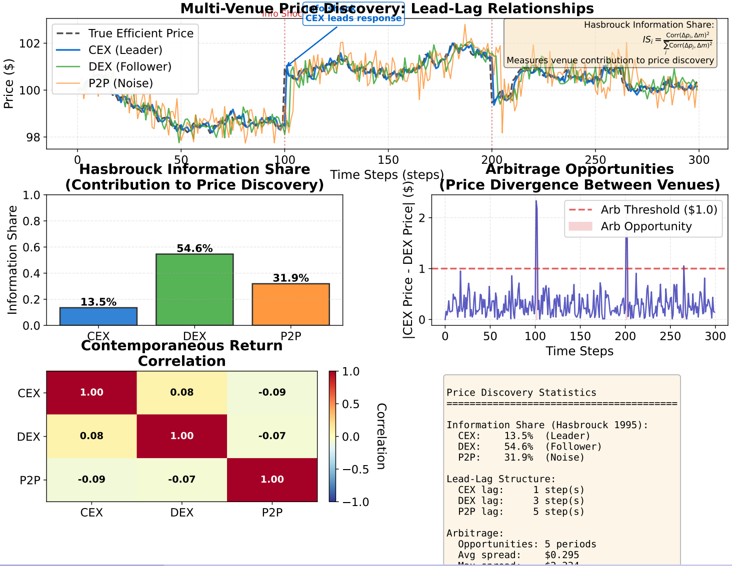
Higher IS_i means venue i leads in price discovery.
Example: If CEX contributes 64% of price variance, DEX 28%, and P2P 8%, then $IS_{CEX} = 0.64$, $IS_{DEX} = 0.28$, $IS_{P2P} = 0.08$. The CEX leads price discovery.

Empirical Findings

- CEXs dominate price discovery
- DEXs lag by seconds to minutes
- Arbitrage costs determine efficiency
- MEV complicates traditional metrics

Crypto markets test traditional price discovery theory due to permissionless arbitrage and MEV

Price Discovery Across Fragmented Venues



	CEX	DEX	P2P
CEX	1.00	0.08	-0.09
DEX	0.08	1.00	-0.07
P2P	-0.09	-0.07	1.00

Maximal Extractable Value (MEV)

What is MEV?

Definition

- Value extractable by ordering transactions
- Enabled by block producer (the entity assembling the next block) control
- Zero-sum redistribution (mostly)

Types of MEV

- Front-running (trading ahead of someone else's order)
- Back-running
- Sandwich attacks (buying before and selling after a victim's trade)
- Liquidations
- Arbitrage

Economic Impact

MEV Magnitude

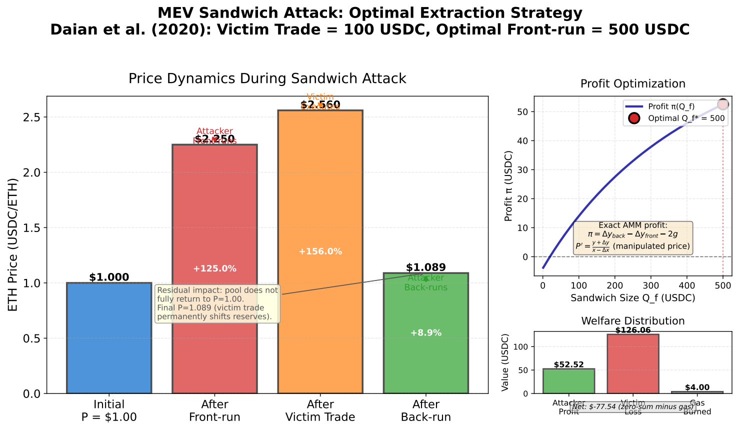
- Over \$1.5B+ extracted on Ethereum alone since 2020 (Flashbots, 2024)
- 5-10% of some DEX trades
- Growing with DeFi adoption

Welfare Effects

- Transfers wealth from traders to extractors
- Increases transaction costs
- May improve price efficiency
- Potential consensus instability

MEV is a new phenomenon requiring new economic models beyond traditional market microstructure

Anatomy of a Sandwich Attack



Sandwich attacks optimize profit $\pi = Q_f(P' - P) - 2 \cdot \text{gas}$; welfare panels show transfers from users to extractors

Economics of MEV Extraction

MEV Supply Chain

Actors

- Searchers (bots scanning the mempool for profitable transaction orderings): find MEV opportunities
- Builders (entities assembling transactions into candidate blocks): construct blocks
- Validators (nodes that propose and finalize blocks on the network): propose blocks
- Users: suffer MEV extraction

Sandwich Profit: $\pi = Q_f \cdot (P' - P) - 2 \cdot \text{gas}$
Example: Front-run $Q_f = 10$ ETH, price P=\$1800 $\rightarrow$ P'=\$1805. Profit $= 10 \times 5 - 2 \times \$3 = \$44$.

Competition Dynamics

- Priority gas auctions (PGAs—users bid up gas fees to get their transactions processed first)
- Flashbots auction mechanism (a private marketplace where searchers bid for block inclusion without spamming the network)
- MEV-Boost infrastructure (middleware connecting validators to block builders for fair MEV distribution)

Mitigation Strategies

Protocol-Level

- Encrypted mempools (hiding pending transactions; the mempool is the waiting area for unconfirmed transactions)
- Fair ordering protocols
- Batch auctions
- Threshold encryption (multiple parties must cooperate to decrypt)

Application-Level

- MEV-protected RPCs (private endpoints for submitting transactions invisible to attackers)
- Slippage tolerance limits
- Time-weighted average pricing (splitting a large trade over time to reduce impact)
- Private order flow (routing trades through channels hidden from MEV searchers)

Market Efficiency in Crypto Markets

Efficiency Metrics

Spread and Depth

- Bid-ask spreads wider than TradFi (Traditional Finance—banks, stock exchanges)
- Lower depth for most pairs
- Improving over time

Price Discovery Speed

- Fast arbitrage (seconds)
- Cross-exchange efficiency
- 24/7 trading advantage

Informational Efficiency

Challenges

- High retail participation
- Limited fundamental anchors
- Sentiment-driven volatility
- Manipulation concerns

Advantages

- Transparent on-chain data
- Permissionless arbitrage
- No trading halts
- Global liquidity pools

Crypto markets exhibit mixed efficiency: fast arbitrage but high volatility and manipulation risk

AMM vs. Order Book: Economic Comparison

Automated Market Makers

Strengths

- Guaranteed liquidity (always tradable)
- Simple passive LP participation
- Transparent pricing formula
- No counterparty matching needed

Weaknesses

- High price impact for large trades
- Impermanent loss risk
- Capital inefficiency (idle reserves)
- MEV vulnerability

Order Books

Strengths

- Better for large trades (lower slippage)
- Sophisticated order types (limit, stop)
- Professional market making
- Familiar interface

Weaknesses

- Requires active market makers
- Liquidity can disappear
- Higher technical complexity
- Custodial risk on CEXs

Optimal structure depends on asset liquidity, trade size, and user preferences; hybrid approaches emerging

Advanced AMM Mechanisms

Uniswap v3: Concentrated Liquidity

Innovation

- LPs choose price ranges
- Higher capital efficiency
- Customizable fee tiers

Trade-offs

- Active management required
- Higher impermanent loss risk
- Complexity barrier

Curve: Stableswap

Innovation

- Optimized for low-volatility pairs
- Hybrid constant sum + constant product
- Lower slippage for stablecoins

Balancer: Weighted Pools

- Multi-asset pools
- Customizable weights
- Index fund functionality

AMM innovation continues; trend toward capital efficiency and specialization by asset type

Empirical Evidence on DeFi Market Microstructure

Key Findings

Liquidity and Trading Costs

- DEX spreads 2-5x CEX spreads
- Improving with liquidity growth
- Uniswap v3 narrows gap

Impermanent Loss

- Most LPs lose vs. HODL (Hold On for Dear Life—crypto slang for holding)
- Fee income often insufficient
- Incentive programs crucial

MEV Impact

Magnitude

- 5-10% implicit cost on some trades
- Concentrated in large trades
- Growing with DeFi TVL (Total Value Locked—money deposited in DeFi)

Price Discovery

- CEXs lead by 30-60 seconds
- Arbitrage profitable despite costs
- Cross-chain discovery slower

Research from Lehar & Parlour (2021), Barbon & Ranaldo (2022), Adams et al. (2024) on AMMs and MEV

Future Directions in DeFi Microstructure

Technical Innovation

Emerging Mechanisms

- Dynamic fees (volatility-adjusted)
- Just-in-time liquidity (providing liquidity for a single block to capture fees)
- Intent-based architectures (users specify desired outcomes, solvers compete to execute)
- ZK-rollup order books (order books on blockchain scaling technology)

MEV Solutions

- Encrypted mempools
- Fair ordering protocols
- MEV redistribution to users

Economic Research Needs

Open Questions

- Optimal LP compensation design
- MEV welfare impact measurement
- Cross-chain price discovery
- Decentralized governance efficiency

Policy Implications

- Market manipulation regulation
- Investor protection in DeFi
- Systemic risk from MEV

DeFi market microstructure is rapidly evolving; economic theory must adapt to new mechanisms

Key Takeaways

Core Concepts

1. AMMs use constant product formula for automated trading
2. Order books rely on active market makers
3. Impermanent loss is key LP risk
4. MEV extracts value via transaction ordering
5. Price discovery faster but less efficient than TradFi

Economic Insights

- Trade-offs between decentralization and efficiency
- Liquidity provision requires compensation for IL
- MEV creates new welfare considerations
- Market fragmentation enables arbitrage
- Innovation continues with v3, Curve, etc.

Application to Practice

Market microstructure theory helps evaluate DEX design, understand LP economics, and assess efficiency of crypto trading venues.

Next lesson: Regulatory Economics of Digital Finance

Key Terms (1/2)

AMM (Automated Market Maker) Smart contract providing liquidity through algorithmic pricing (e.g., constant product formula $x \cdot y = k$).

Order Book Traditional market structure listing buy and sell orders at various prices.

Liquidity Provider (LP) Party depositing assets into AMM pool to enable trading, earning fees in return.

Impermanent Loss Loss LPs experience when asset prices diverge from deposit ratio, compared to simply holding.

MEV (Maximal Extractable Value) Profit extractable by reordering, inserting, or censoring transactions within a block.

Price Discovery Process by which market determines asset prices through trading activity and information aggregation.

Market Microstructure How trading actually works at the detailed level (order matching, price formation, liquidity provision).

Adverse Selection Informed traders profit at uninformed traders' expense, causing market makers to widen spreads.

Slippage Price change between when you submit an order and when it executes, especially on large trades.

Price Impact How much your trade moves the market price; larger trades have higher price impact.

Arbitrage Profiting from price differences across markets (e.g., buying ETH on one exchange and selling on another).

Front-Running Trading ahead of someone else's order to profit from the expected price change.

Sandwich Attack MEV strategy: buy before victim's trade, then sell after, profiting from price manipulation.

CLOB (Central Limit Order Book) Order book matching system that pairs buy and sell orders by price-time priority.

Market microstructure concepts are essential for understanding DeFi efficiency and risks

Key Terms (2/2)

Constant Product Formula AMM pricing rule $x \cdot y = k$ that automatically adjusts prices as traders swap tokens.

TradFi (Traditional Finance) Banks, stock exchanges, and conventional financial institutions (vs. DeFi).

TVL (Total Value Locked) Total amount of money deposited in DeFi protocols, a measure of adoption and liquidity.

Gas Fees Transaction fees paid to blockchain validators for processing transactions (high gas = expensive trades).

Block Time Time between new blocks added to blockchain (e.g., 12 seconds on Ethereum); determines MEV opportunities.

Bid-Ask Spread Difference between highest buy price and lowest sell price; narrower spreads = more liquid markets.

Order Book Depth Volume of buy/sell orders at each price level; deeper books absorb large trades without price impact.

HODL (Hold On for Dear Life) Crypto slang for holding assets long-term instead of trading; origin of "impermanent loss vs. HODL" comparison.

Mempool The waiting area for unconfirmed transactions before they are included in a block; MEV searchers monitor mempools for opportunities.

Concentrated Liquidity Uniswap v3 innovation allowing LPs to provide liquidity within a chosen price range, improving capital efficiency.

Understanding these terms is crucial for analyzing DeFi trading efficiency and risks

Further Reading

Foundational Papers

- Kyle (1985): "Continuous Auctions and Insider Trading"
- Hasbrouck (1995): "One Security, Many Markets"
- Adams et al. (2024): "Uniswap v3: The Economics of Concentrated Liquidity"
- Lehar & Parlour (2021): "Systemic Fragility in Decentralized Markets"

MEV Research

- Daian et al. (2020): "Flash Boys 2.0"
- Qin et al. (2022): "Quantifying MEV on Ethereum"
- Barbon & Ranaldo (2022): "On the Quality of Cryptocurrency Markets"

All readings available on course platform