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Algorithmic Stablecoins: A Simulator for the Dual-Token Model in Normal and Panic Scenarios

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Stablecoins: Overview (I)

- What is a **stablecoin**?

  A crypto asset designed to maintain a **stable value** relative to a reference asset (e.g. USD)

- Main types

  Fiat-collateralized (e.g. USDT, USDC) – Backed by reserves of fiat currency

  Crypto-collateralized (e.g. DAI) – Over-collateralized with ETH or other tokens

  Algorithmic (e.g. UST, AMPL) – Supply adjusted automatically via smart-contract rules

Stablecoins: Overview (II)

- Market scale

  USD-denominated stablecoins have surpassed **$240 billion**, representing 1% of the U.S. money supply

- Key **use cases**

  Global payments

  DeFi lending and borrowing

  Hedging against market volatility

Motivation

- **Terra–Luna collapse** (May 2022)
  - UST lost peg, LUNA hyperinflated
  - Burned over **$50 billion** market value

- Gap in risk-assessment tools
  - No simulation framework for dual-token models

- **Our goal**
  - Develop a **simulator** that captures both normal and panic dynamics

DualTokenSim

- A **Python-based**, **open-source** simulator for dual-token algorithmic stablecoins
- Replicates real-world collapse events (e.g. UST–LUNA May 2022)
- Test and compare novel stabilization mechanisms before on-chain deployment

Algorithmic Stablecoins

Definition

No external (exogenous) collateral: stability via **supply and seigniorage adjustments**

Types:

- **Rebase models**
  - Adjust user balances (e.g. AMPL)
- **Dual-token models**
  - Stablecoin (e.g. UST) and collateral token (e.g. LUNA)
  - Mint/burn mechanism enforces peg via arbitrage

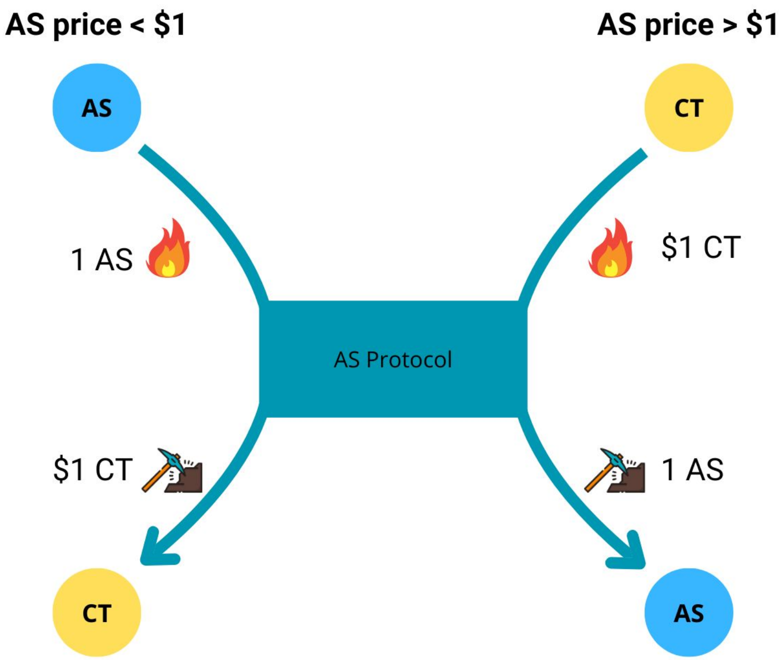
Dual-Token Mechanism

Asset roles

- **AS token** (e.g. UST): price-pegged stablecoin
- **CT token** (e.g. LUNA): collateral and volatility absorber

Arbitrage loop

1. If AS < \$1 → mint CT by burning AS
2. If AS > \$1 → mint AS by burning CT



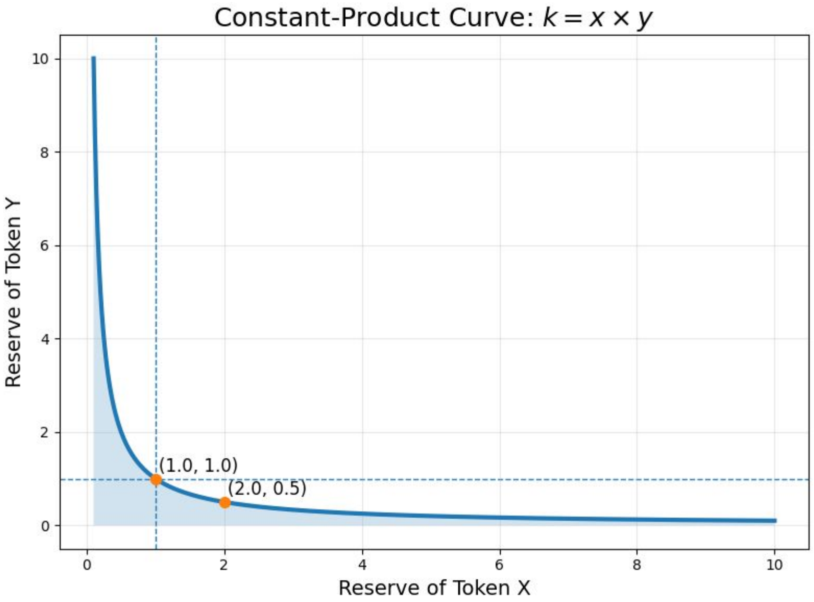
Automated Market Makers (AMM)

- *Constant-product formula:* $x \cdot y = k$

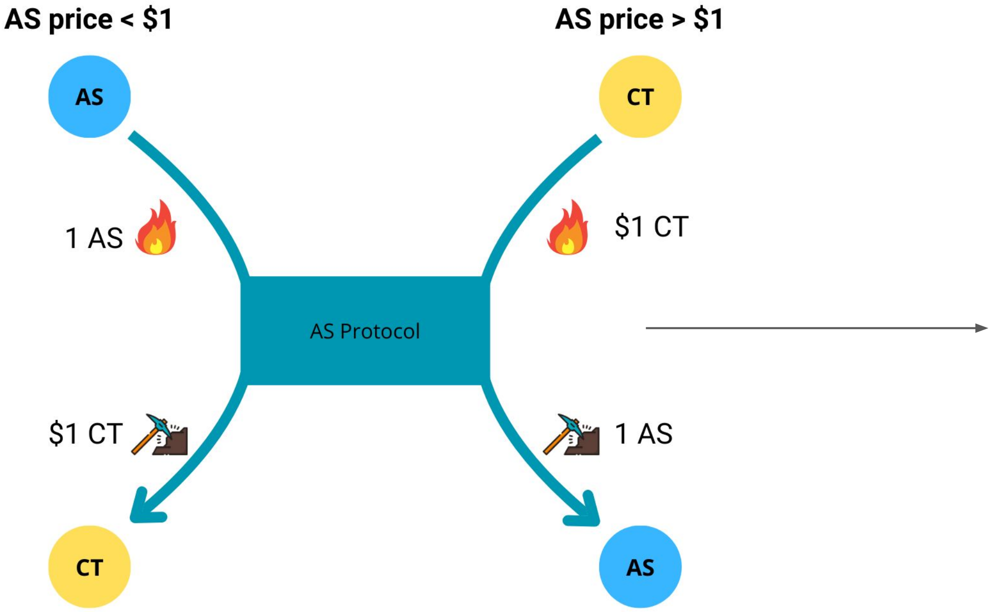
  x and y are token reserves, k is the invariant

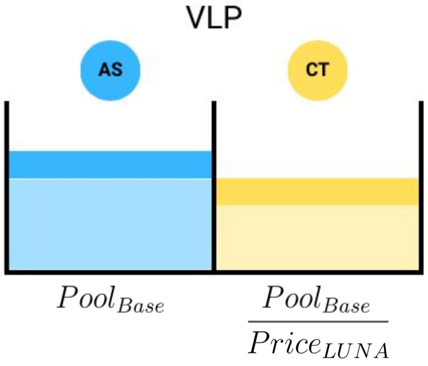
- Price determination: $P_X = \frac{y}{x}, \quad P_Y = \frac{x}{y}$

- Relevance to *DualTokenSim*
  - Two LPs to drive **price dynamics** via swap simulations
  - Models the price impact on large token swaps



Virtual Liquidity Pool – VLP (I)





Virtual Liquidity Pool – VLP (II)

Market-making algorithm implementing a constant-product formula

$$CP = Pool_{Base}^2 \cdot \frac{1}{Price_{LUNA}}$$

- $Pool_{Base}$ represents the **baseline quantity** of UST
- $Price_{LUNA}$ expresses the **price** of LUNA in USD as observed in external markets

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Virtual Liquidity Pool – VLP (III)

δ represents the **deviation** of UST amount in the VLP compared to $Pool_{Base}$

$$Pool_{UST} = Pool_{Base} + \delta, \quad Pool_{LUNA} = \frac{CP}{Pool_{UST}}$$

When swaps occur in VLP, δ is updated

Virtual Liquidity Pool – VLP (IV)

"Virtual" because it had the capacity to **replenish** itself, bringing δ back to zero

At the end of each block produced in the Terra blockchain, the new value of delta is computed:

$$\delta := \delta \cdot \left(1 - \frac{1}{PoolRecoveryPeriod}\right)$$

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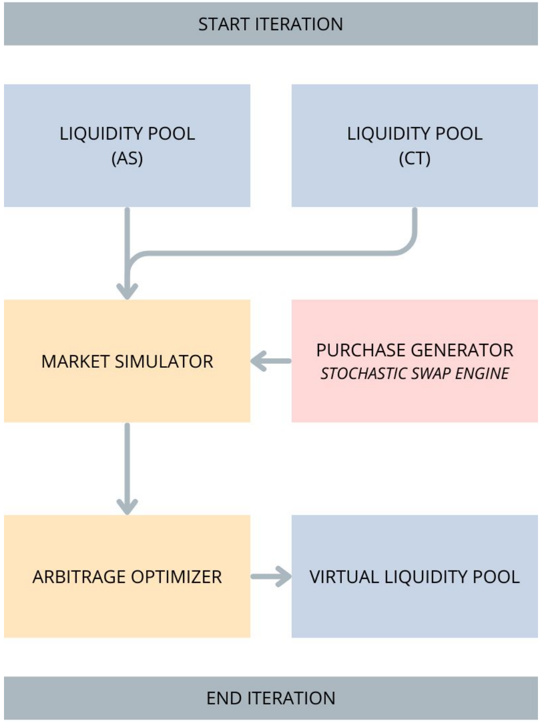
DualTokenSim Overview

- **Python-based** simulator
  - Modular, open-source codebase

- **Discrete-time iterations**
  - Blocks of 6 s per step, customizable duration

- **Two liquidity pools**
  1. AS / TU pool (stablecoin ↔ USD proxy)
  2. CT / TU pool (collateral ↔ USD proxy)

- **Stochastic swap engine**
  - Buy/sell events drive price dynamics



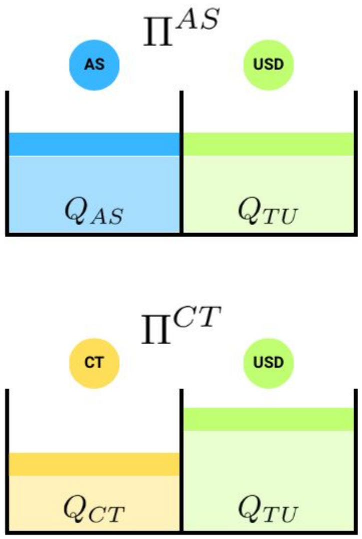
Price Dynamics (I)

- Two AMMs implementing a CPF to **replicate the market dynamics** affecting AS and CT, Π^{AS} and Π^{CT}

- Liquidity pool state variables
  - Q_{AS}, Q_{TU}: quantities of stablecoin and USD proxy

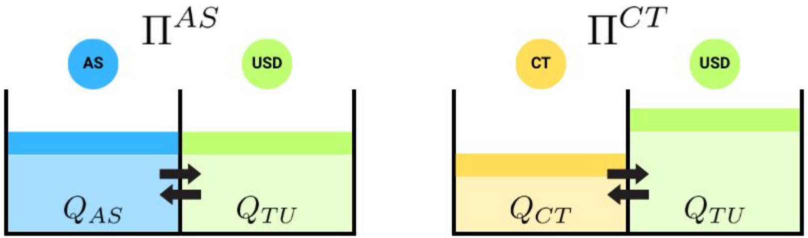
- Price proxy
  - The instantaneous price of the stablecoin AS is calculated as the ratio of USD-proxy reserves to AS reserves:

$$P = \frac{Q_{TU}}{Q_{AS}}$$



Stochastic Swap Model (I)

- At each iteration **a swap occurs** within Π^{AS} and Π^{CT}



- Token swaps are modeled as **stochastic processes**

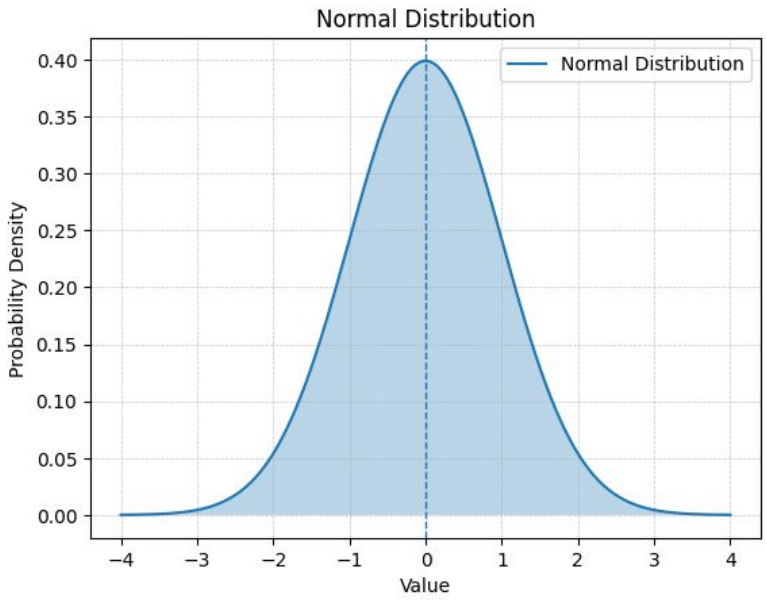
Stochastic Swap Model (II)

The **swap quantity** q of each transaction is defined as:

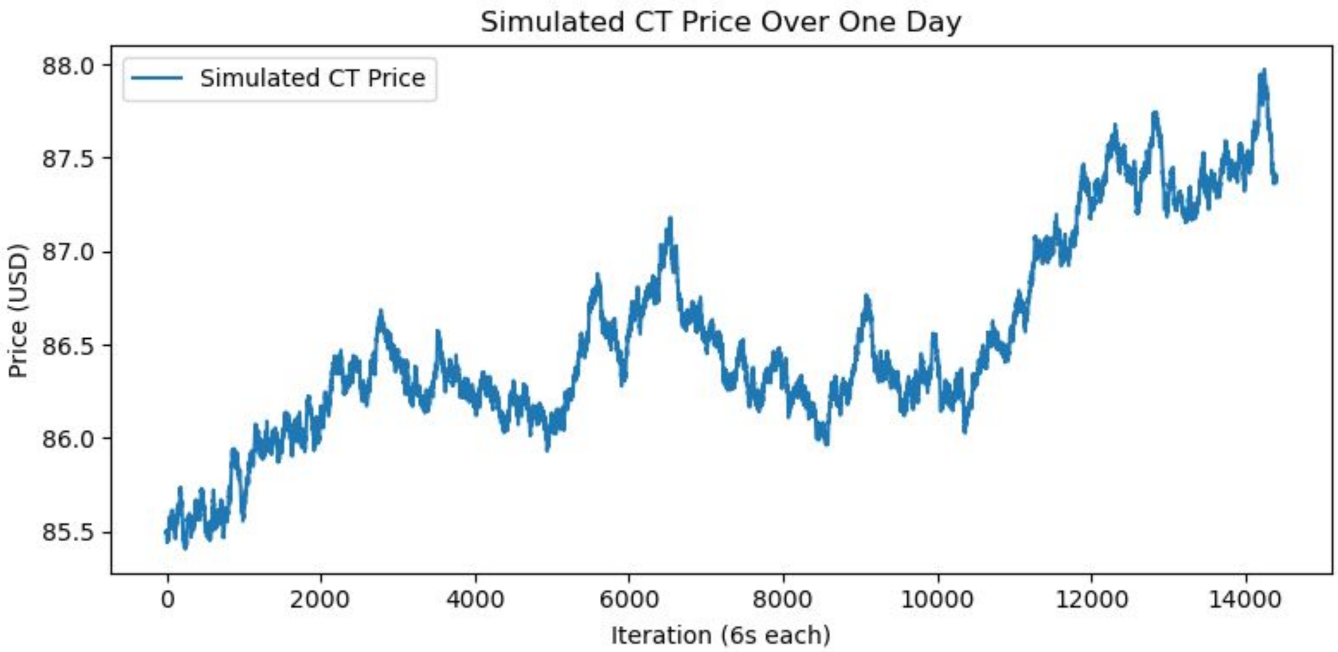
$$q = \frac{|p| \cdot v}{P_{market}}$$

where:

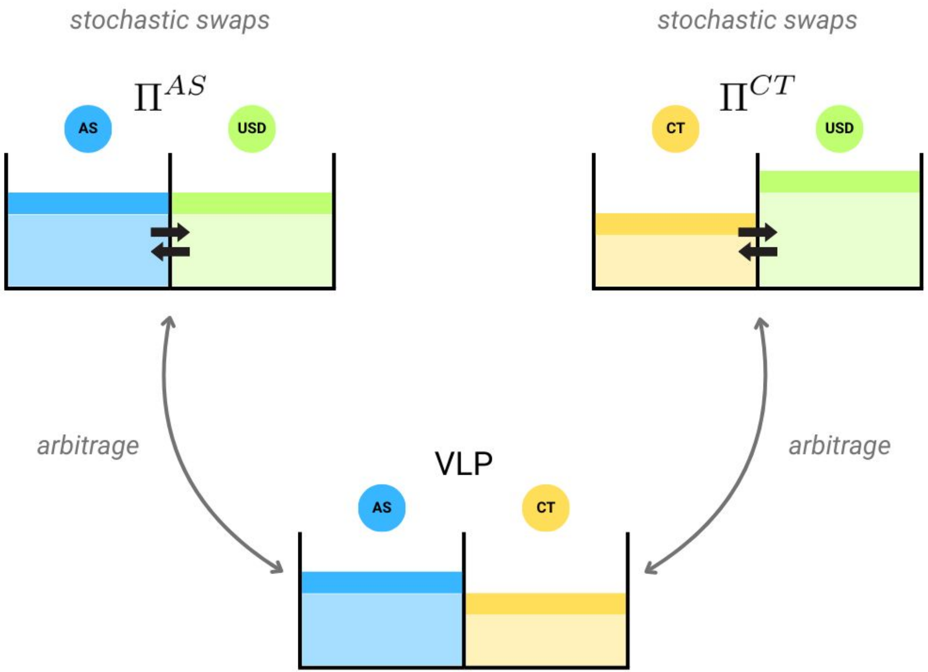
- $v \rightarrow$ swap volume
- $P_{market} \rightarrow$ current market price of the token
- $p \rightarrow$ r.v. sampled from a normal distribution



Stochastic Swap Model (III)



The Complete System



Panic Scenario (I)

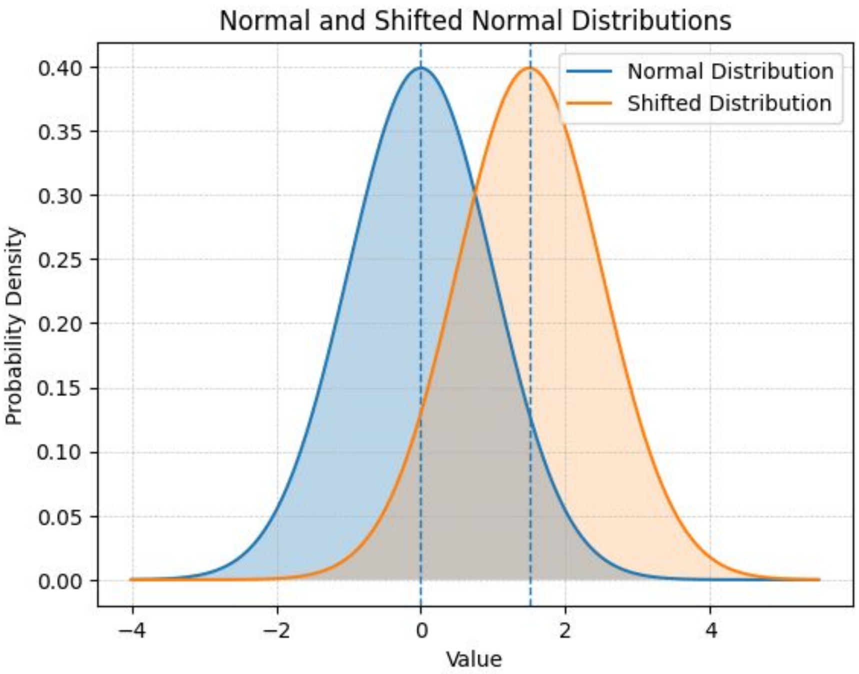
- **Panic shifts**
  - During panic, mean of distribution shifts, causing a **selling pressure** on AS and CT

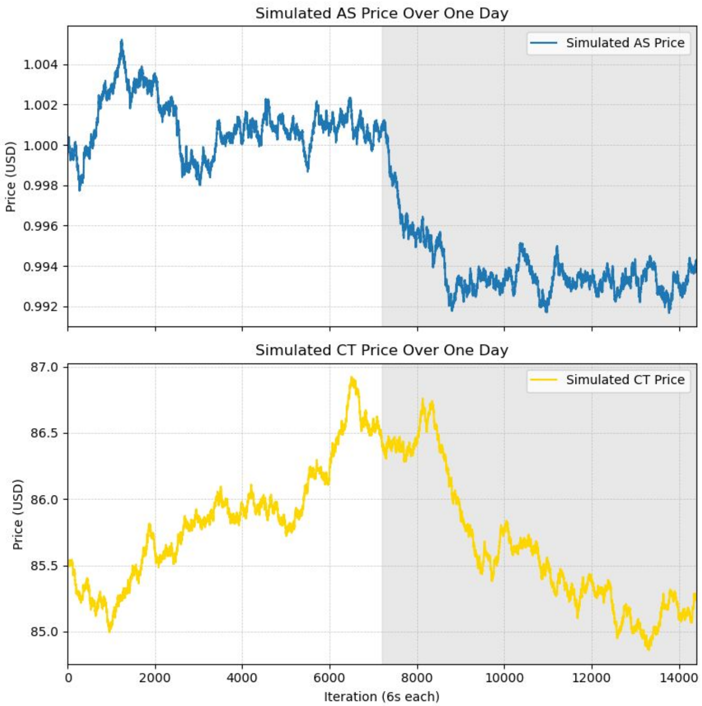
- Dynamic mean update
  - If $P_{AS} \geq \text{threshold}:$ $\mu = 0$ (healthy/balanced situation)
  - If $P_{AS} < \text{threshold}:$ $\mu = f(P_{AS})$ (captures panic behavior)

  By default,
  - the "panic function" is: $f(P_{AS}) = \frac{1}{P_{AS}}$
  - threshold = 0.95

- Affects both tokens

Panic Scenario (II)





Validation: Objectives and Challenges

- Purpose of validation
  - Ensure simulator reproduces real-world AS–CT interactions under different scenarios

- **Test case: UST collapse** (May 2022)
  - Leverages rich data on volumes, prices, supplies

- Key **challenges**

- Complex system dynamics: trader psychology and herd behavior
- Market fragmentation: liquidity spread across multiple pools and exchanges
- Data calibration: careful parameter tuning is required

Validation: Approach

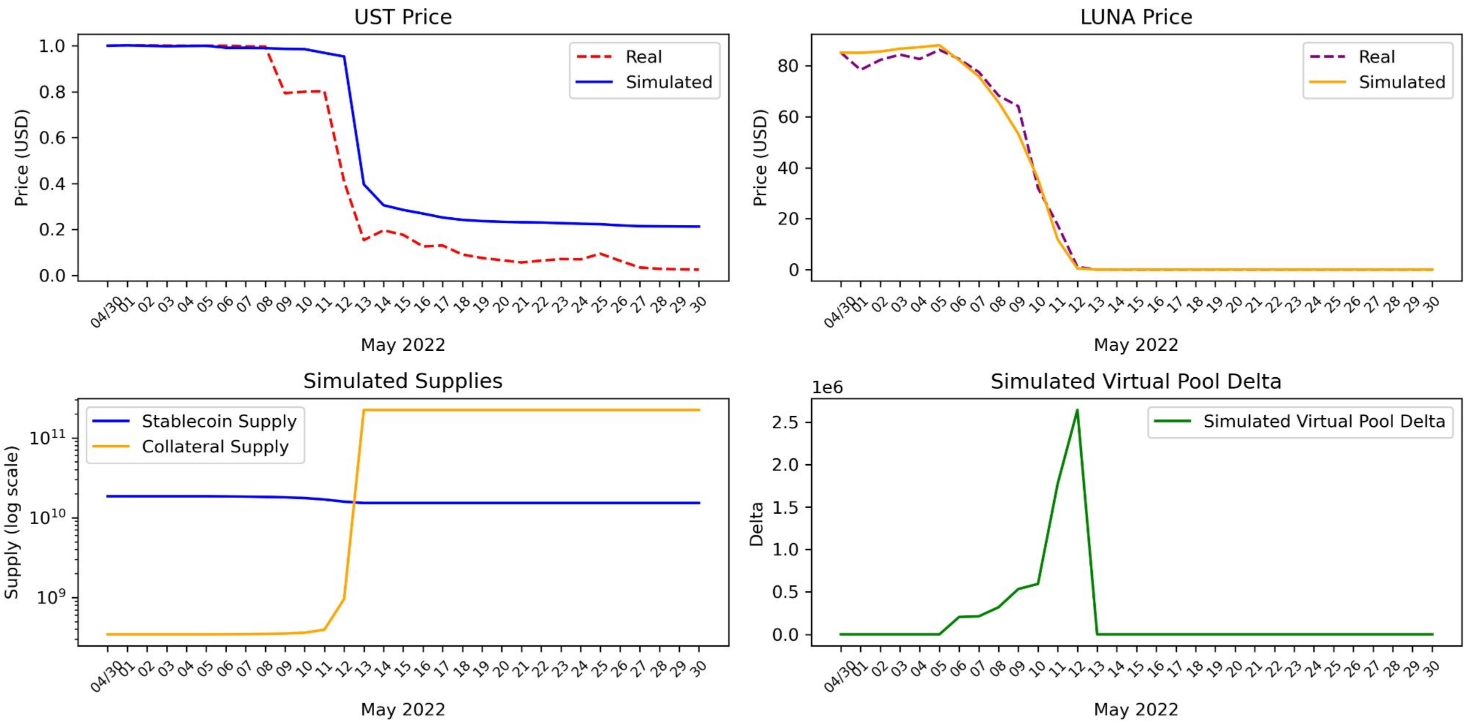
1. **Data Acquisition**
   - Daily trading volumes and circulating supplies for UST/LUNA (May 1–30, 2022)

2. **Parameter Mapping**
   - Calibrate volatility list and initial LP reserves from real data

3. **Simulation Execution**
   - 30-day run at 6 s time steps (14 400 iterations/day)

4. **Results Analysis**
   - Compare simulated prices and supplies vs. actual trajectories

Results (I)


UST Price
Real
Simulated
Price (USD)
May 2022
LUNA Price
Real
Simulated
Price (USD)
May 2022
Simulated Supplies
Stablecoin Supply
Collateral Supply
Supply (log scale)
May 2022
Simulated Virtual Pool Delta
1e6
Simulated Virtual Pool Delta
Delta
May 2022

Results (II)

Prices and supplies at the end of the simulation (May 30)

Token	Sim prices	Real prices	Sim supply	Real supply
UST	$0.2116	$0.0251	15.24×10^9	11.27×10^9
LUNA	$0.0573	$0.000127	2.232×10^{11}	6.536×10^{12}

Future Work and Applications

Future work

- **Model Refinement**: integrate additional market factors and arbitrage behaviors
- **Automated Calibration**: use ML/optimization algorithms for parameter tuning
- **Advanced Stress-Testing**: simulate network congestion, flash crashes, liquidity shocks

Applications

- Test new dual-token AS designs across diverse stress scenarios
- **Evaluate and compare** alternative stabilization mechanisms

Beyond the Peg:

Future Roles and Strategies for Stablecoins

Stablecoins Today and Growth Projections

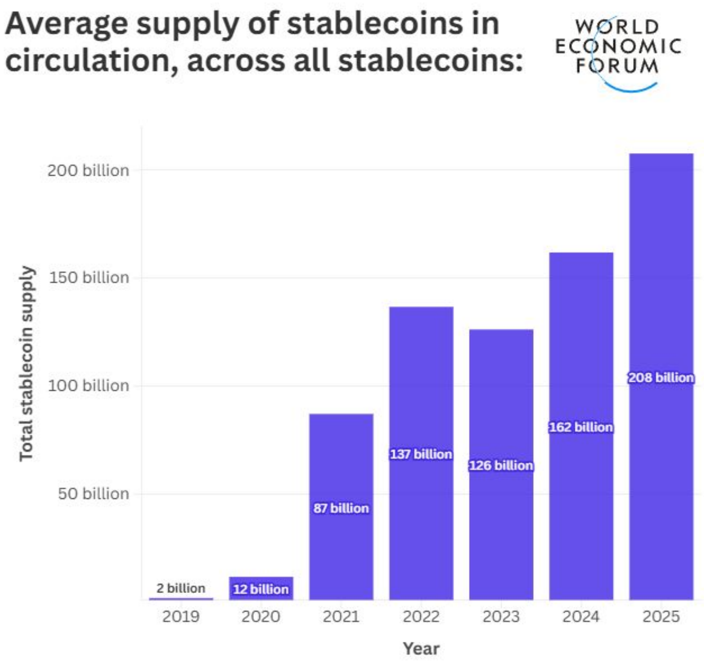
Current market size: **> $240 bn** (March 2025)

Adoption: **+ 28 %** average increase

2030 projections (Citigroup)

- Base-case: **$1.6 trn**
- Upside: $3.7 trn
- Downside (regulatory drag): $0.5 trn

Key growth drivers:
– Institutional adoption
– DeFi and programmable-money use cases
– Cross-border payment



Source: Allium & Visa

Future Roles of Stablecoins

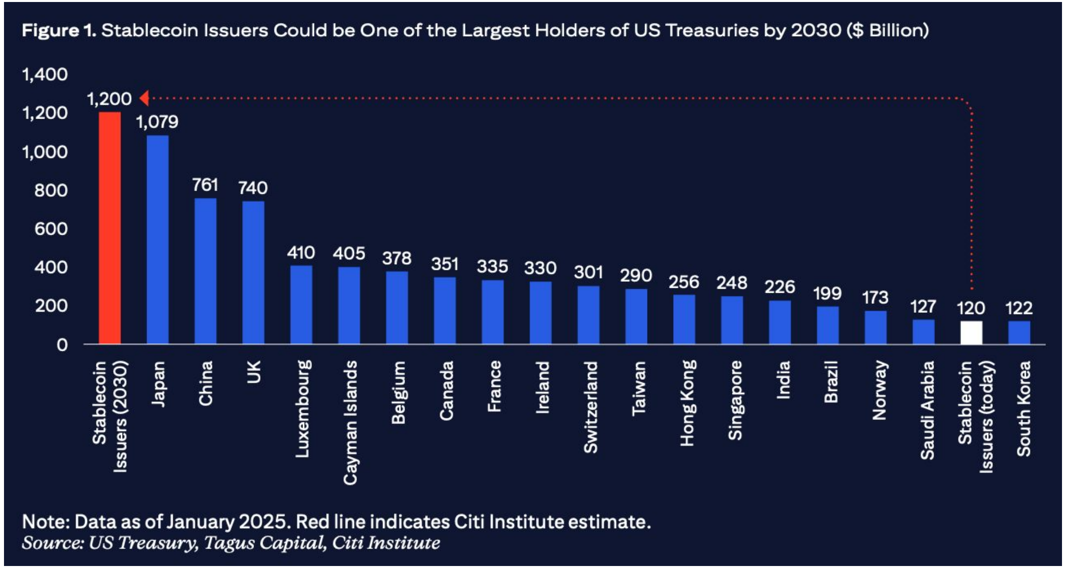
- Global Payments
- DeFi Collateral
- Programmable Money
- Financial Inclusion
- Trade Finance and Supply Chain
- Store of Value / Hedging

Risks and Challenges

- Reserve transparency
- Run risk and liquidity crunch
- Regulatory fragmentation
- Cyber and smart-contract security
- AML/KYC compliance

Stablecoins and U.S. Debt Financing

- Issuer holdings of **Treasuries**: **~$120 bn** today (~0.3 % of $35 trn debt)
- Foreign holders ↓34 %→23 %
- Growth potential: **$500 bn–$1 trn** (2030)



Strategic Implications

- **Dollar Dominance**: Sustain the U.S. dollar's global supremacy
- **Blockchain On-Ramp for Institutions**: Leverage blockchain technology at scale
- **CBDC Interoperability**: Clarify how private stablecoins will coexist and interact with CBDCs