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The Evolution of Pricing Power: A Paradigm Shift in Virtual Asset Valuation Driven by Algorithms and AI?

Zanxi Wang

Abstract:

This study constructs a theoretical framework for algorithm-driven pricing, revealing how algorithms fundamentally reshape pricing logic across three dimensions: market structure, equilibrium mechanisms, and value discovery. Automated market makers algorithmize pricing mechanisms through mathematical functions, arbitrage algorithms become micro-level mechanisms for market equilibrium, and AI prediction models pioneer a new data-driven paradigm for value discovery. Simultaneously, algorithmic pricing has triggered deep-seated contradictions, including the restructuring of systemic risk, shifts in power dynamics, and regulatory efficacy dilemmas. The homogenization of algorithmic consensus, positive feedback loops, and oracle dependency constitute novel sources of vulnerability. Meanwhile, the democratic paradox of code governance and the implicit concentration of algorithmic power pose fundamental challenges to traditional financial governance frameworks. Consequently, establishing a new governance framework tailored to algorithmic finance is urgently needed. This research breaks through the explanatory boundaries of traditional financial theory, offering a fresh analytical perspective for studying price formation mechanisms in the digital finance era.

Keywords: Algorithmic pricing; Virtual assets; AI finance; Fintech governance

1. Introduction

Since the 21st century, the virtual economy system—represented by cryptocurrencies, non-fungible tokens (NFTs), and various digital assets—has experienced explosive growth. Its total market capitalization has surged from a marginal niche to an indispensable component of the global financial system. While demonstrating immense potential and appeal, these emerging asset classes are also characterized by extreme price volatility and low correlation with traditional financial assets. This presents speculative

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opportunities while fundamentally challenging classical financial theories.

Within traditional financial frameworks, asset pricing typically relies on quantifiable "fundamental" analysis, such as discounted future cash flows of companies, macroeconomic indicators, or interest rate term structures. However, virtual assets largely lack such traditional valuation anchors. Bitcoin yields no dividends, DeFi protocol tokens feature ambiguous and volatile cash flow mechanisms, while the artistic value and utility of NFTs remain highly subjective. This absence of "fundamentals" frequently renders classical theories like the Efficient Market Hypothesis (EMH) and Capital Asset Pricing Model (CAPM) inadequate in explaining virtual asset price behavior [1]. This raises a fundamental question: In a market devoid of traditional "fundamentals," what ultimately determines asset prices? What underpins the logic of value discovery? Against this backdrop, the deep integration of algorithmic and artificial intelligence (AI) technologies offers a novel perspective for understanding and addressing these questions. From automated market makers (AMMs) replacing traditional order books with mathematical functions, to arbitrage bots endlessly capturing cross-market spreads, to machine learning-based predictive models attempting to extract alpha from vast alternative data—algorithms and AI are no longer peripheral tools detached from the market. Instead, they are deeply embedded within and profoundly shaping every facet of market operations. Therefore, this study aims to systematically explore the following core questions: What role do algorithms and AI actually play in the pricing process of virtual assets? Are they merely technical tools that enhance pricing efficiency, or have they evolved into a disruptive force that reconstructs market structures and pricing logic? Algorithms and artificial intelligence have transcended their traditional positioning as auxiliary tools, evolving into the architects of novel market structures, the formulators of pricing logic, and the central contenders for pricing power within the virtual asset market. By elevating the role of algorithms and AI from exogenous technological variables to endogenous core market elements, this study seeks to construct an analytical framework for the virtual asset market that integrates computer science and financial economics. This framework aims to provide a new theoretical lens for understanding value determination mechanisms in a digital-native environment.

2. Relevant Theory and Technical Foundations

2.1 Traditional Asset Pricing Theory and Its Challenges in the Virtual Asset Domain

The cornerstone of modern finance rests upon rigorous asset pricing models that elucidate the equilibrium relationship between risk and expected return. Among these, the Capital Asset Pricing Model stands as a seminal theory of neoclassical finance. Its core formula is:

$$E(R_i) = R_f + \beta_i \left(E(R_m) - R_f \right) \quad (1)$$

Here, $E(R_i)$ represents the expected return of asset i, R_f is the risk-free rate, $E(R_m)$ is the expected return of the market portfolio, and β_i is the systematic risk coefficient of asset i, measuring the sensitivity of its return to market volatility. The CAPM reveals that an asset's expected return stems solely from its exposure to non-diversifiable market risk. Subsequently, the Fama-French three-factor model extended the CAPM by incorporating additional sources of systematic risk beyond the market risk premium. Its model expression is:

$$E(R_i) - R_f = \beta_i \left(E(R_m) - R_f \right) + s_i SMB + h_i HML \quad (2)$$

Building upon the market factor, this model adds the size factor and the book-to-market ratio factor. SMB measures the return differential between a portfolio of small-cap stocks and a portfolio of large-cap stocks, while HML measures the return differential between a portfolio with a high book-to-market ratio and a portfolio with a low book-to-market ratio. The coefficients s_i and h_i respectively measure the exposure of asset i to these two risk factors.

However, applying the Capital Asset Pricing Model to Bitcoin, Ethereum, and other virtual assets faces significant challenges in both explanatory power and predictive capability: First, the inapplicability of pricing factors and the absence of "fundamentals." Virtual assets lack traditional pricing anchors such as dividends, cash flows, or profitability metrics. The market capitalization factor becomes ambiguous in highly concentrated virtual asset markets, while the book-to-market ratio factor cannot be calculated for many projects lacking tangible assets. The value drivers of virtual assets are more likely tied to dimensions like network effects, developer activity, social media sentiment, or protocol utility—factors that traditional factor models cannot effectively capture [2]. Second, the ambiguity in defining the market portfolio and the failure of the beta coefficient. The core of CAPM and its derivative models relies on a market portfolio that represents all risky assets. In the virtual asset sphere, no consensus exists on what constitutes the "market portfolio," and the market itself remains highly fragmented and compartmentalized. This renders calculated beta coefficients unreliable for measuring systemic risk. Finally, behavioral finance factors exert an overwhelming influence. Virtual asset markets exhibit significantly higher volatility, speculative tendencies, and bubble characteristics than traditional markets, indicating that irrational behavior among market participants plays a far more central role in price formation than rational risk pricing.

2.2 Algorithmic Trading and AI Applications in Finance

Since the late 20th century, rapid advancements in computing technology have driven profound transformations in finance, with algorithms and artificial intelligence evolving from theoretical concepts into core drivers of market practice. In traditional finance, their application manifests across three progressively sophisticated layers: execution, arbitrage, and prediction. The most fundamental application is algorithmic trading, which primarily refers to the automated execution of trading orders via computer programs based on predefined rules and conditions. Common strategies include Volume-Weighted Average Price (VWAP) and Time-Weighted Average Price (TWAP) algorithms. These break down large orders into smaller portions executed over specific time periods to conceal trading intentions and mitigate market impact [3]. At this level, algorithms primarily function as efficient order executors, operating with static and reactive logic. More advanced applications emerge in high-frequency arbitrage and statistical arbitrage. Here, algorithmic strategies elevate algorithms from mere execution tools to detectors and exploiters of fleeting market imbalances. High-frequency arbitrage relies on ultra-fast communication and execution speeds to capture minute, fleeting price discrepancies across trading venues, thereby promoting instantaneous price convergence between markets and enhancing market efficiency. Statistical arbitrage employs more complex mathematical models to identify asset pairs exhibiting long-term stable cointegration relationships. When spreads deviate from historical averages, it constructs long-short positions to capture returns from spread reversion. High-frequency and statistical arbitrage algorithms intervene in the price discovery process, acting as micro-level forces that maintain market equilibrium [4]. The most cutting-edge applications focus on machine learning and artificial intelligence in financial forecasting. Traditional econometric models often struggle with nonlinear, high-dimensional financial market data, whereas machine learning methods—with their superior pattern recognition and function approximation capabilities—are widely used for asset price volatility forecasting, credit risk scoring, and algorithmic trading strategy optimization. Models such as Support Vector Machines (SVM), Random Forests, and Deep Learning extract predictive signals from vast amounts of structured and unstructured data, aiming to transcend traditional analytical frameworks and reveal more complex market dynamics. At this level, AI assumes predictive and cognitive roles, with its decision-making processes often constituting an opaque “black box” that is difficult to fully interpret.

In traditional finance, the application of algorithms and AI has formed a clear evolutionary path from “execution” to ‘equilibrium’ and finally to “prediction.” However, these applications are largely built upon mature, stable market microstructures, with algorithms functioning as participants within established rules.

2.3 Related Research on Virtual Asset Pricing

As the virtual asset market expands, academic research into its price formation mechanisms has also intensified. Existing literature can be broadly categorized into several strands: First, a significant body of research follows the econometric and macro-financial paradigm, focusing on correlating traditional financial factors with virtual asset prices. Extensive studies examine the dynamic linkages between Bitcoin prices and stock markets, exchange rates, gold, macroeconomic uncertainty indices, and even investor sentiment indices [5]. The interplay between virtual assets and traditional asset classes is complex and time-varying, and their role in investment portfolios remains contentious. Another strand of research focuses on market efficiency testing, employing statistical methods such as variance ratio tests and long-memory analysis to argue whether virtual asset markets conform to the weak-form efficient market hypothesis. Most findings point to gradually improving market efficiency or periodic inefficiencies. Secondly, studies incorporating on-chain data analysis utilize publicly accessible blockchain data as new valuation fundamentals to construct predictive models. This approach breaks through the limitations of traditional financial data, seeking value support from the asset’s own network ecosystem.

Nevertheless, despite providing valuable empirical evidence and correlations, a fundamental research gap persists: the vast majority of studies treat virtual asset markets as a given, static “black box,” focusing on analyzing the relationship between inputs (macro factors, on-chain data) and outputs (prices, yields), while severely neglecting the decisive role of algorithms themselves as the “engine” driving internal market operations [6]. Existing literature fails to systematically address: When algorithms themselves constitute market structure, what fundamental shifts occur in pricing mechanisms? When arbitrage algorithms become the sole equilibrating force, how do price convergence dynamics fundamentally differ from traditional markets? When AI models directly process on-chain and social data to generate trading signals, are they discovering value or self-fulfilling their predictions? This study shifts the analytical focus from external market connections to its intrinsic, algorithm-driven generative mechanisms. This establishes a pricing theoretical frame-

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work closer to the technological essence of virtual asset markets, laying a solid foundation for subsequent comparative analysis.

3. Algorithm-Driven Pricing Paradigms: From Market Construction to Value Discovery

Virtual asset markets are undergoing a profound transformation driven by algorithms and artificial intelligence, manifested in revolutionary trading methods and a fundamental restructuring of asset pricing logic. The traditional financial model—where prices form through order book games based on supply and demand—is being replaced in this emerging domain by three interrelated and progressively layered algorithmic paradigms.

3.1 Automated Market Makers: Reconstructing Market Structure

Traditional financial markets rely on order book models and professional market makers for price discovery. Decentralized finance (DeFi), however, has fundamentally altered the foundations of market microstructure by introducing Automated Market Makers (AMMs). The core breakthrough of AMMs lies in replacing the subjective judgment of traditional market makers with deterministic mathematical functions, achieving a fully algorithmic pricing process. The Constant Product Model (CPM) gained the widest adoption due to its simplicity and robustness. The CPM requires that the quantities of two reserve assets, x and y, in a liquidity pool always satisfy the constraint $x * y = k$, where k is a constant. This defines a continuous hyperbolic price curve, forming the mathematical boundary for the pool's operation [7]. Within the AMM framework, the instantaneous marginal price of asset x relative to asset y is determined by the slope of the tangent line at a specific point on this curve, specifically expressed as $P = y / x$. This makes price a direct function of the reserve asset ratio, meaning any transaction altering the reserve ratio triggers a continuous price change.

The algorithmic pricing mechanism of AMM yields two significant economic implications. First, transaction slippage transforms from a friction cost in traditional markets into an inherent mathematical property of the system. Mathematical derivation shows that executing a transaction of magnitude Δx results in a new price $P' = (y - \Delta y) / (x + \Delta x)$. Applying the constant product formula further reveals that the price change is $\Delta P = -y \cdot \Delta x / (x(x + \Delta x))$, clearly demonstrating a nonlinear inverse relationship between price movement and trade size. Secondly, when external market prices fluctuate, arbitrageurs use algorithmic trading to drive AMM pool prices toward external market levels. This inevitably alters the proportion of reserve assets, causing the value of liquidity providers' asset portfolios to systematically fall below the value of simply holding the original assets. The opportunity cost of impermanent loss formation is the economic manifestation of the inherent mathematical properties within the functional pricing mechanism.

3.2 Arbitrage Robots and Market Efficiency

Within the highly fragmented and decentralized ecosystem of virtual asset trading, arbitrage algorithms play a pivotal role in achieving and maintaining cross-market equilibrium. These algorithms essentially constitute an automated enforcement mechanism for the "law of one price" in the digital age, ensuring the efficient transmission of price information across different trading venues through continuous monitoring and instantaneous responses. Arbitrage algorithms operate on precise economic calculations [8]. Their core decision-making relies on accurately identifying arbitrage conditions: when the price difference between the same asset across markets satisfies the inequality $|P_{DEX} - P_{CEX}| > C$, the algorithm detects an arbitrage opportunity, where C represents the total transaction cost comprising trading fees and network fees. The corresponding profit function is expressed as $\pi = Q \bullet |P_{DEX} - P_{CEX}| - C$, where Q represents the optimal trade size. The algorithm employs optimization methods to determine trading strategies that maximize expected profits. In the undervalued market, buy orders generate additional demand pressure, driving P_{DEX} upward; simultaneously, in the overvalued market, sell orders increase supply pressure, causing P_{CEX} to decline. Under ideal market conditions, this process iterates until the spread converges to an equilibrium level equal to transaction cost C. This algorithm-driven equilibrium process forms the microfoundation of virtual asset market efficiency, ensuring rapid price signal transmission and resource allocation efficiency. It is particularly noteworthy that algorithms can identify and execute arbitrage opportunities within milliseconds, with trade sizes dynamically adjusted based on spread magnitude. While this enhances overall market efficiency, it may also exacerbate short-term volatility under certain conditions. Especially during extreme market conditions, simultaneous execution of similar strategies by numerous algorithms could trigger a "stampede effect"—a novel risk requiring attention in algorithmic equilibrium processes.

3.3 Data-Driven Value Discovery

In the virtual asset domain, where traditional valuation benchmarks are absent, the paradigm shift pioneered by artificial intelligence centers on transitioning from reliance on conventional fundamental analysis to predictive modeling based on big data. Machine learning algorithms extract valuable signals from vast amounts of alternative data. The fundamental model can be expressed as $r?_{t+1} = f\left(X_t\right) + \epsilon_t$, where $r?_{t+1}$ represents the predicted asset return for period t+1 at time t, X_t is an input set comprising a multidimensional feature vector, typically including novel pricing factors such as social media sentiment scores, net inflow of on-chain whales, and the ratio of network value to transaction volume. f(·) represents a complex machine learning model trained through data, while ϵ_t denotes the random error term. Machine learning predictive models offer three significant advantages over traditional linear models. First, they effectively capture the nonlinear relationships prevalent in virtual asset markets [9]. For instance, the impact of investor sentiment on prices often exhibits pronounced threshold effects and asymmetry, which are difficult to accurately describe using traditional linear parameters. Second, the model can automatically identify complex interactions among features. Finally, this framework effectively handles high-dimensional and potentially redundant feature data, filtering out the most predictive factor combinations through techniques like regularization.

At the practical application level, data-driven value discovery mechanisms are fostering new market behavior patterns. Institutional investors are integrating AI predictive models into their decision-making processes, while retail investors indirectly access these models' outputs through various analytical platforms. This is forming a novel "algorithmic consensus" mechanism, where market participants increasingly rely on algorithm-generated signals to form value judgments. However, this new value discovery mechanism also presents fresh challenges. For instance, model homogeneity may trigger herd behavior, while black-box models raise transparency issues—factors that must be thoroughly considered when assessing AI prediction models' market impact.

Algorithms have become deeply embedded across all dimensions of virtual asset pricing. From foundational market structure design to cross-market equilibrium mechanisms, and extending to cutting-edge value discovery processes, algorithms have not only transformed the technical implementation of price formation but also redefined market participants' behavioral patterns and interaction dynamics. This signifies that virtual asset markets are developing a distinct pricing system separate from traditional finance, whose evolutionary trajectory will profoundly impact the entire financial ecosystem.

4. The Hidden Power Structure and Systemic Paradoxes in Virtual Asset Pricing

When pricing authority shifts from humans to algorithms, fundamental questions emerge regarding market fairness, systemic stability, and regulatory efficacy. Beneath the veneer of enhanced market efficiency, how do algorithms reshape financial power dynamics and breed novel systemic risks?

4.1 The Illusion of Efficiency in Algorithmic Pricing and Market Vulnerability

While algorithmic pricing mechanisms enhance surface-level market efficiency, they also harbor systemic fragility rooted in three interrelated structural characteristics: First, the homogenization risk of algorithmic consensus forms the foundation of systemic vulnerability. Most mainstream automated market maker protocols are built upon similar mathematical models (such as the constant product formula). This convergence in technical approaches means global digital asset liquidity is effectively built upon a single risk factor. When extreme market conditions arise, this homogeneity triggers cross-market, cross-protocol chain reactions, forming systemic crises. Second, positive feedback loops in algorithmic behavior amplify inherent market instability. The strict execution of pre-set instructions by algorithmic trading can create self-reinforcing market dynamics. When prices fall below a certain threshold, numerous liquidation algorithms activate simultaneously, triggering a chain reaction of forced liquidations [10]. This rapidly drains market liquidity, causing severe divergence between prices and intrinsic value. Third, the vast majority of DeFi protocols function as executors of oracle-provided price data, making off-chain data sources the foundational trust anchors of the entire system. Should critical price information sources be manipulated or suffer technical failures, the entire edifice of algorithmic pricing built upon them would instantly lose its foundation.

4.2 Power Realignment and Governance Dilemmas Within the Algorithmic Black Box

The rise of algorithmic pricing has not only transformed market operations but also profoundly restructured the financial power landscape, triggering a series of governance challenges: Firstly, while the immutability of smart contracts provides certainty, it also leads to governance rigidity. When protocols contain vulnerabilities or design flaws are discovered, traditional negotiation and remedia-

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tion mechanisms become largely ineffective, often evolving decentralized governance into rule by technical elites. Second, while algorithmic pricing ostensibly creates a fairer and more open market environment, top quantitative teams and miners/validators gain disproportionate market influence through technological advantages [11]. Participants with advanced algorithms and technical resources can prioritize lucrative trading opportunities, while ordinary users passively become profit sources for these strategies—spawning new inequalities in finance. Third, when autonomous code replaces traditional intermediaries as the core of market operations, existing legal liability frameworks prove inadequate. If collective algorithmic actions trigger market crashes or smart contract vulnerabilities cause user asset losses, accountability becomes ambiguous. This blurred responsibility creates potential safe havens for market misconduct.

4.3 Regulatory Lag and Jurisdictional Challenges

Traditional regulatory frameworks exhibit pronounced incompatibility and structural lag when confronting algorithm-driven virtual asset markets: Firstly, conventional financial regulation targets identifiable legal entities—be they financial institutions or market participants. Yet within algorithmic pricing systems, autonomous smart protocols neither qualify as traditional financial institutions nor align with the definition of natural persons, rendering existing regulatory classifications incapable of accurately covering these novel market actors. Second, algorithmic protocols are inherently global and borderless, while regulatory authority remains confined to traditional sovereign boundaries. This renders regulatory actions by any single jurisdiction ineffective when confronting globally distributed liquidity pools and user bases. Regulatory arbitrage thus ceases to be a marginal phenomenon and becomes a systemic design feature, attracting capital and innovation to regulatory havens [12]. Finally, an inherent time lag exists between the prudential nature of regulatory processes and the rapid iteration of technological innovation. By the time regulators comprehend and formulate rules for a particular business model, the technological frontier has often advanced to a new stage. This perpetual lag frequently renders regulatory measures obsolete upon implementation or inadvertently stifles beneficial technological innovation.

In the new financial landscape dominated by algorithms, how can we construct a regulatory paradigm that safeguards market integrity and investor protection without stifling technological innovation? This demands a fundamental rethinking of the philosophy of financial regulation.

5. Conclusion

This study systematically elucidates the comprehensive reshaping role of algorithms in virtual asset markets—from market structure construction to value discovery—by constructing a triple paradigm theoretical framework for algorithm-driven pricing. Key findings are as follows: First, algorithms have become the core constructive force in virtual asset pricing systems. Automated market makers have restructured market microstructure through mathematical functions, arbitrage algorithms function as micro-level mechanisms for market equilibrium, and AI prediction models have pioneered a new data-driven paradigm for value discovery. These three mechanisms are mutually embedded, forming a self-reinforcing algorithmic pricing system. Second, while enhancing market efficiency, algorithmic pricing introduces new systemic risks. Issues such as the homogenization of algorithmic consensus, positive feedback loops, and oracle dependency expose virtual asset markets to novel vulnerabilities in their pursuit of efficiency. Finally, algorithmic pricing triggers profound governance and regulatory dilemmas—the democratic paradox of code governance, the implicit concentration of algorithmic power, and the ambiguity of accountability—fundamentally challenging traditional financial governance frameworks. Regulatory lag and jurisdictional failure further highlight the structural tension between existing institutions and technological innovation. This study's theoretical contribution lies in constructing an integrated framework for understanding algorithmic pricing, transcending the explanatory boundaries of traditional finance theory and offering new analytical perspectives for studying price formation mechanisms in the digital finance era.

Based on these findings, the paper proposes the following policy recommendations: Regulators should establish adaptive regulatory frameworks and implement regulatory sandbox mechanisms to provide secure testing environments for algorithmic financial innovations. Concurrently, algorithmic governance responsibilities must be clarified, establishing developer due diligence exemption standards and ongoing oversight obligations. Furthermore, cross-border regulatory collaboration should be strengthened to establish globally unified algorithmic finance regulatory standards. Simultaneously, risk management must be enhanced by developing risk control mechanisms targeting algorithmic homogeneity risks and positive feedback loops. Future research should deepen algorithmic governance studies, explore the interface between code governance and legal regulation, and construct new paradigms for financial governance in the algorithmic era. Interdisciplinary integration should be strengthened by promoting deep cross-pollination among computer science, law, and finance to cultivate new research paradigms in digital finance.

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