Dynamic Minting and Pegging:

A Novel On-Chain Framework for Issuing and Stabilizing RWA-Backed Stablecoins

Dr. Avtar Sehra

Abstract

Decentralized finance (DeFi) stablecoins have traditionally relied on over-collateralization or algorithmic seigniorage mechanisms to maintain a $1 peg. This paper presents a novel minting and stabilization framework leveraging real-world assets (RWAs), specifically tokenized fixed-income instruments. In this design, the principal component is stripped, discounted, and locked as collateral to back the stablecoin, while the coupon payments are issued as a separate yield-bearing accumulating token. To maintain peg stability for the stablecoin, a dynamic minting interest rate is introduced—rising with the magnitude and optionally the velocity of price deviation—to discourage excess issuance during downward pressure. Complementing this, a burn incentive, also driven by price deviation and optionally its derivative, promotes supply contraction when the stablecoin trades below par. These mechanisms constitute a fully on-chain, self-correcting stabilization system that functions independently of centralized redemptions, arbitrage operations, or external market makers. The underlying dynamic and incentive equations are formulated in a general parametric form, enabling flexible deployment and cost-efficient optimization via protocol governance. This architecture offers a transparent and adaptable foundation for maintaining price stability across diverse market conditions.

1. Stripping Debt Products

When coupons are stripped from a debt product, both the principal (often called the residual) and the individual coupon payments are issued and traded at a discount. The coupons, once separated, become zero-coupon bonds and are priced at a discount, while the principal is also priced at a discount.

All strips, principal and coupons, are discounted based on time to maturity and they share the same credit risk as they originate from the same issuer. However, in practice, the principal strip can often be perceived as riskier for two reasons: (i) as it has the longest duration (paid at the very end), (ii) if default occurs, the principal payment is at most risk since coupons might still be paid before the event.

As a result, when using debt products as reserves for minting stablecoins the ideal product would be a daily dealing period risk free asset, such as money market instruments (MMIs). However, the combined effect of discounting and credit risk can generally be captured as a "haircut" applied to the strips, which enables longer duration and risky debt products to be used as reserves for minting stablecoins. Such a haircut model would also enable a basket of debt products of different durations and risk profiles to be used as reserves.

2. Stripped Principal as Stablecoin Reserves

2.1 Time Discounting

For an asset with maturity T years and a discount rate r, the time discount factor under continuous compounding is given by:

$$D(T) = e^{-rT}$$

This factor converts the par value (value at maturity) to its present value, ignoring credit risk.

2.2 Default Risk

Let PD be the probability of default. The probability that the asset does not default i.e. survives, is given by S:

$$S = 1 - PD$$

If default occurs, we assume for this work the asset pays nothing, or an insignificantly small recovery value, $R \sim 0$.

2.3 Expected Present Value and Haircut

The expected present value, EPV, of a unit strip is:

$$EPV = S\ D(M) = (1 - PD)\ e^{-rT}$$

Where PD can also be written in terms of the credit spread, s, of the debt product, keeping recovery in case of default being $R \sim 0$:

$$1 - PD\ (1 - R) = 1 - PD = e^{-sT}$$

Therefore, EPV can also be written as:

$$EPV = e^{-(r+s)T}$$

The haircut, H, applied to a unit strip can also be written as:

$$H = 1 - EPV = 1 - e^{-(r+s)T} = 1 - (1 - PD)\ e^{-rT}$$

Example:

For $T = 1$ year, $r = 5\%$, and $PD = 10\%$:

$$D(1) = e^{-0.05} \approx 0.9512,$$

$$EPV \approx (1 - 0.1)\, 0.9512 \approx 0.8561,$$

$$h \approx 1 - 0.8561 \approx 0.1439\ (or\ about\ 14.4\%).$$

2.4 Basket of Assets and the Optimal Haircut

When using a basket of debt assets as reserves for minting each asset i may have its own maturity T_i and probability of default PD_i. We assume that each asset has a par value of \$1 and appears in the portfolio with a weight w_i, where$\sum_i w_i = 1$.

For asset i the expected present value is:

$$EPV_i = (1 - PD_i)\ e^{-rT_i}$$

Then the overall expected present value is the weighted sum:

$$EPV_{portfolio} = \sum_i w_i\ (1 - PD_i)\ e^{-rT_i}$$

Accordingly, the average portfolio haircut is defined as:

$$h_{portfolio} = 1 - EPV_{portfolio} = 1 - \sum_i w_i\ (1 - PD_i)\ e^{-rT_i}$$

2.5 Principal and Coupon Stripping Protocol

A user can buy a money market RWA instrument and lock it into an onchain protocol. Then using the above-mentioned coupon stripping mechanism, the principal and coupons can be split and locked into separate pools, where each pool would have its own LP (Liquidity Pool) token. This enables the user to burn the LP token and release the principle and coupon strips and unlock the underlying money market instrument.

While the stripped principal LP tokens can be transferred freely, the stripped coupon LP tokens would only be transferable to addresses that were whitelisted to hold the underlying money market RWA assets i.e. the coupon LP tokens would be treated like securities.

2.6 Stablecoin Backed by Stripped Principals

If we have a pool of striped money market instrument residuals the ownership of this pool can then be divided into tokenized units i.e. the LP tokens of the principal pool. Therefore, we can define a single LP token of this pool as having an EPV of \$1. In this way tokenized money market stripped residuals collected in the pool form the backing of an RWA stablecoin.

The advantage of this model is that the holder of a money market instrument can easily mint a stablecoin in a permissionless manner and use the stablecoin as a medium of exchange. But at the same time, they can retain their yield through controlling the LP token for the coupon residual pool. This structure also enables any yield bearing asset to be used for minting a stablecoin, and the minter is then able to retain and control their accrued returns, but at the same time use a stable standard coin to make payments.

2.7 Positive Price Deviations of the Stablecoin: $P > \$1$

Even though each stablecoin token is backed by \$1 of MMIs (or similar), with an appropriate haircut, the value of the token may deviate from \$1 depending on market depth and supply and demand.

If the token price is greater than a dollar in the market, $P > \$1$, such a deviation can be corrected even in shallow markets as any individual can buy MMIs to mint stablecoins and sell the stablecoin in the market to bring the price down. Such $+ve$ deviation arbitrage opportunities could be quickly closed as the market would be open to any user.

2.8 Negative Price Deviations of the Stablecoin: $P < \$1$

When the stablecoin price falls below its \$1 peg i.e. $P < \$1$, the consequences can become more nuanced and systemically destabilizing. In a steady-state scenario – where the stablecoin is widely adopted, liquid, and listed across centralized and decentralized venues – rational arbitrageurs (especially original minters) can purchase underpriced stablecoins from the market, burn them to unlock their collateralized MMIs, and then sell those MMIs at or near par (\$1), thereby closing the arbitrage loop.

However, this arbitrage mechanism is largely accessible only to those who hold the residual vault LP token, i.e., the original minters. General users without this claim cannot access the underlying collateral, which limits broad-based arbitrage participation and makes the peg recovery path more fragile during market stress.

A particularly dangerous and perverse feedback loop can emerge when users exploit short-term liquidity needs and pricing inefficiencies:

2.9 Looping-Induced Depeg Risk

A particularly dangerous and perverse feedback loop can arise when users exploit a short-term profit opportunity that persists even when the stablecoin is consistently sold below its peg. By repeatedly cycling the position — minting the stablecoin, selling it at a discount, using proceeds to mint more, and eventually repurchasing enough to unlock their collateral — users can earn a net positive yield regardless of market price deviations. This creates a strong incentive to loop the process:

- Each cycle increases stablecoin supply.
- Selling pressure further depresses stablecoin price.
- Lower market price doesn't directly impact short term profits from minting/looping.

This leads to self-reinforcing negative deviations, increasing volatility and the risk of a cascading depeg. The situation becomes more severe in illiquid market conditions, where repeated discounted sales have outsized price impact, and where market makers are unwilling or unable to arbitrage due to lack of LP access, uncertainty, or high transaction costs. An illustrative example of this scenario is as follows:

- User mints stablecoin:
  - Deposits: $100,000 of MMIs into vault
  - Haircut: 10% gives minting capacity of $90,000 stablecoin
  - Sells stablecoin below market price: $0.95, receiving $85,500
  - Cash outlay: $14,500
- User unwinds position:
  - Buys $90,000 stablecoin in the market at $1
  - Unlocks $100,000 MMIs and sells in the market
  - Haircut: $10,000 (at 10%) *minus* fees returned
  - Receives interest earned on locked deposit: $5,000 annualized (5%)
  - Cash received: $15,000
  - Net Profit: $500

Even though the stablecoin is sold at a discount, the total returns (including interest) exceed the user's net outlay. This structural profit opportunity, if unaddressed, can cause a breakdown in peg stability.

The rest of this work provides an overview of an automated onchain pegging mechanism that incentivizes the appropriate behaviors for the stablecoin peg to be maintained when price of the stablecoin deviates from $1.

3. Pegging Mechanism Basics

3.1 Setup of the Problem and Solution

Let the market price of the stablecoin at time t be $P(t)$, and define the price deviation from the peg as:

$$x(t) = P(t) - 1$$

Where:

- $x(t) = +0.05 \ means \ P(t) = \$1.05$ (positive deviation),
- $x(t) = -0.05 \ meansP(t) = \$0.95$ (negative deviation).

The deviation $x(t)$ is the core signal around which minting incentives and corrective mechanisms will be established.

In the absence of an immediate redemption mechanism with the issuer:

- When $x(t) < 0$: Users can buy stablecoin below $1, but cannot easily redeem it for $1 of collateral, unless they own the coupon LP token, making arbitrage difficult. This weakens the correction for negative deviations.
- When $x(t) > 0$: Users are strongly incentivized to mint, since any user can issue a stablecoin at par ($1) and sell above ($\$P(t) > 1\$$), which increases supply and pushes the price back toward the peg.

This creates an asymmetry:

- Undersupply ($x > 0$): Easy to correct (users mint and sell).
- Oversupply ($x < 0$): Hard to correct (users can't easily redeem).

Thus, persistent negative deviations are the greater systemic risk — especially in looping dynamics — as shown earlier.

3.2 Proposed Peg-Stabilization via Minting Interest Rate and Burn Incentive

To mitigate depeg risks — particularly when the stablecoin trades below the peg ($x(t) < 0$) — we introduce a minting interest rate, r, which acts as a cost incurred by users when minting new stablecoins. This interest rate is designed to dynamically respond to both the magnitude and the momentum of price deviations from the peg, providing a self-regulating mechanism for supply expansion and contraction.

The interest rate r can be modeled as a function of deviation and its velocity:

$$r = r(x, \dot{x})$$

Where

$x(t) = P(t) - 1$ is the deviation from the $1 peg,

$\dot{x} = \frac{dx}{dt}$ captures the speed of deviation i.e. how fast the price is moving away from the peg.

3.2.1 Oversupply Regime ($x(t) < 0$)

When the stablecoin trades below peg:

- Users are disincentivized to mint further.
- The minting rate $r(x, \dot{x})$ increases as:
    - The deviation $|x|$ becomes larger,
    - The rate of downward movement $\dot{x} < 0$ accelerates.

- This makes minting increasingly costly, dampening excess supply.
- As well as increase rate for minting, the rate should also provide burn incentive.

A burn incentive $b = b(r(x, \dot{x}))$ will be used to incentivize users to burn supply.

- While the minting rate discourages new issuance, it does not directly reduce existing supply.
- To address this, the same interest rate function $r(x, \dot{x})$ can be repurposed as a burn incentive, b, — for example, by reducing burn fees or haircut penalties when users burn stablecoins.
- This incentive should increase as the negative deviation grows, i.e., the further below peg the price falls, the greater the reward for burning.
- This aligns incentives to reduce circulating supply and accelerates peg recovery during depeg events.

Formally:

$\frac{\partial r}{\partial x}$>0 $\frac{\partial r}{\partial \dot{x}}$>0, $\frac{\partial b}{\partial r}$<0 for $x < 0$

3.2.2 Undersupply Regime ($x(t) > 0$)

When the stablecoin trades above peg:

- Users should be incentivized to mint to bring price down.
- The interest rate r can be reduced as x increases which makes minting cheaper when the stablecoin is scarce and expensive.
- In some cases, r may become negative i.e., a minting rebate, effectively reducing or offsetting fees like haircuts to encourage issuance.
- Market dynamics already favor minting to overcome undersupply so increased velocity sensitivity to deviation may not be necessary.

Formally:

$\frac{\partial r}{\partial x}$<0, $\frac{\partial b}{\partial r}$>0 for $x < 0$

By embedding the interest rate function directly into both the minting and burning processes, the mechanism symmetrically addresses deviations on both sides of the peg. This creates a self-contained and responsive stabilizing system that dynamically adjusts supply incentives and disincentives, without relying on external redemption or arbitrage mechanisms.

4. Stablecoin and Pegging Model Setup

4.1 Key Features in Stablecoin Charts and Their Implications

The chart in Figures 1a and 1b show that the price deviations of USDC and USDT from their \$1 peg are not well described by simple random walk behavior or linear mean-reversion, as might be modeled by a basic Ornstein–Uhlenbeck (OU) process. Instead, the observed dynamics are oscillatory, nonlinear, and occasionally disrupted by sharp negative shocks. These characteristics point to a more realistic and flexible modeling framework: a second-order stochastic differential equation (SDE) augmented with a shock term. This class of models better captures the momentum-driven dynamics, delayed responses, and impact of rare but severe market events.

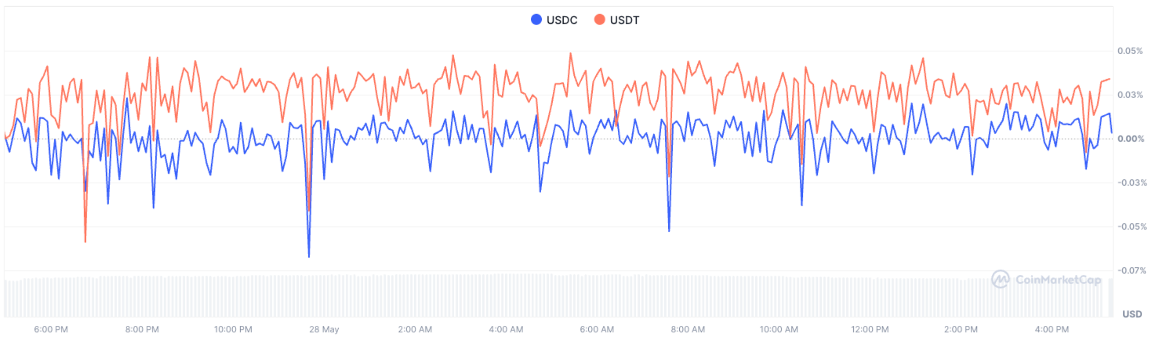


Figure. 1a: Timeseries of USDC and USDT over a 24 hour period.

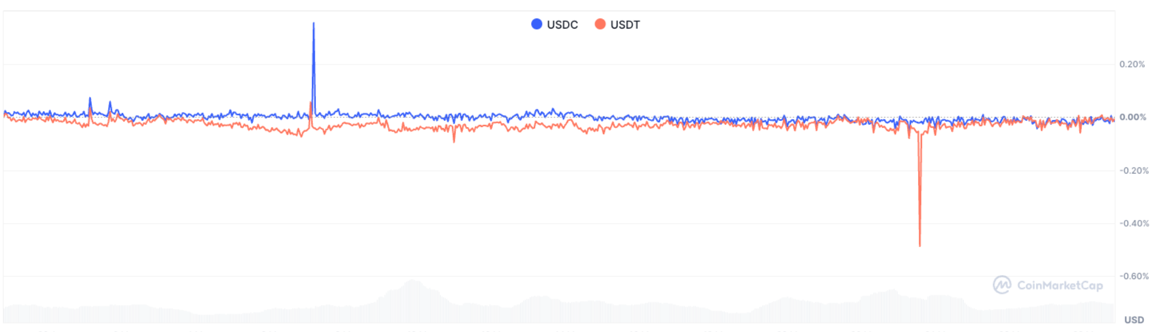


Figure. 1b: Timeseries of USDC and USDT over a one-month period.

4.1.1 Oscillations and Noise

The price trajectories of both USDC and USDT exhibit quasi-periodic oscillations around the peg, overlaid with stochastic noise. These oscillations are not purely random—they display structure and inertia, indicating that the system exhibits delayed corrective behavior rather than immediate mean-reversion. This behavior is incompatible with first-order systems (like OU), which assume a memoryless, frictionless path back to equilibrium. In contrast, second-order systems incorporate momentum (through second derivatives) and capture oscillatory trajectories, for example via the characteristic equation of underdamped dynamics:

$$\ddot{x}(t) + \gamma \cdot \dot{x}(t) + \kappa \cdot x(t) = noise$$

Where $x(t)$ is the deviation from the peg, where γ is the damping coefficient, and κ is the restoring force.

$$noise = \sigma \cdot \xi(t)$$

Where $\xi(t)$ is Gaussian white noise and σ is the volatility factor that scales the noise

4.1.2 Overshoot and Undershoot

In practice, stablecoins often overshoot the peg after an initial deviation and then return from the other side—a hallmark of an underdamped second-order system. This dynamic reflects lag in correction mechanisms (e.g., arbitrage latency, protocol reaction delay) and suggests the system has internal memory and inertia. The presence of these cycles directly contradicts the behavior expected in first-order models, which lack such overshooting by construction.

4.1.3 Nonlinearity

The amplitude and damping of the oscillations in the chart are not constant, suggesting nonlinear system dynamics. In particular:

- The restoring force (e.g., burn/mint incentive) likely increases nonlinearly with deviation magnitude.
- The damping may also vary with the speed of price change or available liquidity.

These effects imply that the SDE coefficients—restoration and damping—must be state-dependent functions, such as:

$$\ddot{x}(t) + \gamma \cdot (x, \dot{x}) \cdot \dot{x}(t) + \kappa(x) \cdot x(t) = \sigma \cdot \xi(t)$$

where $\gamma(x, \dot{x})$ and $\kappa(x)$ capture nonlinear damping and recovery incentives respectively. This structure aligns with real-world stablecoin models that apply stronger burn or mint incentives as the deviation increases, or that respond differently depending on whether the coin is above or below the peg.

4.1.4 Sudden Negative Shocks

Occasional sharp price drops (negative spikes) are visible for both USDC and USDT. These are not easily explained by endogenous dynamics alone i.e. they cannot be derived from the system's internal feedback rules. Rather, they point to exogenous shocks such as:

- Large liquidations
- Market-wide panic events
- Loss of confidence in a stablecoin issuer
- Sudden withdrawal of liquidity

To model these events realistically, one must extend the SDE with a jump or shock term, typically represented as:

$$J(t) = \sum_i \Delta_i \cdot \delta(t - t_i)$$

Where Δ_i are the shock magnitudes and t_i the times at which they occur. These shocks can be modeled as a compound Poisson process or embedded in a jump-diffusion framework, depending on the frequency and statistical structure of the events.

4.2 Second Order Non-linear Ornstein–Uhlenbeck Equation

The combined characteristics of oscillatory behavior, overshoot, nonlinear corrections, and discrete external shocks makes a strong case for modeling stablecoin deviations and the pegging mechanisms using a second-order nonlinear Orsetein-Ulhenbeck SDE with an exogenous jump term. As described previously, this approach better aligns with observed behaviors and provides a robust framework for simulating and designing stabilization mechanisms for a stablecoin.

Such a second order model would be an extension of the standard Ornstein-Uhlenbeck, equation:

$$dx(t) = -\kappa \cdot (\mu - x(t))\, dt + \sigma \cdot \xi(t)$$

Where μ is the long term mean and can be set to zero for our case of zero deviation from the peg. The second order form of this can be written as a system of two coupled SDE, and by adding the damping and the shocks terms we have a type of Mixed Orstein-Uhelenbeck (MOU) process:

$$dx(t) = \mathrm{V}(t)\, dt$$

$$dV(t) = -\gamma \cdot V(t) - \kappa \cdot x(t)\, dt + \sigma \cdot \xi(t) \ + \mathit{\Delta}_i \cdot \delta(t - t_i)$$

In essence, the second-order Ornstein-Uhlenbeck process with the damping and shocks offers a more nuanced and flexible way to model a stochastic system that exhibit mean reversion and more complex local dynamics than the first-order OU process can provide. The Langevin equation form of the MOU process provides the most intuitive form of the model, which also provides insights into market characteristics and the pegging mechanism underpinning stablecoin behavior:

$$\ddot{x}(t) = -\gamma(x, \dot{x}) \cdot \dot{x}(t) - \kappa(x) \cdot x(t)\, dt + \sigma \cdot \xi(t) \ + \sum_i \mathit{\Delta}_i \cdot \delta(t - t_i)$$

This second order Langevin equation enables:

- Random noise with mean-reverting (OU-like) behavior — pulling deviations back to the peg, and
- Second-order inertial dynamics — accounting for momentum, overshooting, and oscillations, and

- Nonlinear damping and random shock terms.

This creates a more realistic model for pegged assets like stablecoins, especially when deviations show inertia and shocks as seen in the chart of USDC and USDT.

5. Stablecoin Price Deviation Framework and Simulation

5.1 Simple Harmonic Oscillator Framework

Using the general Langevin form of the model we can consider deviations of a stablecoin's market price from its peg as a second-order stochastic system akin to a damped harmonic oscillator SHO with both continuous gaussian noise and discrete external shocks. This SHO framework provide a simple mental model on how to think about the complex dynamics observed in stablecoin markets, and what an appropriate pegging mechanism would entail:

- **Stablecoin Peg = Equilibrium**:
  - The peg, or zero deviation (e.g. $x(t) = P(t) - 1 = 0$), is the equilibrium position of the SHO.
- **Deviation from Peg = Displacement from Equilibrium:**
  - A movement in the stablecoin's price away from the peg is analogous to displacing the SHO from rest.
  - This displacement sets off a corrective process — a dynamic push to return to equilibrium.
- **Arbitrage & Market Incentives = Nonlinear Restoring Force:**
  - Market forces, especially arbitrage incentives and protocol-based corrections (e.g., buybacks, redemption mechanisms), act like the restoring spring force in a harmonic oscillator:
  - $F_{restoring} = -\kappa(x) \cdot x(t)$
  - This force grows as the deviation increases, and its magnitude and structure can be tuned via an automated policy that is a function of deviation e.g. burn incentives.
- **Minting Interest Rate = Nonlinear Damping:**
  - Protocol-level controls, particularly interest rate adjustments and supply incentives, function as nonlinear damping and restoring mechanisms.
  - These dynamically respond to both the direction and magnitude of price deviation
  - When price falls below the peg, a higher minting fee discourages further expansion of supply.
  - This slows the downward momentum, analogous to damping increasing with speed or direction:
  - $F_{damping} = -\gamma(x, \dot{x}) \cdot \dot{x}(t)$
- **Gaussian Market Noise = Stochastic Force:**

- Day-to-day fluctuations due to liquidity changes, order book dynamics, and random trades introduce white noise into the system. This is modeled via the stochastic forcing term:
- $F_{noise} = \sigma \cdot \xi(t)$
- This component drives minor perturbations even when the system is near equilibrium.

- **Exogenous Market Shocks = Discrete Impulse Forces:**
  - Sudden, large-scale deviations (e.g., redemptions, regulatory actions, liquidity collapses) correspond to impulse forces in the SHO system:
  - $F_{impulse} = \sum_i \Delta_i \cdot \delta(t - t_i)$
  - These are discontinuous inputs that cannot be explained by endogenous dynamics and must be explicitly modeled as shock terms.

5.2 Generalized Governing Equation within the SHO Framework

5.2.1 Generalized Governing Equation

A general form of the governing equation for the price deviation $x(t) = P(t) - 1$ is given by the following equation:

$$\ddot{x}(t) + \left[c_0 + c_1\left(e^{c_2|x(t)|} - c_3\right) + c_4 \cdot x(t)\right] \cdot \dot{x}(t) + (a_0 + a_1 \cdot x(t)) \cdot x(t) = \sigma \cdot \xi(t) + \sum_i \Delta_i \cdot \delta(t - t_i)$$

Where:

- $\ddot{x}(t)$: acceleration of peg (second derivative of deviation)
- $\dot{x}(t)$: velocity of peg (rate of change of deviation)
- $\xi(t)$: Gaussian white noise
- $\delta(t - t_i)$: Dirac delta function at discrete shock times
- c_0, c_1, c_2, c_3, c_4: Damping coefficients to generalize the nonlinear damping term
- a_0, a_1: Restoring coefficients to generalize the nonlinear restoring term

5.2.2 Minting Interest Rate $r_{\text{mint}}(x, \dot{x})$

Using the generalized damping term and a contribution from the restoring force, we can formulate a Minting Interest Rate, $\boldsymbol{r_{\mathbf{mint}}(x, \dot{x})}$, which would penalize or incentivise minting depending on the deviation from the peg:

$$r_{\text{mint}}(x,\dot{x}) = \begin{cases} r_0 + (\lambda_d \cdot D(x,\dot{x}) + \lambda_r \cdot R(x)), & x < 0 \\ r_0 - (\lambda_d \cdot D(x,\dot{x}) + \lambda_r \cdot R(x)), & x > 0 \\ 0, & x = 0 \end{cases}$$

Where:

r_0, is the base interest rate for minting when price is close to the peg; and

$$D(x,\dot{x}) = \left[c_0 + c_1\left(e^{c_2|x|} - c_3\right) + c_4 x\right] \cdot |\dot{x}|$$

is the contribution to the minting rate from the velocity (rate of change) of deviation; and

$$R(x) = a_0 \cdot |x|$$

is the contribution to the minting rate from the restoring force and is related to deviation only. Finally, the λ_d, λ_r are scaling parameters to align the damping and restoring forces to be calibrated to an appropriate interest rate.

This minting rate would drive the following behavior:

Deviation	**Rate Direction**	**Behavior**
$x < 0$	Positive	Interest rate increase slowly near the peg and strongly further away, thus discourages minting below peg
$x > 0$	Negative	Interest rate decreases above the peg, slowly close to the peg and then moves faster to the minimum further above the peg
$x = 0$	Zero	Neutral (at peg)

5.2.3 Burning Incentive Rate $\boldsymbol{r_{\mathbf{burn}}(x)}$

Using the generalized restoring term we can formulate a burning incentive rate, $\boldsymbol{r_{burn}(x)}$, which would reward burning supply i.e. this incentive could be returned to the user from the haircut and other fees to encourage minters to burn their holding and make a higher return. This burn incentive would need to be a gentle rewarding mechanism that does not result in aggressive overshoot, as such having a simple linear dependence on deviation would be sufficient.

$$r_{\text{burn}}(x) = \begin{cases} \beta \cdot a_1 \cdot x^2, & x < 0 \\ 0, & x \geq 0 \end{cases}$$

Where $(a_1 \cdot x) \cdot x$ is the restoring force contribution to the burn incentive and the β is the scaling factor to calibrate the rate to align with appropriate levels.

Deviation	**Rate Direction**	**Behavior**
$x < 0$	Positive	Interest rate incentive will increase linearly as peg deviates below zero, which will increase incentive rate rebate paid back to minter to burn stablecoins.
$x \geq 0$	Zero	Interest rate incentive will be zero, so users wont be provided with an incentive not to burn, and deviations in the positive direction will just be managed through the natural arbitrage incentive provided through the restoring force i.e. lower minting rate above.

5.3 Simulation Configuration

Parameter	**Value**
Damping Coefficients c_0, c_1, c_2, c_3, c_4	$c_0 = 20, c_1 = 15, c_2 = 1, c_3 = 1, c_4 = 10$ c_2 and c_3 are set to 1 to ensure that the interest rate does not change too much for small deviations
Restoring Force a_0	30
Burn Coefficient a_1	0.5
Damping contribution scaling weight λ_d	$\lambda_d = 0.01$:
Restoring contribution scaling weight λ_r	$\lambda_r = 0.005$
Burn Incentive Scaling weight β	$\beta = 0.2$
Noise Magnitude σ	0.10
Shock Magnitude Δ_i	-5
Shock Times t_i	5 random times between 1 and 59 units
Initial Conditions	$x(0) = 0, \ \dot{x}(0) = 0$
Simulation Duration	60 units

Time Step	0.01 (6000 over 60 units)
ODE Solver	RK45 (Runge-Kutta method)

6. Generalized Equation Simulation

6.1 Results

Figure 2 below shows the simulation results for the stablecoin price deviations, and the resulting Minting Rate and Burn Incentive Rate.

- The **minting interest rate** dynamically adjusts to penalize or incentivize new issuance based on deviation and volatility.
- The **burn incentive rate** increases linearly with negative deviation to encourage supply contraction.
- Combined, these rates provide an **algorithmic policy** to help maintain peg stability.

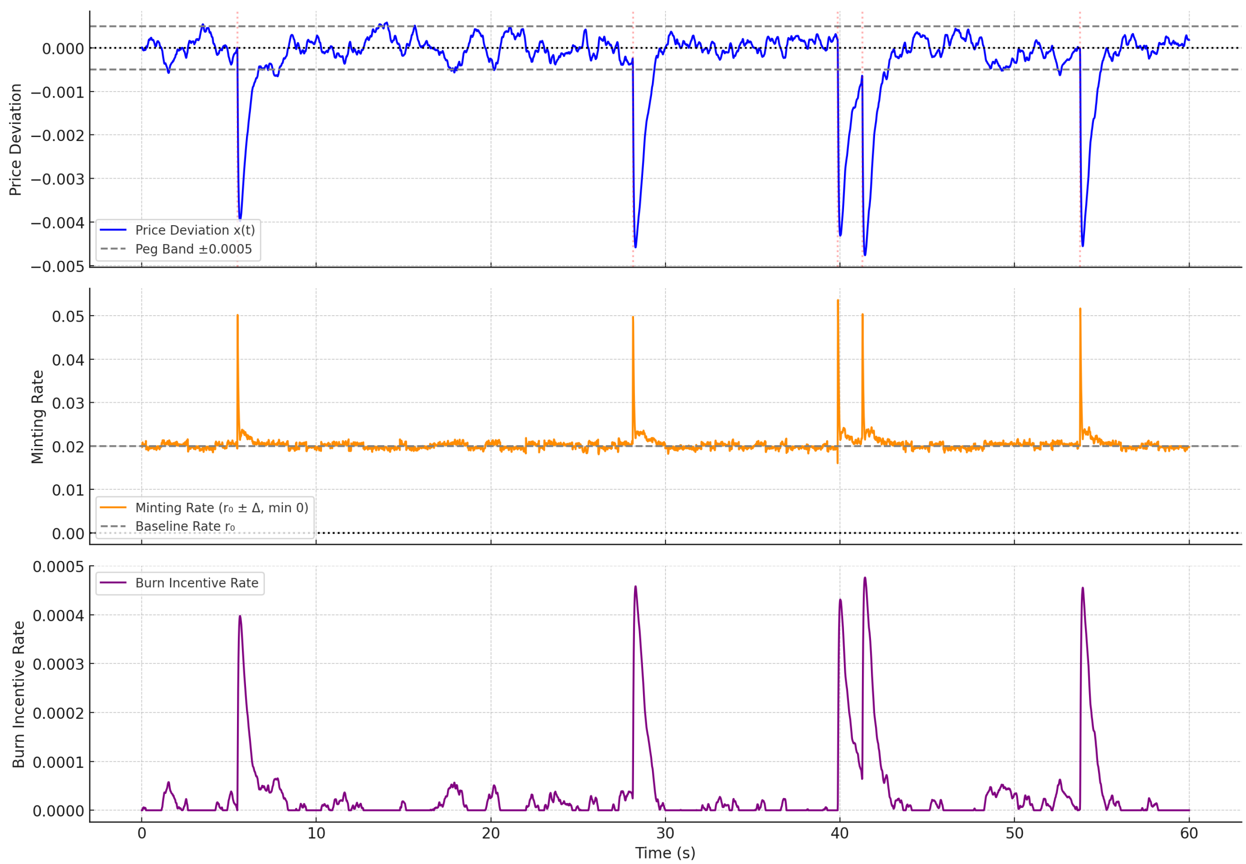


Figure. 2: Simulation results for peg deviation, minting rate and burn incentive.

7. Simplified Equation Simulation

In an initial iteration of the pegging mechanism, we can create a simplified model for the minting and burning rates. This ensures the stablecoin can be launched and early behavior assessed and monitored in the simplified case, before adjusting model and calibrating the more generalized version using market feedback.

7.1 Simplified Nonlinear Model Overview

1. **Deviation**

$$x(t) = P(t) - 1.$$

2. **Minting Rate**

$$r_{\text{mint}}(x) = \begin{cases} r_0 + k\,|x|^p, & x < 0, \\ r_0 - k\,|x|^p, & x \geq 0. \end{cases}$$

3. **Burn Incentive Rate**

$$r_{\text{burn}}(x) = \begin{cases} b\,|x|^q, & x < 0, \\ 0, & x \geq 0. \end{cases}$$

7.2 Simplified Simulation Equations and Parameters

We simulate a continuous, nonlinear pegging policy with:

- **Deviation** $x(t) = P(t) - 1$ driven by noise ($\sigma = 3\%$) plus four random -20% shocks.
- **Minting rate**: $r_{\text{mint}}(x) = \begin{cases} r_0 + k\,|x|^2, & x < 0, \\ r_0 - k\,|x|^2, & x \geq 0, \end{cases}$ $[r_{\min}, r_{\max}] = [0.25\%, 50\%]$.
- **Burn incentive**: $r_{\text{burn}}(x) = \begin{cases} b\,|x|^2, & x < 0, \\ 0, & x \geq 0, \end{cases}$ o $[r_{\min}, r_{\max}] = [0\%, 50\%]$.

Parameter	Value	Description
T	200 steps	Total simulation length
σ_x	0.03	Deviation volatility (3 %)
#shocks	4	Number of -20 % shocks
shock_mag	0.20	Shock magnitude (20 %)
r_0	0.01 (1 %)	Base mint rate
k	5.0	Mint sensitivity
p	2	Mint exponent (convexity)
$[r_{\min}, r_{\max}]$	[0.0025, 0.5]	Mint rate bounds (0.25 %–50 %)

b	2.0	Burn sensitivity
q	2	Burn exponent
$r_{burn,max}$	0.50	Burn rate cap (50 %)

7.3 Worked Examples

- **At a deep negative shock** $x = -0.20$:

  $r_{\text{mint}} = 1\% + 5 \cdot (0.20)^2 = 1\% + 5 \cdot 0.04 = 1\% + 0.20 = 21\%$ (clamped to 50 %).

  $r_{\text{burn}} = 2 \cdot (0.20)^2 = 2 \cdot 0.04 = 8\%.$

- **At a small positive deviation** $x = 0.02$:

  $r_{\text{mint}} = 1\% - 5 \cdot (0.02)^2 = 1\% - 5 \cdot 0.0004 = 0.998\%$ (≈1 %, floored at 0.25 %).

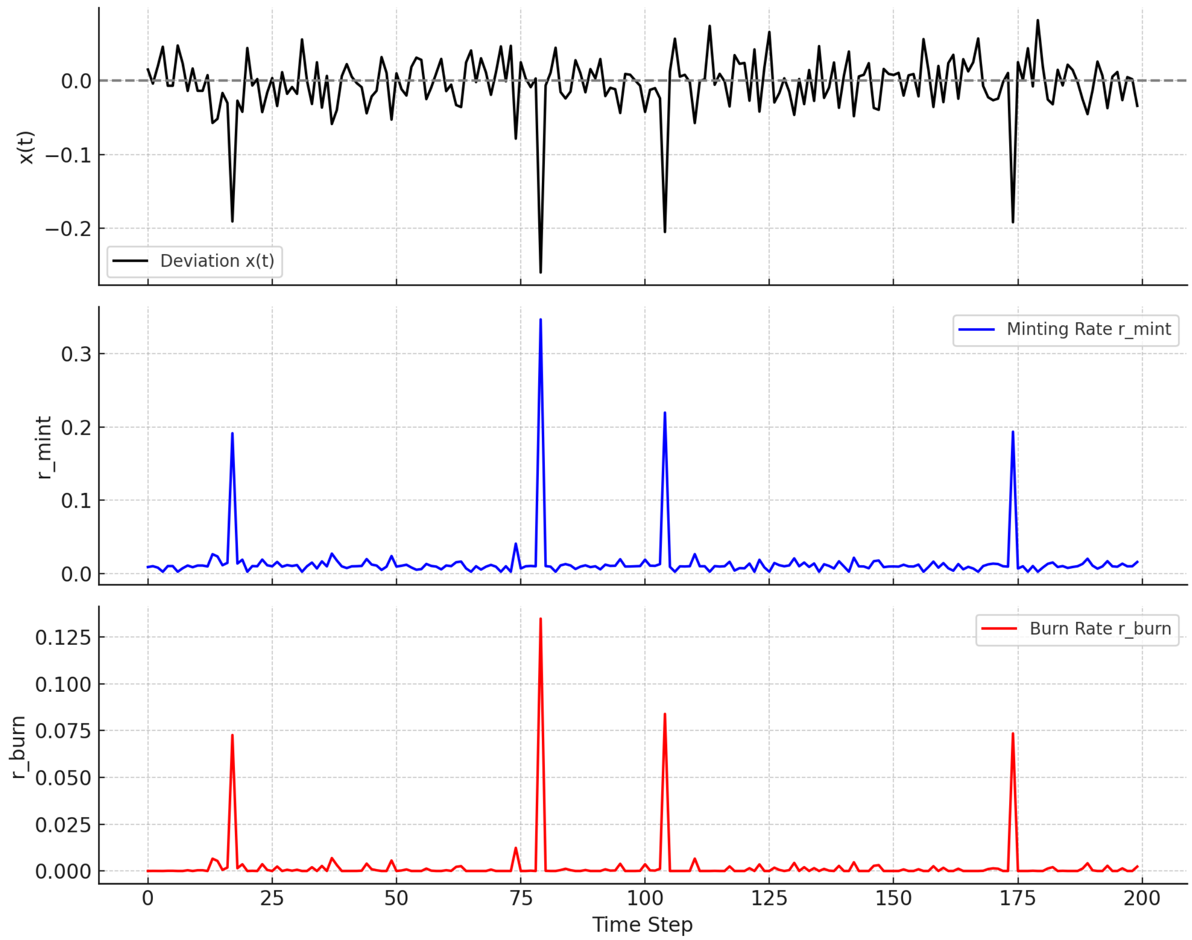
  $r_{\text{burn}} = 0\%.$

7.4 Comparison to Perpetual Funding

Feature	Perpetual Swap	This Peg Model
Deviation	$P_{perp} - P_{spot}$	$P - 1 = x$
Rate Adjustment	$F = \kappa\left(P_{perp} - P_{spot}\right)$	$r_{mint} = r_0 - k\|x\|^2$ / $r_0 + k\,\|x\|^2$
Flat Dead Zone	None (linear across x)	Yes ($\frac{d}{dx}x^2\|_{x=0} = 0$)
Additional Incentive	Single funding flow	Separate burn rebate lever r_{burn}

7.5 Simulation Charts

1. **Deviation** $x(t)$: random noise + four −20 % shocks.
2. **Minting Rate** $r_{\text{mint}}(t)$: flat near zero, spikes on large drops.
3. **Burn Rate** $r_{\text{burn}}(t)$: non-zero only for $x < 0$, convex response.



7.6 Further Work

The generalized and simplified simulations were conducted as a proof-of-concept using a carefully selected set of parameters that qualitatively reproduced the desired market characteristics—namely, bounded oscillations around the peg, controlled responses to shocks, and convergence back to equilibrium. These parameters were chosen based on theoretical expectations and numerical experimentation, rather than empirical calibration. While the results demonstrate the feasibility of the proposed mechanism and highlight its potential stability under baseline conditions, this preliminary setup remains illustrative rather than prescriptive.

While the generalized model provides much finer control for minting and burning rates in response to deviations compared to the simplified mode, the differences are not significant. So in the early launch phase to minimize complexity, where volume will be lower, and likely lower market volatility, the simplified model would be suitable.

To transition from conceptual demonstration to practical deployment, a robust calibration framework is necessary. This would involve estimating the key parameters—such as damping coefficients, restoring force multipliers, and scaling weights—using historical stablecoin price data and observed liquidity conditions across multiple venues. This would also help provide better comparison between the generalized and simplified versions.

Moreover, extensive robustness testing should be performed to assess system performance under adverse or extreme conditions. This includes:

- Simulating large, clustered redemption events or liquidation cascades,
- Stress-testing under illiquid markets or sudden withdrawal of market makers,
- Testing asymmetric shocks that persist over extended periods,
- Incorporating agent-based behavior to capture heterogeneity in arbitrage access, transaction costs, or latency.

Such extended analysis would not only validate the effectiveness of the dynamic minting and burn mechanism under stress, but also inform the safe operational bounds and contingency measures for real-world protocol implementation.

8. Summary

This work introduces a novel, principled, and dynamically adaptive mechanism for maintaining the peg of stablecoins that are minted and burned directly on-chain using real-world asset (RWA) collateral—specifically through the use of stripped principal components of money market instruments as stablecoin backing.

By structurally decoupling yield from principal and applying a calibrated discount and fee haircut to reflect time and credit risk, the system defines a stable residual value used as collateral for minting. On top of this collateral model, a mathematically grounded pegging framework is introduced to manage both incentive structures and stochastic price behavior, ensuring that the stablecoin remains anchored at its $1 target.

At the core lies a second-order nonlinear stochastic differential equation (SDE) model that captures mean-reversion dynamics, momentum effects, oscillatory behavior, and the impact of exogenous market shocks. The model's parameters are tightly coupled to two protocol-level policy levers—the minting interest rate and the burn incentive rate—which adjust endogenously based on both the magnitude and velocity of price deviations from the peg. The dynamics are further grounded in an intuitive physical analogy: the system behaves like a damped simple harmonic oscillator subjected to stochastic and impulsive forces, where restoring forces and damping terms correspond to supply-side incentives that drive peg stabilization.

Specifically, the minting interest rate increases when the price drops below the peg, discouraging new issuance during oversupply regimes. Concurrently, the burn incentive rate rises linearly with negative deviation, rewarding users for reducing circulating supply.

Together, these two mechanisms generate dynamic damping and restoring forces that stabilize the system across a range of market conditions.

Simulation results validate the model's effectiveness in absorbing volatility, countering destabilizing behaviors such as looping-induced depegs, and reestablishing equilibrium even under stochastic shocks. This design advances the frontier of decentralized monetary policy by providing a fully on-chain, algorithmic, and incentive-compatible stablecoin architecture.

Future work may focus on refining the generalized model, calibrating parameters using empirical market data, and extending simulations to include agent-based models for more realistic arbitrage dynamics. Nevertheless, the current formulation establishes a robust foundation for building stablecoins that are both financially sound and mathematically resilient.

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