L34: AMM Mechanics

Module E: DeFi Ecosystem

Blockchain & Cryptocurrency

December 2025

Learning Objectives

- Understand the constant product formula ($x \cdot y = k$)
- Analyze how liquidity provision works in AMMs
- Calculate impermanent loss and its implications
- Understand slippage and price impact
- Compare AMMs to traditional order book exchanges

Traditional Order Book Exchanges

How They Work:

- **Buyers** place bids, **sellers** place asks
- **Matching engine** pairs buy/sell orders
- Trade executes when bid meets ask

Example Order Book:

	Price	Size
Bids (Buy)	$1,999	5 ETH
	$1,998	10 ETH

	Price	Size
Asks (Sell)	$2,000	8 ETH
	$2,001	12 ETH

Challenges on Blockchain: Gas costs for order updates, slow block times, front-running.

Automated Market Makers (AMMs)

Key Idea: Replace order books with liquidity pools governed by mathematical formulas.

How It Works:

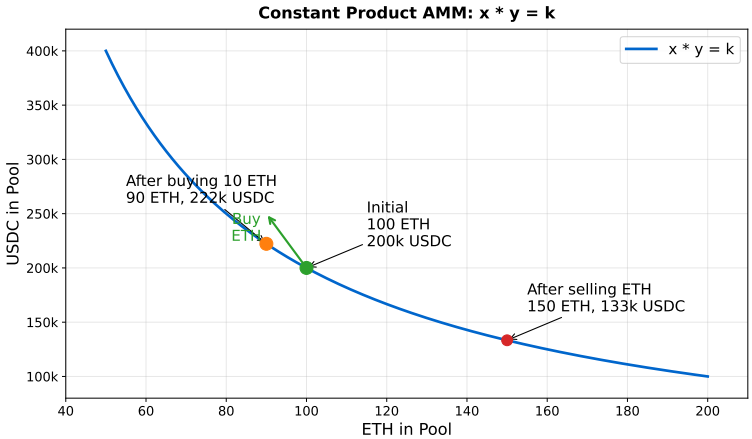
- Liquidity Providers (LPs) deposit token pairs into a pool
- Algorithm sets price based on pool ratio
- Users trade directly against the pool

Advantages:

- Always available liquidity (no need to wait for orders)
- Passive income for LPs (earn trading fees)
- Gas efficient (fewer transactions)

Trade-off: Price determined by formula, not market consensus.

The Constant Product Formula



Trades move along the curve; price is the slope at any point

Constant Product: Mathematics

Uniswap V2 Model:

$$x \cdot y = k$$

where x = token A quantity, y = token B quantity, k = constant.

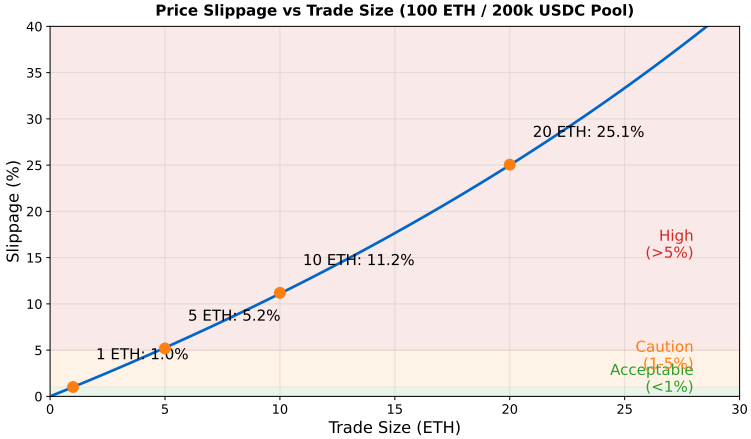
Example Pool:

- 100 ETH and 200,000 USDC
- $k = 100 \times 200{,}000 = 20{,}000{,}000$
- Price: $\frac{y}{x} = \frac{200{,}000}{100} = 2{,}000$ USDC per ETH

After Buying 10 ETH:

- New ETH: 90, New USDC: $\frac{20{,}000{,}000}{90} = 222{,}222$
- Cost: 22,222 USDC for 10 ETH = \$2,222/ETH average

Slippage vs Trade Size



Slippage increases non-linearly; larger pools reduce slippage

Slippage Explained

Definition: The difference between expected price and executed price due to trade size.

Why Slippage Occurs:

- AMM formula moves price as reserves change
- Larger trades = larger price impact
- Smaller pools = more slippage

Slippage Formula:

$$\text{Slippage} = \frac{\text{Executed Price} - \text{Initial Price}}{\text{Initial Price}} \times 100\%$$

Slippage Tolerance: Users set maximum acceptable (e.g., 0.5%, 1%). Transaction reverts if exceeded.

Liquidity Provision

How to Become an LP:

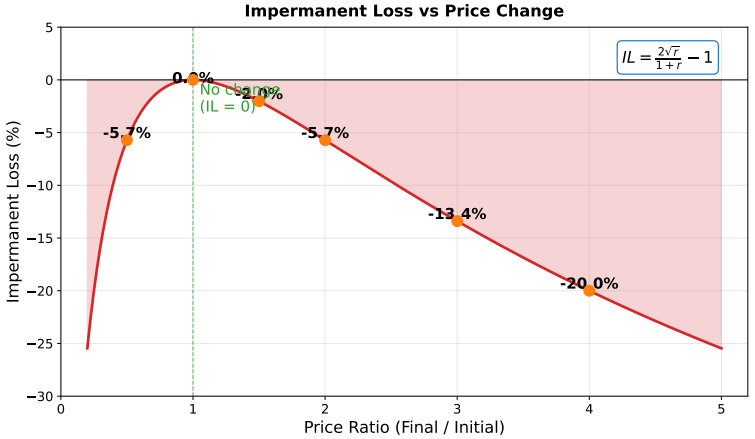
1. Deposit equal value of both tokens (e.g., 1 ETH + 2,000 USDC)
2. Receive LP tokens representing pool share
3. Earn trading fees proportional to share
4. Withdraw anytime (burn LP tokens, receive reserves)

Example:

- Pool has 100 ETH + 200,000 USDC
- You deposit 10 ETH + 20,000 USDC
- Your share: $\frac{10}{110} = 9.09\%$ of pool

Fee Earnings: Uniswap charges 0.3% per trade; fees compound in pool reserves.

Impermanent Loss



IL increases with price divergence; symmetric whether price rises or falls

Impermanent Loss: Concept

Definition: The opportunity cost of providing liquidity vs. simply holding tokens.

Occurs when:

- Token prices diverge from deposit ratio
- Arbitrageurs rebalance pool to match external prices
- LPs end up with more of the depreciated token

Example: ETH doubles to $4,000

- Initial: 1 ETH + 2,000 USDC = $4,000 total
- If held: 1 ETH @ $4,000 + 2,000 USDC = $6,000
- If LP: 0.707 ETH + 2,828 USDC = $5,656
- **IL: $344 (5.7%)**

Impermanent Loss: Key Values

Formula:

$$\text{IL} = \frac{2\sqrt{r}}{1+r} - 1$$

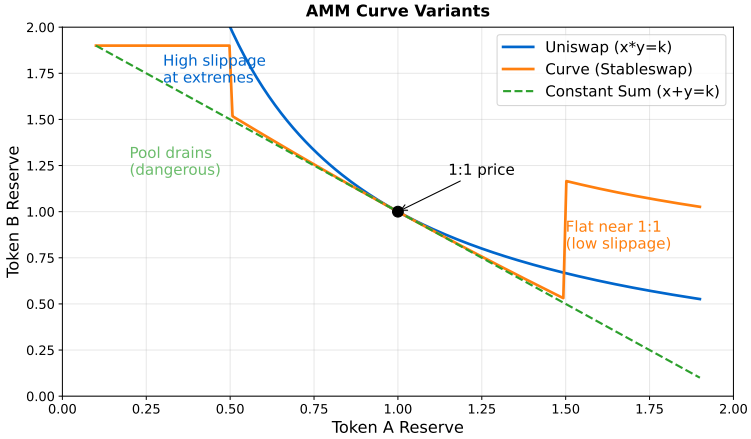
where r is the price ratio (final/initial).

Common Scenarios:

- 1.25x price change: -0.6% IL
- 1.5x price change: -2.0% IL
- 2x price change: -5.7% IL
- 3x price change: -13.4% IL
- 4x price change: -20.0% IL

Why "Impermanent"? Loss only realized on withdrawal; if prices return, loss disappears.

AMM Curve Variants



Different curves optimize for different use cases

AMM Variants Explained

Uniswap (Constant Product): $x \cdot y = k$

- General purpose, works for any pair
- Higher slippage near extremes

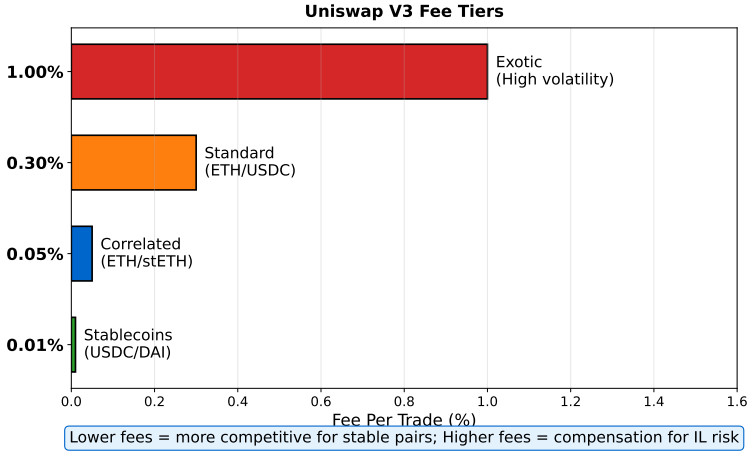
Curve (Stableswap): Hybrid formula

- Flat curve near 1:1 (low slippage for stables)
- Dominates stablecoin swaps (USDC/DAI)

Balancer (Weighted): $\prod x_i^{w_i} = k$

- Custom weights (e.g., 80/20 instead of 50/50)
- Index fund functionality

Fee Tiers in AMMs



Higher fees compensate LPs for impermanent loss risk in volatile pairs

Arbitrage in AMMs

How Arbitrage Works:

1. External market price deviates from AMM price
2. Arbitrageur buys cheaper asset, sells expensive one
3. AMM pool rebalances to match external price

Example:

- CEX: 1 ETH = \$2,100
- Uniswap pool: 1 ETH = \$2,000
- Arbitrageur: Buy on Uniswap, sell on CEX, profit \$100/ETH

Benefit: Keeps AMM prices aligned with global markets.
Cost: LPs experience impermanent loss from adjustments.

MEV and Front-Running

Maximal Extractable Value (MEV):

- Profit from reordering/inserting transactions
- Particularly prevalent in AMM trades

Common MEV Strategies:

1. **Front-Running:** See large buy, buy first, sell after
2. **Sandwich Attacks:** Buy before user, sell after
3. **Arbitrage:** Exploit price differences

Mitigation:

- Private mempools (Flashbots Protect)
- Batch auctions (CoW Swap)

Comparison: AMM vs Order Book

AMM (Uniswap)

- Always available liquidity
- Passive LP income
- Slippage on large trades
- Impermanent loss risk

Order Book (Binance)

- Liquidity depends on makers
- Active market making
- Better for large trades
- No impermanent loss

Trend: Hybrid models emerging (e.g., dYdX order book on Cosmos).

Summary

Key Takeaways:

- AMMs use $x \cdot y = k$ to provide algorithmic liquidity
- Price determined by reserve ratio; trades move price
- Slippage increases non-linearly with trade size
- LPs earn fees but face impermanent loss when prices diverge
- IL formula: $\frac{2\sqrt{r}}{1+r} - 1$ (up to 20%+ for 4x moves)
- Curve optimizes for stables; Balancer for weighted pools
- MEV is a hidden cost for AMM traders

Next Lecture: Uniswap Deep Dive - V1 to V4 evolution, concentrated liquidity.

Questions for Reflection

1. Calculate the cost to buy 5 ETH from a pool with 100 ETH and 200,000 USDC.
2. Why does slippage increase non-linearly with trade size?
3. How do trading fees help offset impermanent loss for LPs?
4. Why is Curve more suitable for stablecoin trading than Uniswap V2?
5. What are the trade-offs of concentrated liquidity in Uniswap V3?