# 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:**

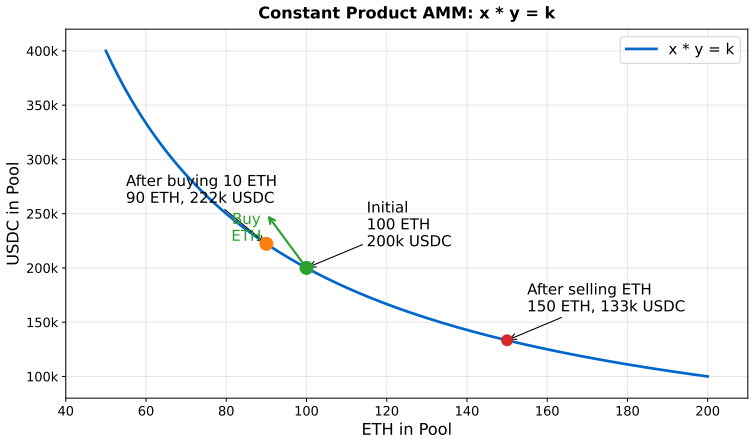
- Liquidity Providers (LPs) deposit token pairs into a pool
- Algorithm sets price based on pool ratio
- Users trade directly against the pool

**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.

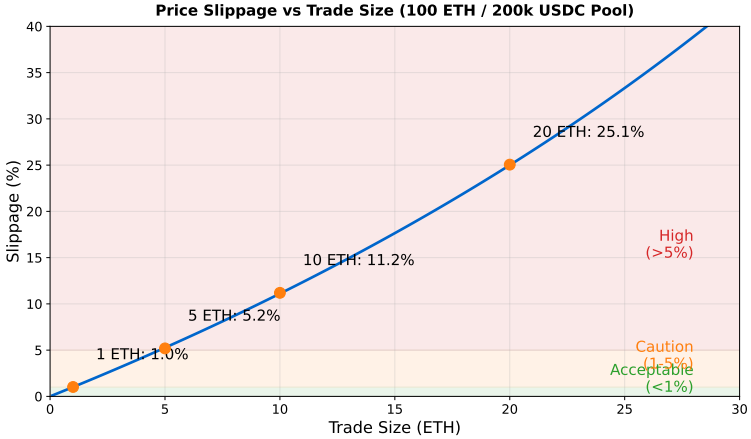
**Example Pool:**

- 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:**

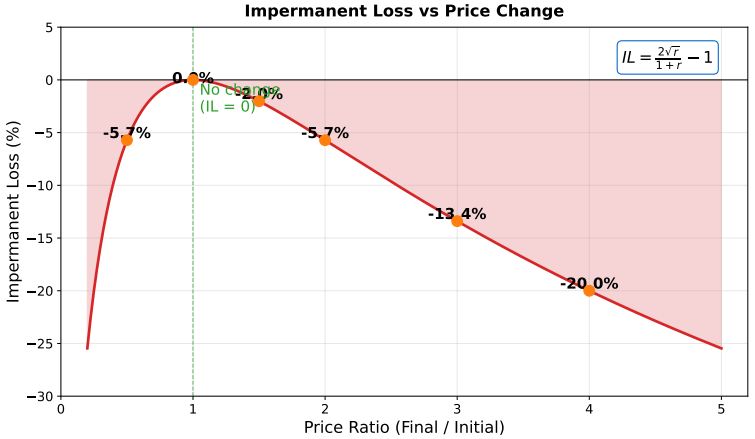
1. Deposit equal value of both tokens (e.g., 1 ETH + 2,000 USDC)
2. Receive LP tokens representing pool share
3. Earn trading fees proportional to share
4. Withdraw anytime (burn LP tokens, receive reserves)

**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:**

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

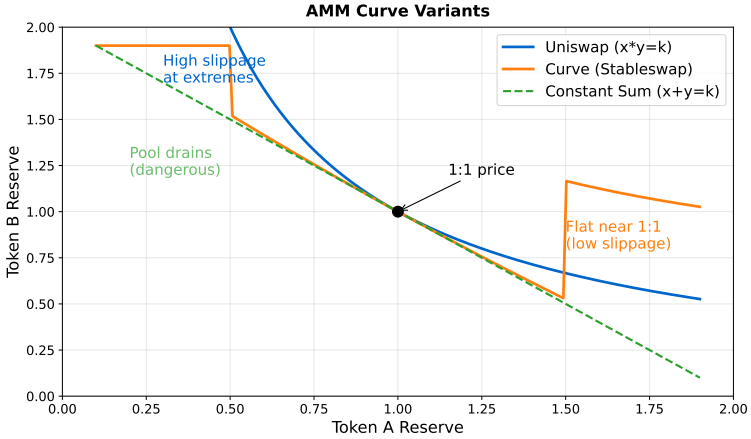
where $r$ is the price ratio (final/initial).

**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

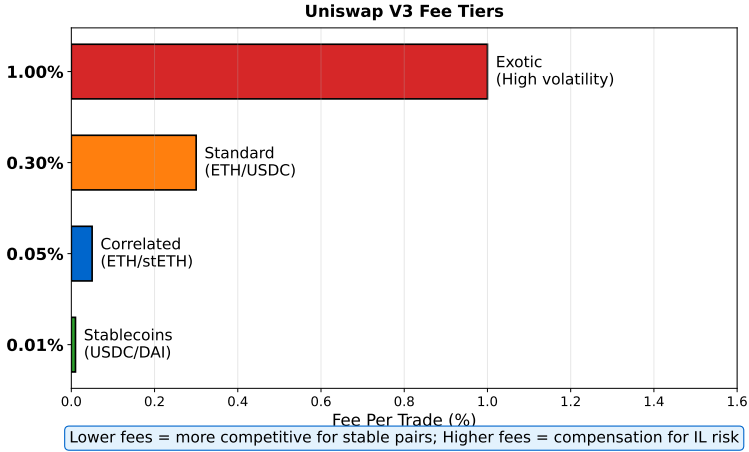
**Curve (Stableswap): Hybrid formula**

- 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?