Nebula: A Digital Currency with a Dynamic Stability Mechanism

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The Cryptocurrency Landscape

- Still volatile – Although lowest on record, the realized historical volatility for Bitcoin (the bellwether asset in this class) span the 40% to 55% range to H1 2024. See Glassnode (2024).
- Marked price fluctuations continue to hinder the widespread adoption of cryptocurrencies.
- Existing stablecoins are technically vulnerable to depegging events. See Lyons (2020).
- Plus regulatory challenges steadily coming into the mix (e.g., EU MiCA framework). See EU Commission (2022).

Has Bitcoin Failed its Core Objective?
The Hook

Let's focus on two sentences from the onset of Satoshi Nakamoto's Bitcoin whitepaper (2008; underlined for emphasis).

- *Commerce on the Internet has come to rely almost exclusively on financial institutions serving as trusted third parties to process electronic payments.*
- *What is needed is an electronic payment system [electronic cash] based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party* (electronic cash is the subject matter of the paper itself).

Clearly, Satoshi's vision was to create a disintermediated payment system for commerce on the Internet foreseeing an increasingly digital world where such a system would become essential.

How would that payment system work? By using electronic cash as a means of payment within a P2P (trustless) network.

Has Bitcoin Failed its Core Objective? The Line and Sinker

Today, 15 years later, can we say that Satoshi's objective been met?

To factually answer this question, let's dive into the data from the *2023 Survey and Diary of Consumer Payment Choice* conducted by the Atlanta Fed in the US.[1]

Some key findings from this survey:

- Ownership of cryptocurrencies → only 7.3% of respondents.[2]
- Median value of cryptocurrencies owned (self-reported figure) → a mere USD 360.
- Use of cryptocurrency as means of payment (for goods, services, bills, gifts) → just by 0.4% (or equivalently by 5.7% of those who own cryptocurrencies).

The veredict? Bitcoin, and cryptocurrencies at large, have indeed failed to fulfill Satoshi's original intention.

[1] Answers were collected from 4579 respondents. See Foster, Greene & Stavins (2024) available online at https://tinyurl.com/3yaa3enf. Why choosing this survey? Firstly, it's an authoritative source. Secondly, the US is a significant crypto market (fourth for overall crypto adoption in 2023, according to Chainalysis). Finally, the survey showcases the usage of multiple payment means in a highly developed economy, rather than an edge case.

[2] Other sources estimate this number to be between 15% to 18% by the end of 2023; see, e.g. https://tinyurl.com/3eaub9u6.

Nebula – A Digital Currency for the Current Age and Beyond

What is Nebula? Nebula is a stabilized digital currency designed to maintain its price within a dynamic corridor, balancing stability with market responsiveness.

Key features:

- Multi-regime market modeling and monitoring.
- Secondary instrument for enhanced price control.
- Sophisticated, algorithm-driven intervention mechanism.
- Adaptable, asymmetric response to market shocks.
- Fractional Brownian motion to capture long-range dependence.

While Nebula's design presents unique challenges compared to Bitcoin and other cryptocurrencies, it more closely resembles real-world market interventions by monetary authorities. However, Nebula's interventions are entirely algorithmic (automatic and coded) rather than discretionary, ensuring transparency and predictability.

Key Contributions to the Crypto Ecosystem

- Solid theoretical foundation – The design is anchored on a rigorous mathematical formulation, including the proof for the existence and uniqueness of solutions (providing a strong theoretical basis).
- Adaptive stability mechanism – The non-linear intervention function, responsive to both Nebula's price movements and the secondary instrument (a unique stabilizing asset), offers a nuanced approach to maintaining price stability.
- Market microstructure integration – Nebula's model incorporates elements such as transaction costs, network effects, and market depth, to achieve a realistic representation of cryptocurrency dynamics.
- Enhanced usability – By mitigating extreme price volatility while allowing for gradual value changes, Nebula is ideally positioned to serve as both a medium of exchange and a store of value, possibly to be ultimately taken as a unit of account.
- A beacon of market stability – Unlike fixed-peg stablecoins or highly volatile cryptocurrencies, Nebula's adaptive nature could contribute to overall cryptocurrency market stability through its dynamic price corridor, potentially addressing regulatory concerns.

Nebula – Bridging Theory and Practice for Next-Generation Cryptocurrency Design

Comparing Stablecoins to Nebula

Stablecoin	Nebula (Stabilized Coin)
Aims to maintain a fixed value relative to a specified asset or a basket of assets $\rightarrow$ **pegged**	Allows for controlled price fluctuations within a pre-defined corridor $\rightarrow$ **not pegged**
Vulnerable to depegging as a consequence of market shocks or speculative attacks	Designed to be much more resilient to market shocks and speculative attacks
Subject to specific oversight (e.g., MiCA in EU)	May not fall under existing stablecoin regulations
Must rely on collateralization (as algorithmic variants have been regulated out)	Relies on a dynamic stability mechanism coupled with regime-switching monitoring and adaptation
Limited to no potential for value appreciation	Potential for long-term value growth (conditional on policy target) while maintaining stability
Primarily used as a store of value or medium of exchange (typically for crypto on/off-ramp)	Aims to serve as a medium of exchange, unit of account, and store of value (function as money)

Technical Innovations of Nebula

- Fundamental Process Driven by Fractional Brownian Motion – Through a mapping that enables us to embed long-range dependence (or mean-reversion) in the market.
- Incorporates Regime-Switching Dynamics – It ensures an adaptive behavior across varying market conditions.
- Defining a Nonlinear Intervention Function – Offers a proportional and adaptive response to price deviations.
- Integrating the Market Microstructure – To account for transaction costs and liquidity effects.
- Modeling Network Effects – To capture the impact of adoption on price dynamics.
- Incorporating Stochastic Volatility – With leverage effects and volatility feedback for realistic market behavior modeling.
- Within a Smart Contract Implementation – Allows us to decentralize Nebula's operation and provide transparency to market participants.

Key Terms

- **Dynamic Price Corridor** – Flexible range for Nebula's price fluctuation.
- **Regime-Switching** – Model's adaptation to different market states.
- **Fractional Brownian Motion (fBm)** – A mathematical model that captures long-term market dependencies and trends.
- **Hurst Index** – Measure of long-term memory in time series, indicating trend strength.
- **Secondary Instrument** – Additional financial tool enhancing Nebula's price stability.
- **Intervention Mechanism** – System for maintaining Nebula's price within a (dynamic) target corridor.
- **Stability Ratio** – Key metric balancing price stability with market responsiveness.
- **Market Depth Function** – Captures liquidity dynamics of the Nebula market.

Nebula's Mathematical Model

Adaptive Recalibration

Fundamental Process

$$d\mathbf{F}(t) = \mu(r_t, \mathbf{dC}(t))dt + \boldsymbol{\Sigma}(r_t, \mathbf{dC}(t))d\mathbf{B}^H(t) + \mathbf{g}(\mathbf{dC}(t))dt$$

Drives

Price Dynamics

$$S(t) = (\bar{S}(t) + \omega'\mathbf{F}(t) + h(\mathbf{F}(t), r_t) + q(\mathbf{C}(t), I(t))) \cdot (1 - \varpi|dS(t)|) + z\log(1 + \mathbf{dV}(t)) \cdot \mathrm{sign}(\mathbf{dV}(t))$$

Linked to

Secondary Instrument

$$dI(t) = -k \cdot g(\phi(t)) \cdot (I(t) - \bar{I}(t)) \cdot dt + \mu_I(\ldots)dt + \sigma_I(\ldots)dW_I(t) + \Upsilon(\ldots)dt$$

Interacts with

Intervention Mechanism

$$\psi(S, I, r)_t = \pm v(r_t)I(x; \theta(r_t)) \cdot (1 + w(r_t)u(SR(t), r_t))$$

Stabilizes

Nebula Model – Formal Justification

1. **Adaptive Stability Mechanism**
   - **Feature** – Regime-dependent parameters in the fundamental process.
   - $\rightarrow \mu(r_t, \mathbf{dC}(t))$ and $\boldsymbol{\Sigma}(r_t, \mathbf{dC}(t))$ in $d\mathbf{F}(t)$ equation.
2. **Market-Responsive Pricing**
   - **Feature** – Integration of fundamental values and market factors in price equation.
   - $\rightarrow \omega'\mathbf{F}(t)$ and $g(\mathbf{C}(t), I(t))$ terms in $S(t)$ equation.
3. **Built-in Risk Management**
   - **Feature** – Nonlinear intervention function and secondary instrument.
   - $\rightarrow h(\mathbf{F}(t), r_t)$ in $S(t)$ equation and entire $dI(t)$ equation.

Nebula Model – Formal Justification (cont.)

4. **Long-Range Dependence Modeling**
    - **Feature** – fBm in fundamental process.
    - $\rightarrow d\mathbf{B}^H(t)$ term with regime-dependent Hurst index $H(r_t)$ mapped to $H_{\text{eff}}(t)$.
5. **Transparency**
    - **Feature** – Explicit intervention function with smart contract implementation.
    - $\rightarrow$ Intervention function $\psi(S(t), I(t), r_t)$.
6. **Existence of a Unique Strong Solution**
    - Formal proof in paper by Salazar (2024, Appendix A) for the entire coupled system.
    - Demonstrates that solutions exist globally in time, ensuring the model remains well-defined $\forall t \geq 0$.

Robustness of Nebula

a. **Dynamic Price Corridor**
    - Allows for controlled price fluctuations.

b. **Secondary Instrument**
    - Stabilizing force, incorporating a dynamic portfolio for enhanced robustness.
    - Only tradeable against Nebula, to prevent direct system leakage.

c. **Intervention Mechanism**
    - Automatically activates to bring Nebula's price within bounds.

d. **Regime-Switching Dynamics**
    - Allows adaptation to different market conditions (including extreme events).
    - Enhances resilience against potential run scenarios.

e. **Market Depth Function**
    - Captures liquidity dynamics of the Nebula market.

Robustness of Nebula (cont.)

f. **Stability Ratio** $SR(t)$
   - Additional metric for system health.
   - Triggers issuance or redemption of secondary instrument.

g. **Fractional Brownian Motion**
   - Captures long-range dependence in markets.
   - Enhances model's ability to adapt to persistent trends.

h. **Nonlinear Intervention Function**
   - Provides proportional and adaptive response to price deviations.
   - Increases intervention strength as deviation grows.

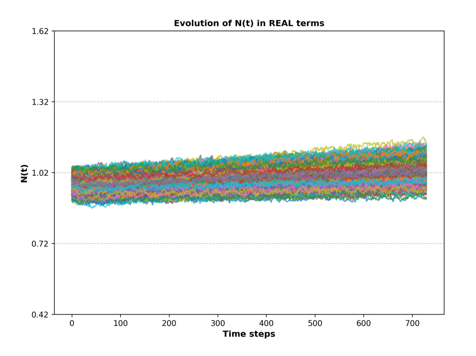
i. **Flexible Design**
   - Model could be expanded in several directions (at the expense of simplicity).
   - Via liquidity dynamics integration, dynamic supply adjustment, and liquidity pools.

Empirical Results

Random pick of 500 simulations (from a batch of 21,900 runs) over 730 epochs (2 calendar years of daily data) of a computational model simulating Nebula.

The simulation code incorporates key elements of market microstructure theory, including an order book matching engine, dynamic market making, and heterogeneous agent behaviors represented through distinct trader classes (retail and speculators). Other notable features include dynamic agent population modeling and market friction implementations, such as bid-ask spreads and market depth effects.

Overall, the code captures real-world market dynamics by combining institutional features (e.g. position limits, inventory management) and emergent phenomena (such as herding behavior and liquidity spirals through agent interaction mechanisms).



When deflated against the forcing variable $\mathbf{C}(t)$ Nebula consistently attains the stability predicted by its theoretical construct.

Implementation Impact

1. **Offer a Stabilized Digital Currency in an Otherwise Volatile Market**
   - Reduction in price volatility (based on simulations).
   - Smoother price transitions during market shifts.
2. **Stimulate its Adoption for Everyday Transactions**
   - Potential increase in transaction volume.
   - Improved user confidence due to price predictability.
3. **Provide a Clear Price Discovery Mechanism**
   - More efficient market that reflects the true asset value.
   - Reduced impact of speculative trading.

Implementation Impact (cont.)

4. **Become a Mechanism to Facilitate International Trade**
    - Possibility of Nebula as a stable medium for cross-border transactions.
    - Potential reduction in forex-related costs for businesses.
5. **Provide a Means for Financial Inclusion**
    - Access to stable digital assets for unbanked populations.
    - Potential reach of new users in developing economies.
    - This would require (for easier onboarding) the development of a friendly and flexible UX.

Advantages Over Existing Solutions

Feature	BTC/Cryptos	Stablecoins	Nebula
Price Stability	×	✓	✓
Resistance to Market Shocks	×	×	✓
Potential for Value Growth	✓	×	✓
Decentralization[a]	∼	×	?
Regulatory Compliance[b]	×	∼	✓
Scalability[c]	∼	∼	?
Routine Medium of Exchange	∼	✓	✓
Serves as Store of Value	✓	∼	✓
Potential as Unit of Account	×	✓	✓

[a] It's heavily conditional on the protocol. Concerning Nebula, we're actively evaluating which L1 platform to adopt.

[b] Not all stablecoins offered in the cryptocurrency market adhere to the regulatory frameworks currently in place.

[c] Not for BTC at the moment. For other cryptos, it depends on the adopted protocol. For Nebula, it depends on the choice of L1 (see above).

Advantages Over Existing Solutions (cont.)

1. **Resilience to Market Shocks and Speculative Attacks**
    - **Mechanism** $\rightarrow$ Regime-switching in r_t and nonlinear function $h(\mathbf{F}(t), r_t)$.
    - **Implication** $\rightarrow$ Enables multi-regime modeling and nonlinear intervention.

2. **Balanced Stability and Market-Driven Valuation**
    - **Mechanism** $\rightarrow$ Target rate $\bar{S}(t)$ with adaptive bounds.
    - **Implication** $\rightarrow$ Allows for controlled (price) fluctuations within a dynamic price corridor.

3. **Sophisticated Risk Management**
    - **Mechanism** $\rightarrow$ Regime-dependent parameters throughout the model.
    - **Implication** $\rightarrow$ Makes the model capable of continuously adapt to market conditions.

Advantages Over Existing Solutions (cont.)

4. **Automated and Transparent Mechanism**
   - **Mechanism** $\rightarrow$ Algorithmic intervention function $\psi(S, I, r)_t$.
   - **How?** Through the implementation of core functions in smart contracts.
5. **Long-Term Value Preservation**
   - **Mechanism** $\rightarrow$ Long-range dependence captured by the fBm component $\mathbf{B}^H(t)$.
   - **How?** Provides the Nebula system the ability to adapt to persistent market trends.

Risk Management and Adaptability

1. **Regime-Switching Mechanism**
   - **Mechanism** $\rightarrow$ Through r_t (embedded in all major model equations).
   - **How?** Automatic updating of model parameters based on the detected market regime.
   - **Result?** Leads to a wider price corridor and more frequent interventions in high volatility regimes.

2. **Nonlinear Intervention Function**
   - **Mechanism** $\psi(S, I, r)_t = \pm v(r_t) m(\,\cdot\,; \boldsymbol{\theta}(r_t)) \cdot (1 + w(r_t) u(SR(t), r_t))$.
   - **How?** Provides for exponential increase in intervention during extreme price movements.
   - **Result?** Increases the intervention strength as price deviates from target.

Risk Management and Adaptability (cont.)

3. **Secondary Instrument for Stability Control**
   - **Mechanism** $\rightarrow dI(t)$ equation.
   - **How?** Provides for flexible issuance and redemption of Nebula based on market conditions.
   - **Result?** Increases Nebula's issuance during periods of high demand to maintain price stability.

4. **Continuous Parameter Optimization**
   - **Strategy** $\rightarrow$ Use machine learning algorithms for model tuning.
   - **How?** Generate real-time updates of Nebula's model parameters, based on market data (likely to demand off-chain computations).
   - **Result?** One example is the adjustment of the Hurst index $H(r_t)$ based on observed long-range dependence.

Challenges

Technical Challenges

- Computational Demand – Complex calculations necessitate efficient off-chain solutions.
- Real-time Parameter Estimation – Generating accurate, swift estimation of regime states and model parameters is crucial.
- Smart Contract Constraints – Balancing on-chain security with off-chain flexibility is essential.

Market and Regulatory Challenges

- User Adoption – Overcoming barriers to public understanding and trust.
- Regulatory Landscape – Adapting to evolving cryptocurrency regulations across jurisdictions.
- Extreme Market Scenarios – Ensuring model robustness against severe market disruptions.

Mitigation Strategies

- **Hybrid Architecture** – Implement on-chain/off-chain solution without compromising decentralization.
- **Governance Structure** – Explore smart contract ownership renunciation (in specific instances) and/or robust governance protocols.
- **Continuous Improvement** – Establish a clear protocol for ongoing model refinement and stress testing.
- **Regulatory Compliance** – Maintain transparency and proactively engage with regulatory bodies, when necessary.
- **User Education** – Develop comprehensive resources to enhance user understanding and trust.

Nebula's Value Proposition

- **Dynamic Stability Mechanism** – Balances price stability with market responsiveness.
- **Adaptive Model** – Multi-regime approach ensures resilience across various market conditions.
- **Sophisticated Risk Management** – Integrates long-range dependence and regime-switching dynamics.
- **Transparency and Decentralization** – Core functions to be implemented through smart contracts.
- **Financial Inclusion** – Potential to provide a stable means of payment to under-served populations.

Nebula represents a significant advancement in digital currency design by offering a solid, adaptive solution to the challenges of price volatility perennial in cryptocurrency markets.

Nebula in Action: The Technological Edge

- Nebula bridges traditional economic theories (like target zone models and regime-switching dynamics) with modern cryptocurrency concepts, defining a novel framework in the field of digital currency design.
- It is anchored on advanced mathematical modeling, particularly noteworthy for incorporating fBm with regime switching. This combination is a major theoretical contribution, allowing Nebula to adapt to different market regimes and conditions through its various regime-dependent parameters.
- Nebula's approach to stability, using a price corridor with a nonlinear intervention function, is novel in this space. While the adoption of a secondary instrument is not new, Nebula's approach is theoretically robust and could potentially pave the way for broader cryptocurrency adoption.
- The rigorous proof of existence and uniqueness of strong solutions for Nebula's system of SDEs provides solid theoretical support, a crucial element often lacking in cryptocurrency design.
- Nebula successfully combines elements from various fields including economics, finance, mathematics, and computer science. This interdisciplinary approach is crucial for addressing the complex challenges of digital currency design.

Nebula in Practice: The User Benefits

- Nebula could provide an inflation hedge with stability. It preserves purchasing power better than fiat currencies while offering more stability than traditional cryptocurrencies.
- For those wanting exposure to the crypto market but wary of extreme volatility, Nebula's dynamic stability mechanism offers a safe middle ground.
- Unlike traditional collateralized stablecoins, Nebula uses a hybrid design combining algorithmic methods with a secondary (highly liquid) financial instrument to maintain price stability.
- This sophisticated mechanism could potentially offer better capital efficiency for users and provides more flexibility than traditional fixed-peg, rigid stablecoin designs.
- The multi-regime model allows Nebula to adapt to different market conditions ensuring resilience in turbulent periods.
- For cross-border transactions, Nebula could offer enhanced stability over traditional cryptocurrencies while reflecting broader economic trends, potentially providing advantages in international trade.

Thank you

To know more about our team simply go to http://forctis.io and browse the About Us section.

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