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SOLANA AS A HIGH-FREQUENCY GOVERNANCE MODEL: TEMPORAL ANTIFRAGILITY AND MICROTRANSACTION BUSINESS MODELS

Roman Pavlov
Candidate of Economic Sciences, Associate Professor of the Department of Economics, Entrepreneurship and Enterprise Management, Oles Honchar Dnipro National University, Dnipro, Ukraine;
e-mail: r.pavlov.dnu@gmail.com
ORCID: 0000-0001-7629-2730
(Corresponding author)

Olena Zarutska
D.Sc. in Economics, Professor of the Department of Finance, Banking, and Insurance, University of Customs and Finance, Dnipro, Ukraine;
ORCID: 0000-0001-7870-9608

Tetiana Pavlova
D.Sc. in Philosophy, Professor of the Department of Philosophy, Oles Honchar Dnipro National University, Dnipro, Ukraine;
ORCID: 0000-0001-7178-3573

Tetiana Grynko
D.Sc. in Economics, Professor of the Department of Economics, Entrepreneurship and Enterprise Management, Oles Honchar Dnipro National University, Dnipro, Ukraine;
ORCID: 0000-0002-7882-4523

Oksana Levkovich
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Banking and Insurance, Oles Honchar Dnipro National University, Dnipro, Ukraine;
ORCID: 0000-0002-4570-4963

Polina Sokol
Candidate of Economic Sciences, Associate Professor of the Department of Marketing and International Management, Oles Honchar Dnipro National University, Dnipro, Ukraine;
ORCID: 0000-0001-9217-9869

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ABSTRACT

The study aims to conceptualize the temporal antifragility of high-frequency blockchain systems and identify the potential of microtransaction business models using Solana as an example. In contrast to the traditional understanding of antifragility as the ability of a system to improve under stress, the work focuses on the temporal dimension of this phenomenon, which represents a new approach to analyzing the resilience of decentralized systems. The relevance of the study is due to the increasing role of high-frequency interactions in the digital economy, where the speed of decision-making and adaptability are becoming critical success factors.

The research methodology includes theoretical analysis and synthesis, comparative analysis of blockchain platforms, case studies of microtransaction models, and conceptual modeling. Based on the analysis of Solana technical documentation and scientific literature, four key mechanisms of temporal antifragility are identified: temporal stratification of consensus, a system of temporal cascades, fractal temporal organization, and microtemporal feedback loops. Such mechanisms work synergistically, creating a system capable of self-improvement under stress.

The main results show that Solana enables instant adaptation to changes at the microsecond level thanks to its Proof of History mechanism and high throughput. A detailed typology of microtransaction business models is developed, including continuous micropayments, high-frequency arbitrage, microstaking, and microtemporal smart contracts. Such models become economically feasible due to extremely low transaction costs.

The comparative analysis revealed fundamental differences between Solana's temporal antifragility and the institutional antifragility of traditional blockchains. The proposed conceptual model of temporal antifragility demonstrates how multi-level temporal organization allows the system not only to withstand stress loads, but also to improve under their influence. The results of the study open up new prospects for the creation of innovative entrepreneurial strategies that can use volatility and uncertainty as a source of competitive advantage in the digital economy, which has important theoretical and practical implications for the development of high-frequency business models.

Keywords: blockchain, Solana, entrepreneurship models, decentralized governance, risk management, stratagems, development, antifragility, philosophy of information, digital ontology

JEL Classification: G14, L26, P40, O31

INTRODUCTION

The development of blockchain technologies has led to the emergence of new models of economic and social interactions that transform traditional approaches to governance and coordination in a digital environment. Current research on blockchain systems has predominantly focused on the institutional aspects of decentralized governance (Davidson et al., 2018; De Filippi & Wright, 2018), while the temporal dimension remains an understudied area. Solana, launched in 2020 under the leadership of Anatoly Yakovenko (Solana Labs, 2020; Solana Explorer, 2020), is a unique example of a high-frequency blockchain platform where temporal characteristics determine not only the technical architecture but also the possibilities for making management decisions and implementing innovative business models. With its Proof of History (PoH) mechanism and high throughput (tens of thousands of transactions per second), Solana provides the responsiveness and adaptability necessary to function effectively in an uncertain environment.

Solana opens up new perspectives for the digital economy by enabling microtransaction-based business models that were previously economically unviable due to limitations of traditional systems, such as high fees and slow processing speeds. The concept of antifragility, proposed by Nassim Taleb (2012), which describes systems that strengthen under stress, has previously been studied in the context of blockchains primarily from an institutional perspective, for example, in the analysis of Ethereum antifragility (Pavlov et al., 2024). This study shifts the focus to the temporal dimension of antifragility by considering Solana as an example of a high-frequency model of blockchain governance.

The relevance of the work is due to the increasing role of high-frequency blockchain systems in the digital economy, where speed and flexibility are becoming key competitive advantages. In such conditions, understanding temporal antifragility is of particular importance for creating systems that can not only adapt to changes but also improve due to them, which optimizes management processes and opens up new market opportunities. This study seeks to fill the gap in the literature by proposing a conceptual model of temporal antifragility and a typology of microtransaction business models, which makes it a timely and practically significant contribution to the study of blockchain technologies.

LITERATURE REVIEW

The concept of antifragility, first formulated by Nassim Taleb (Taleb, 2012), describes systems that are not only resilient to stress and volatility but also able to improve under their influence. In the context of blockchain technologies, antifragility is most often viewed through the prism of institutional change. Thus, De Filippi and Wright (2018) examine the impact of blockchain on legal and social institutions, emphasizing its role in creating a rule of code and arguing that blockchain is not just a technological solution, but a new paradigm of social and economic coordination, where trust and control are delegated to decentralized networks and smart contracts. Davidson et al. (2018) analyze blockchain from the perspective of institutional economics, noting its potential to reduce transaction costs and transform traditional economic structures. This approach is complemented by Allen et al. (2020), who consider blockchain as an institutional technology that can influence innovation policy and stimulate economic development through decentralized mechanisms. Pavlov et al. (2024) deepen this analysis by studying the institutional antifragility of Ethereum through the lens of decentralized autonomous organizations (DAOs), smart contracts, and economic incentives that ensure the resilience of the system in the face of uncertainty. Swan (2015) is one of the first to highlight the potential of blockchain for digital asset governance, which contributes to the creation of resilient systems capable of adapting to uncertainty.

Despite their importance, temporal aspects of blockchain systems remain under-researched. Liu et al. (2025) highlight the critical role of temporal coordination in achieving consensus in distributed networks, focusing on temporal properties as a key performance factor. Larsen et al. (2024) propose formal models for verifying the temporal properties of smart contracts, which is especially important for ensuring their reliability in dynamic settings. The seminal work by Yakovenko (2018) on the temporal properties of Solana introduces the concept of PoH, which uses cryptographically verifiable timestamps to solve the consensus problem. This mechanism allows Solana to process transactions at unprecedented speeds, opening new horizons for high-frequency interactions in the digital economy. Hossain et al. (2024) highlight the impact of the choice of consensus algorithm on the resilience and adaptability of blockchain systems, which is directly related to the concept of antifragility. Abdelhamid et al. (2024) provide a comprehensive overview of current challenges in blockchain technologies, such as scalability, security, and energy efficiency, and argue that artificial intelligence (AI) can optimize these aspects by offering solutions that enhance the adaptability of systems, which is especially relevant for Solana, where high throughput can be enhanced by AI approaches to load management and consensus optimization.

From a management perspective, blockchain is radically changing approaches to governance and coordination. Santana and Albareda (2022) demonstrate how DAOs rethink traditional governance processes by offering a decentralized alternative to hierarchical structures. Such governance systems, based on transparency and automation, allow organizations to adapt to change faster than traditional models, which directly relates to the idea of temporal antifragility. Witt et al (2025) highlight the potential of blockchain for governance and decision-making in dynamic settings. In the context of entrepreneurship, Zhou et al. (2021) explore the potential of high-frequency blockchain systems to enable microtransaction business models such as streaming payments or instant real-time settlements. These models, previously inaccessible due to the limitations of traditional financial infrastructures, illustrate how blockchain supports innovative start-ups and entrepreneurial initiatives. Duan et al (2023) analyze the application of blockchain in supply chain management, highlighting its

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potential to improve the resilience and adaptability of supply systems, which serves as an example of the practical application of microtransaction models in real business scenarios.

Research on high-frequency economic interactions has traditionally focused on financial markets (Ekinci & Ersan, 2022), but their application to blockchain systems opens up new perspectives. Mishra et al. (2021) note that high-frequency platforms such as Solana have the potential to revolutionize microtransactions by creating ecosystems where entrepreneurs can test and scale innovative ideas at minimal cost. This is especially relevant in increasingly volatile markets, where temporal antifragility is becoming a competitive advantage.

The conducted literature review revealed significant gaps in the study of the temporal characteristics of blockchain systems, especially in the context of governance and entrepreneurship. Insufficient attention to temporal antifragility, limited research on high-frequency blockchain platforms, and the lack of a systematic approach to microtransaction business models point to unresolved issues in this area.

AIMS AND OBJECTIVES

The aim of this study is to conceptualize the temporal antifragility of high-frequency blockchain systems using Solana as an example and to identify the potential of microtransaction business models in this environment. The paper shifts the focus from the institutional aspects of antifragility to the temporal dimension, which allows us to expand our theoretical understanding of the mechanisms of stability of decentralized systems and their practical application in the digital economy. To achieve this goal, the following research tasks have been defined:

1. To systematize existing approaches to antifragility in blockchain systems, and also to formulate a definition of temporal antifragility.
2. Identify the key technical components and protocols that enable Solana's temporal antifragility, and analyze the system's multi-level temporal organization and its impact on adaptability.
3. Classify microtransaction business models in the Solana ecosystem and evaluate their economic feasibility given the technical characteristics of the platform.
4. Compare the mechanisms for achieving antifragility in Solana and traditional blockchain systems in the context of identifying the potential for synergy between temporal and institutional antifragility.
5. Develop a conceptual model demonstrating the relationship between time cascades, adaptive mechanisms, and antifragile properties of the system, and also justify the applicability of this model for the design of innovative management systems and entrepreneurial strategies.

The solution to the set tasks will not only deepen the theoretical understanding of antifragility in the context of high-frequency blockchain systems, but also provide practical recommendations for entrepreneurial structures seeking to create adaptive business models in the context of digital transformation of the economy.

METHODS

The study is based on a systematic approach that combines qualitative and quantitative analysis to study the temporal antifragility of high-frequency blockchain systems using Solana as an example and the potential of microtransaction business models. The methodology includes:

1. Theoretical analysis and synthesis. A review of scientific literature on the topics of antifragility, high-frequency blockchain systems, and microtransaction business models was conducted. This allowed us to identify gaps in the study of the temporal aspects of antifragility and justify the novelty of the study.
2. Comparative analysis. Used to compare Solana's temporal antifragility with the institutional antifragility of other blockchain systems. The comparison was made in terms of time scales, adaptation mechanisms, and transaction processing speed based on data from the whitepaper.
3. Case study. An analysis of examples of microtransaction business models (continuous micropayments, high-frequency arbitrage, microstaking, microtemporal smart contracts) was conducted based on the potential of the Solana ecosystem. Technical characteristics (e.g., throughput up to 65,000 transactions per second, transaction costs less

than USD 0.01) and their impact on entrepreneurial strategies were considered, which allowed us to develop a typology of microtransaction business models.

4. Qualitative data analysis. Solana technical documentation was analyzed to identify mechanisms of temporal antifragility, such as temporal stratification of consensus, fractal temporal organization, and microtemporal feedback loops.
5. Conceptual modeling. A conceptual model of Solana's temporal antifragility is developed based on the analysis of temporal cascades (micro-, meso-, and macrocascades) and adaptation mechanisms in the context of justifying microtransactional entrepreneurial business models that use uncertainty as a catalyst for innovation.

RESULTS

Solana's Temporal Antifragility Mechanisms

Before we move on to the analysis of specific mechanisms, it is necessary to define the concept of temporal antifragility. Unlike Taleb's classical antifragility, which focuses on the ability of a system to improve under the influence of stressors in a general sense (Taleb, 2012), temporal antifragility is the ability of a system not only to adapt, but also to improve through the optimization of temporal processes and coordination across different time scales.

For Solana, this means that the system becomes more efficient precisely because of temporal challenges – peak loads, fluctuations in transaction speed, and asynchrony of network interactions. Each temporal stress does not weaken, but strengthens the system through mechanisms of temporal optimization. This is fundamentally different from traditional blockchains, where temporal constraints are treated as obstacles to overcome, rather than sources of improvement.

The study identified four key mechanisms of Solana's temporal antifragility that distinguish it from other blockchain systems and provide the foundation for high-frequency governance. These mechanisms not only ensure resilience to temporary fluctuations and peak loads but also the system's ability to improve under stressful conditions, which is especially valuable for decision makers seeking to quickly adapt to a dynamic business environment.

The first mechanism, "temporal stratification of consensus", is to separate the process of reaching agreement into different time levels (Yakovenko, 2018; Solana Labs, 2020), which distinguishes Solana from traditional blockchains with their single temporal cycle. This approach, implemented through the PoH system, creates a sequence of timestamps that provide local verification of events without global synchronization (Yakovenko, 2018; Solana Labs, 2020). For management, this means the ability to model multi-level management systems where strategic decisions are made on a long scale, and operational ones in real time, such as in supply chain management. Entrepreneurial structures can use this feature to create business models with high transaction speeds, such as instant micropayments for content, which was previously unavailable due to latency in traditional systems (Table 1).

Table 1. Temporal stratification of consensus in Solana across different blockchain systems. *(Source: compiled by the authors based on the analysis of Yakovenko, 2018; Solana Labs, 2020; Mishra et al., 2021; Nakamoto, 2008; Buterin, 2014; Wood, 2014; Ethereum Foundation, 2023; Antonopoulos & Wood, 2018; Antonopoulos & Harding, 2024)*

No.	Parameter	Bitcoin	Ethereum	Solana
1	Basic temporal scale	~10 minutes (block)	~13 seconds (block)	~400ms (PoH slot)
2	Microtemporal processes	None	Limited	PoH sequence (~1 μs)
3	Separation of verification and consensus	No	No	Yes
4	Parallel execution	No	Limited	Full (Gulf Stream)
5	Adaptation to loads	Static complexity	Dynamic complexity	Temporal optimization

Solana operates on significantly smaller time scales than traditional blockchains such as Bitcoin or Ethereum due to its multi-layered time structure that decouples aspects of the consensus process (Nakamoto, 2008; Buterin, 2014). This decoupling allows the system to flexibly adapt to different types of workloads and effectively optimize its performance under stress. In comparison, traditional blockchains typically operate on a single time scale, where consensus is achieved through a uniform process. Solana's multi-layered approach enables parallel processing and accelerates transaction execution, making it more performant and adaptive in high-load situations (Yakovenko, 2018; Solana Labs, 2020). Solana's ability to handle loads may inspire businesses to create more resilient and flexible governance structures.

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The second mechanism, the "temporal cascade system", enables Solana to adapt to change through sequences of events propagated across different time levels (Yakovenko, 2018; Solana Labs, 2020). Unlike static blockchains, Solana distributes the workload between leaders and validators, which speeds up data processing. In the context of organizational management, this mechanism illustrates the potential for creating flexible teams where tasks are distributed according to priorities and timeframes, which echoes waterfall project planning methodologies. Entrepreneurs can apply this approach to optimize platforms, for example, in streaming services, where payments and content access adapt to load in real time.

The third mechanism of temporal antifragility is "fractal temporal organization" – a structure in which temporal patterns repeat at different scales, creating a self-similar architecture. This approach is inspired by the work of Benoit Mandelbrot, the founder of fractal geometry (Mandelbrot, 1982). In Solana, fractal temporal organization manifests itself in the structure of PoH epochs, slots, and ticks, where each level repeats the patterns of the level above, but at a higher granularity (Yakovenko, 2018; Solana Labs, 2020). Such an organization ensures consistency of processes at different time scales and creates the basis for the temporal antifragility of the system (Table 2).

Table 2. Fractal temporal organization of Solana. *(Source: compiled by the authors based on analysis Mandelbrot, 1982; Taleb, 2012; Yakovenko, 2018; Solana Labs, 2020; Mishra et al., 2021)*

No.	Temporal level	Time scale	Function	Adaptive mechanisms
1	Epoch	~2-3 days	Long-term staking management	Adaptation of validator distribution
2	Slot Leadership	~400 ms	Block production	Dynamic Leader Selection
3	PoH slot	~400 ms	Sequence verification	Turbine for parallel processing
4	Tick PoH	~1 μs	Microtemporal verification	Sealevel mechanisms for parallel execution

Fractal temporal organization gives Solana self-similarity and scalability, allowing the system to flexibly adapt to different types of stress without losing key structural characteristics. This property is critical for antifragility (Taleb, 2012), as the system is able to respond to stressors at the appropriate time level while maintaining overall integrity. In a management context, such an organization can serve as a model for creating adaptive structures in organizations, where resources and tasks are effectively distributed across levels, from strategic planning to operational execution.

Solana's fourth mechanism of temporal antifragility, "micro-temporal feedback loops", is a system of fast-acting adaptive processes that enable real-time response to change. Unlike traditional blockchains, where adjustments occur at the block level or at longer intervals, Solana uses loops that operate at the microsecond scale based on PoH ticks (Yakovenko, 2018; Solana Labs, 2020), allowing the system to continuously adapt to dynamic conditions, optimizing resources and increasing resilience to stress loads (Table 3).

Table 3. Comparison of feedback loops in different blockchain systems. *(Source: compiled by the authors based on analysis Yakovenko, 2018; Solana Labs, 2020; Mishra et al., 2021; Nakamoto, 2008; Buterin, 2014; Wood, 2014; Ethereum Foundation, 2023; Antonopoulos & Wood, 2018; Antonopoulos & Harding, 2024; Rocket et al., 2020; Ava Labs, 2020)*

No.	System	Minimum scale	Adaptation mechanisms	Adaptation speed
1	Bitcoin	~2016 blocks (~2 weeks)	Change difficulty	Very low
2	Ethereum	~100 blocks (~22 minutes)	Gas Price, complexity	Low
3	Avalanche	~1-2 seconds	Subnets, C-Chain	Average
4	Solana	~400 ms (slot), ~1 μs (PoH tick)	Turbine, Gulf Stream, Sealevel	Very high

The implementation of microtemporal feedback loops in Solana relies on three interrelated components, each of which makes a unique contribution to the adaptability and efficiency of the system (*Yakovenko, 2018; Solana Labs, 2020; Mishra et al., 2021*):

1. Gulf Stream. A transaction pre-flight protocol that optimizes data routing based on current network load. This allows nodes to predict and pass transactions to the next validator before the current block is completed, minimizing latency. During peak loads, Gulf Stream dynamically reroutes transactions, preventing nodes from becoming overloaded, which is especially important for high-frequency systems such as automated trading platforms, where even a millisecond delay can impact the outcome.

2. Turbine. A block distribution technology that optimizes network bandwidth usage. Turbine breaks block data into small fragments and transmits them across the network in a structured manner using a tree topology. This minimizes redundant data transmission and provides scalability, making Solana suitable for high-bandwidth applications such as decentralized media platforms.
3. Sealevel. A parallel smart contract execution tool that adaptively distributes computing resources. Sealevel allows multiple smart contracts to be processed simultaneously, executing independent transactions in parallel, significantly increasing performance. This is especially useful for complex decentralized applications, such as supply chain management, where multiple transactions need to be processed simultaneously.

These components form a holistic architecture that enables adaptation at different levels of the system. Solana's uniqueness lies in its rapid process optimization, which is not possible with traditional blockchains with their slow cycles. This approach is similar to operational monitoring systems in management, where instant data updates support decisions under uncertainty, such as inventory management (Santana & Albareda, 2022). This highlights Solana's superiority in providing flexibility and efficiency.

Microtemporal adaptive protocols as the basis for antifragility

The key factor in Solana's temporal antifragility is its micro-temporal adaptive protocols. They are a set of rules and mechanisms that enable adaptation on micro-time scales (Yakovenko, 2018; Solana Labs, 2020). Their multi-layered structure resembles organizational management, where different layers, from strategic to operational, solve problems of varying complexity and urgency: the basic PoH layer forms a cryptographically verifiable sequence of events, the parallel execution layer optimizes resource allocation, the network communication layer provides adaptive data routing, and the virtual machine layer improves the efficiency of smart contracts. These layers are equipped with adaptation mechanisms that operate on time scales from microseconds to seconds. This interaction creates a complex system that not only responds to stressful influences but also improves under their influence, providing entrepreneurs with a platform for developing business models that can instantly adapt to market changes and use them as opportunities for growth.

An analysis of Solana technical documentation (Yakovenko, 2018; Solana Labs, 2020) revealed four mechanisms of temporal adaptation that have analogues in management and business:

1. Temporal parallelization, similar to operational delegation of tasks depending on current priorities, distributes the load dynamically.
2. Adaptive prioritization, similar to queue management under tight deadlines, adjusts transaction priorities based on time characteristics.
3. Preventive buffering, similar to advanced resource planning, optimizes their use over time.
4. Microtemporal resource optimization, similar to real-time management, redistributes resources at the microsecond level.

These mechanisms form the core of Solana's micro-temporal adaptive protocols, ensuring the antifragility of the system. For entrepreneurs, this opens up prospects for developing innovative products where speed and flexibility become competitive advantages. Micro-temporal adaptive protocols ensure the resilience and adaptability of the system under stress, which resonates with economic strategies aimed at minimizing the negative impact of external factors and developing resilience (Ivanov et al., 2022).

The study identified key temporal antifragile patterns in Solana that are applicable to management and entrepreneurship: 1) temporal split-and-merge, similar to the modular approach in agile management, divides processes into independent subtasks with subsequent integration of results; 2) cascading buffering, similar to multi-level resource reservation, smooths out peak loads; 3) temporal prediction, similar to forecasting in strategic management, anticipates future load based on current data, preparing resources; 4) adaptive temporal scaling, reminiscent of flexible re-planning depending on circumstances, adjusts the timeframes of processes to system requirements. Such patterns (Table 4) enhance Solana's antifragility, allowing entrepreneurs to create products, for example, based on predictive analytics or dynamic scaling, that adapt to changes and use them for development.

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Table 4. Temporal antifragile patterns in Solana. *(Source: compiled by the authors based on analysis Taleb, 2012; Yakovenko, 2018; Solana Labs, 2020)*

No.	Antifragile pattern	Implementation mechanism	Impact on antifragility
1	Temporal separation and fusion	Sealevel, parallel transaction processing	Increased efficiency as the load increases
2	Cascade buffering	Gulf Stream, transaction mempool	Smoothing out load peaks, preventing overloads
3	Temporal prediction	Pre-routing of transactions	Optimize resource usage, reduce latency
4	Adaptive Temporal Scaling	Dynamic Turbine Adaptation	Optimizing network interactions under changing conditions

These patterns give Solana the ability to not only cope with high loads but also to improve its performance under stress, which is the basis of temporal antifragility. Just as organizations grow stronger in times of crisis through flexibility and adaptation, Solana demonstrates resilience and growth under pressure. This creates unique opportunities for entrepreneurs, as business models built on Solana's platform can thrive in uncertain times, turning volatility into an advantage, for example, by rapidly scaling services or reacting to market shifts.

Antifragile microtransaction business models in a high-frequency environment

Solana's temporal antifragility opens up new horizons for entrepreneurs to develop and implement microtransaction business models—systems based on small, frequent transactions (Zhou et al., 2021) that were previously inaccessible due to technical limitations of traditional blockchain systems, such as high fees and slow processing speeds. Such models provide unique opportunities to optimize management processes and create innovative entrepreneurial strategies based on high-frequency interactions, allowing companies to adapt to dynamic market conditions and use uncertainty as a source of competitive advantage. To implement antifragile systems, not only their technical development but also their popularization is important. Hudoshnyk and Krupskyi (2022) show how visual approaches can simplify the understanding of complex ideas and increase interest in blockchain technologies.

Solana-based microtransaction business models have a number of characteristics that open up opportunities for entrepreneurial entities to create innovative approaches to governance and monetization (Yakovenko, 2018; Solana Labs, 2020):

1. Minimum cost-effective transaction. Solana makes micropayments (from USD 0.0001 and below) economically feasible, enabling real-time payment models for the use of resources or services, such as digital subscription or content streaming platforms.
2. High-frequency interaction. The ability to process thousands or millions of transactions per second creates the basis for highly efficient control systems, such as automated logistics or supply chain monitoring, where every transaction is recorded instantly.
3. Temporal granularity. Programming business logic with microtemporal patterns in mind allows optimizing processes in real time, for example, in managing production lines or smart city infrastructure.
4. Adaptive pricing. Dynamic price management based on supply and demand can be used in e-commerce or decentralized financial markets, providing flexibility and competitiveness.

These characteristics make Solana a platform where entrepreneurs can test new ideas and managers can improve operational efficiency by adapting to change faster than traditional competitors. The success of antifragile microtransaction models largely depends on digital leadership, which allows companies to adapt to change and use it as a competitive advantage (Makedon et al., 2022). In the context of sustainable development, AI technologies can be integrated to analyze microtransaction data in real time, allowing for resource optimization and market trend prediction. This creates the basis for developing innovative strategies aimed at increasing the resilience of economic systems.

Based on the analysis of Solana's capabilities, a typology of microtransaction business models has been developed, demonstrating how business entities can integrate them into their strategies:

1. Continuous micropayment models. Payment for the use of resources or services in real time, for example, monetization of content as it is consumed (videos, articles), which opens up new markets for media companies and content providers, increasing their profitability. As an example, consider a streaming platform that charges for every second of video content watched. Users connect their cryptocurrency wallets to the system, and a smart contract on Solana automatically writes off micro-amounts (for example, 0.001 SOL for every 10 seconds, which is equivalent to about USD 0.10 at the current exchange rate). The high throughput of the platform (up to 65,000 transactions per

second) and minimal transaction costs (less than USD 0.01 per operation) make such payments economically feasible and practically invisible to the user. This model allows media companies to flexibly monetize content, attracting audiences that are not ready for fixed subscriptions, and effectively cope with peak loads thanks to the antifragile properties of the system in a temporal context.

2. High-frequency arbitrage models. Using micro-temporal arbitrage opportunities in decentralized markets allows financial startups or trading platforms to maximize profits by instantly rebalancing liquidity. For example, a financial startup is developing an algorithmic trading bot for a DEX on Solana. The bot analyzes price discrepancies of a single asset between different trading pairs and conducts arbitrage operations by buying the asset at a lower price and selling it at a higher price. Due to the transaction processing speed of Solana (less than 400 milliseconds per block), such trades are executed in a fraction of a second, which provides a competitive advantage over similar systems on less productive platforms. This example illustrates how the temporal antifragility of the system allows businesses to exploit market volatility as a source of income.
3. Micro-staking models. Dynamic allocation of resources at high granularity, such as computing power in cloud services or energy in renewable sources, which optimizes asset management in tech companies. Consider a cloud provider that provides users with access to CPUs or GPUs on a per-second basis. A smart contract on Solana automatically debits micropayments (e.g., 0.0001 SOL per second) and regulates access to resources in real time. This approach allows users to flexibly scale computing power to current needs, and providers to optimize server load. Solana's temporal antifragility ensures the stable functioning of the system even with sharp changes in demand, which emphasizes its adaptive potential.
4. Micro-temporal smart contracts. Automate business processes with a microsecond response. An example is a logistics company using smart contracts on Solana to manage supply chains. Each step (shipment, customs clearance, transportation) is recorded on the blockchain, and if delays occur, the smart contract automatically notifies responsible parties, offering alternative solutions. High data processing speed (less than 400 milliseconds per block) minimizes downtime and increases operational efficiency. This scenario demonstrates how micro-temporal adaptive protocols help reduce costs and increase the adaptability of business processes.

The models reviewed provide entrepreneurs with tools for creating flexible start-ups, as well as for automating and scaling processes adapted to conditions of high uncertainty. Table 5 summarizes the typology of microtransaction business models, including application examples and the connection with temporal antifragility, demonstrating practical significance for entrepreneurial structures.

Table 5. Microtransaction business models in the Solana ecosystem. *(Source: compiled by the authors based on analysis Taleb, 2012; Yakovenko, 2018; Solana Labs, 2020)*

No.	Business model type	Example of application	Connection with temporal antifragility
1	Continuous micropayments	Pay-as-you-go streaming	Adaptation to peak loads, temporal optimization
2	High Frequency Arbitrage	Instant liquidity balancing between DEX	Using Temporal Cascades for Optimization
3	Microstaking	Dynamic allocation of computing resources with second granularity	Fractal temporal organization of resources
4	Microtemporal smart contracts	Automated risk management with microsecond response	Microtemporal feedback loops

An analysis of the antifragility properties of microtransaction business models has revealed their potential as a tool for improving the efficiency of entrepreneurial structures. These models not only exploit Solana's temporal antifragility but also exhibit antifragility characteristics that allow companies to thrive in volatile environments. In this context, key properties of antifragility (Taleb, 2012) include:

1. Temporal risk decomposition. Separating risks into micro-levels reduces a business's vulnerability to, for example, supply chain disruptions, allowing managers to minimize losses in crisis situations. For example, a manufacturing firm uses microtransactions on the Solana blockchain to pay suppliers for each delivered part in real time. This approach minimizes the financial risks associated with major supply chain disruptions, as the firm's liabilities are limited to the cost of the components actually received, demonstrating antifragility by reducing vulnerability to systemic shocks.
2. Fast Feedback. High-frequency interactions enable instantaneous adjustments to strategies, which is useful for operational management in retail or finance, where the market can change by the second. Consider an example where a clothing retailer uses microtransactions to analyze customer interactions with products, recording instances

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when items are tried on but not purchased. With Solana's high throughput, the store quickly receives the data and adjusts its product range or marketing strategies, allowing it to adapt to changing consumer preferences in real time.

3. Optimism by default. The ability to test bold hypotheses with rapid adaptation encourages entrepreneurs to experiment with new products while minimizing the risk of failure. For example, a startup developing an innovative product implements a pay-as-you-go model based on microtransactions through Solana. This allows users to test the product at minimal cost, lowering the barriers to adoption, and the company receives immediate data on its demand, which encourages experimentation and minimizes the risk of a failed launch.
4. Adaptive learning. Continuous process improvement based on transaction data helps companies improve their business models, as in the case of personalized offers in e-commerce. For example, an e-commerce platform analyzes microtransaction data to identify products that are frequently viewed but rarely purchased. Using this information, the platform offers personalized discounts or recommendations, increasing conversion and improving the customer experience. This approach illustrates continuous process improvement based on transaction analytics.

These properties allow microtransaction business models not only to survive in conditions of high volatility and uncertainty but also to benefit from them, which corresponds to the fundamental principle of antifragility (Taleb, 2012).

Temporal Cascades and System Antifragility: Strategic Coordination and Risk Management

Temporal cascades in Solana have a multi-level structure (Yakovenko, 2018; Solana Labs, 2020) that reflects different governance horizons and allows the system to adapt and improve (Taleb, 2012) across different time scales, which underlies its antifragility:

1. Microcascades (PoH tick level, microseconds). At this level, operational decisions are made in real time. Examples include instant price adjustments in trading systems or automatic load balancing in high-bandwidth networks. This approach enables ultra-fast response to external changes, which is especially important for applications where every microsecond matters, such as high-frequency trading or streaming data.
2. Mesocascades (slot and block level, milliseconds). This level is responsible for tactical management covering a wider time range. Here, processes such as transaction logistics or the distribution of computing resources in the network are optimized. The flexibility of mesocascades allows the system to adapt to short-term fluctuations, making them ideal for DEXs, traffic management systems, or platforms with dynamic loads.
3. Macrocascades (epoch level, days). Strategic planning is carried out, including long-term resource allocation, staking management, or the development of global protocol updates. This layer ensures the adaptability of the system in the long term, supporting its ability to improve in the face of large-scale challenges such as economic crises or changes in the blockchain ecosystem.

This hierarchy enables businesses to model their own antifragile systems that not only survive but thrive in conditions of uncertainty (Taleb, 2012).

The interaction of these cascades creates a complex temporal dynamic that enables Solana's antifragility. Unlike traditional blockchains that rely on consensus on a single time scale, Solana's multi-layered architecture allows businesses to flexibly coordinate across multiple time horizons. This enables innovative models like streaming payments that leverage the dynamic interaction of cascades to instantly adapt to market changes, enhancing the antifragility of business structures.

An analysis of the Solana architecture (Yakovenko, 2018; Solana Labs, 2020) identified three mechanisms for the formation of antifragility (Taleb, 2012) through temporal cascades applicable to management and business:

1. Temporal damping. Smoothing out temporal fluctuations through buffering and parallel processing which allows the system to adapt to peak loads, as in retail, and use them to optimize processes. This allows the system to cope with peak loads, such as transaction surges during retail sales, and use such periods to optimize processes. For example, online stores can automatically redistribute server resources to avoid overloads.
2. Cascading amplification of positive changes. Spreading successful micro-solutions (e.g., transaction optimization) to the system level. This process resembles scaling of startups: local improvements turn into systemic advantages, facilitating growth and development.
3. Temporal isolation of negative impacts. Limiting the impact of failures or errors to individual cascade levels prevents them from spreading throughout the system. Similar to risk isolation in supply chains, this mechanism increases reliability and provides the opportunity to learn from mistakes, making the system more resilient to future challenges.

These mechanisms give Solana antifragility, allowing the system to not just cope with stress but to improve under its influence. For businesses, this opens up the possibility of creating antifragile structures that use volatility as a resource for innovation.

Based on an analysis of the Solana architecture and ecosystem, a conceptual model of temporal antifragility was developed that demonstrates how the interaction of temporal cascades and adaptive mechanisms forms an adaptive system capable of improvement (Figure 1). This model goes beyond blockchain technologies and can be applied to management to design flexible structures that can thrive in unstable environments. For example, it can be applied to managing projects in the face of changing priorities or to developing corporate strategies that use market fluctuations as an opportunity for growth.

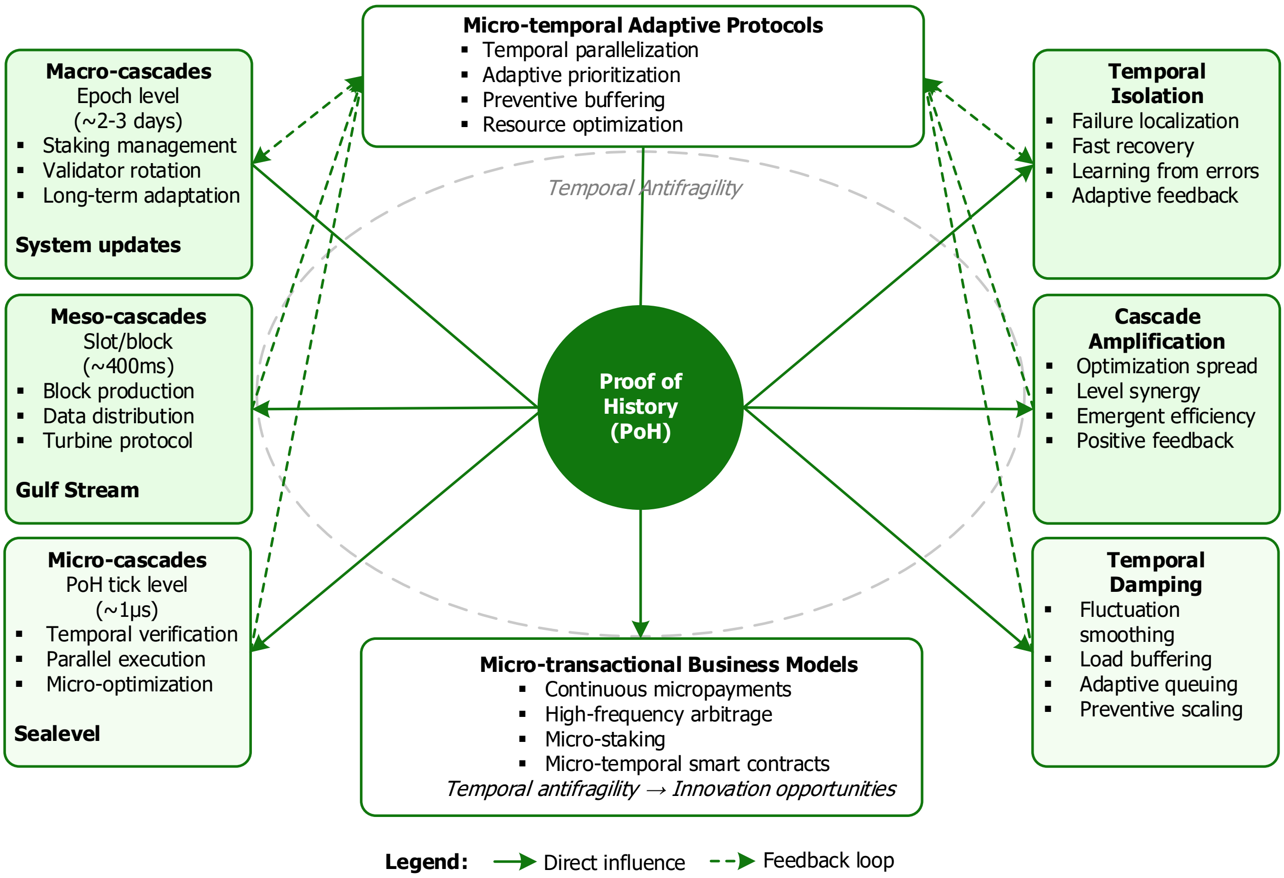

Figure 1. Solana's conceptual model of temporal antifragility. *(Source: developed by the authors based on the analysis of Taleb, 2012; Yakovenko, 2018; Solana Labs, 2020, and analysis of the Solana ecosystem)*

Solana's conceptual model of temporal antifragility demonstrates how a multi-level structure of temporal cascades, from microsecond ticks to multi-day epochs, creates a system that can not only withstand stress, but also improve under its influence. The central role in this model is played by the PoH mechanism, which forms a cryptographically verifiable timeline, ensuring high-precision coordination of processes at all levels of cascades. The novelty of the proposed model lies in the systematization of temporal aspects of antifragility in the context of high-frequency blockchain systems.

This approach creates the basis for entrepreneurial business models that use uncertainty as a catalyst for innovation. For example, Solana's high throughput and low latency make it a suitable platform for microtransaction systems such as streaming payments or instant settlements. These capabilities are unachievable on traditional blockchains with slower consensus mechanisms, highlighting the practical importance of temporal antifragility.

Comparison of the temporal and institutional approaches to the antifragility of blockchain systems in the context of choosing the optimal business strategy

An important aspect of this study is the comparison of the temporal approach to antifragility presented by Solana with the institutional approach characteristic of traditional blockchain systems such as Ethereum. This comparison allows us to identify fundamental differences in the architectural philosophies and mechanisms for achieving antifragility in decentralized systems.

The institutional approach to antifragility, explored in detail in Pavlov et al. (2024), focuses on the socio-economic mechanisms and governance structures that ensure the resilience and adaptability of blockchain ecosystems. This approach views antifragility (Taleb, 2012) as an emergent property arising from the interaction of DAOs, smart contracts, and the economic incentives of network participants. Ethereum demonstrates how a system can strengthen itself through crises due to its mechanisms for collective decision-making, the ability to evolve through improvement proposals (EIPs), and the flexibility of social consensus. This has proven effective in the long term, ensuring the survival and development of Ethereum through multiple crises, including hard forks and attacks on the protocol.

The temporal approach presented in this paper, using Solana as an example, offers an alternative paradigm for antifragility. Instead of relying on human coordination and institutional mechanisms, Solana achieves antifragility by optimizing the temporal organization of the system. The PoH mechanism and associated temporal protocols create a system capable of instantaneous adaptation at the microsecond level. This is fundamentally different from Ethereum, where adaptation occurs through social processes that take days or weeks to reach consensus. Solana's temporal antifragility manifests itself in the system's ability to automatically optimize its performance under stress, using temporal cascades and microtemporal feedback loops to continuously improve.

To systematize the differences between the two approaches, a detailed comparative analysis was conducted, the results of which are presented in Table 6. This analysis reveals not only technical differences but also fundamental philosophical differences in understanding the nature of antifragility in decentralized systems.

Table 6. Comparison of temporal and institutional approaches to the antifragility of blockchain systems. *(Source: compiled by the authors based on analysis by Taleb, 2012; Pavlov et al., 2024; Yakovenko, 2018; Solana Labs, 2020; Buterin, 2014; Wood, 2014; De Filippi & Wright, 2018, and analysis of the Ethereum and Solana ecosystems)*

No.	Comparison parameter	Institutional approach (Ethereum)	Temporal approach (Solana)	Implications for management
1	The source of antifragility	Decentralized governance, social consensus, economic incentives	Temporal coordination, technical protocols, algorithmic optimization	The choice between democracy and efficiency
2	Time horizon of adaptation	Days, weeks, months (EIP processes, DAO voting)	Microseconds, milliseconds (PoH ticks, slots)	Speed of response to market changes
3	Mechanisms of evolution	Community suggestions, voting, forks, social consensus	Automatic optimization, temporal cascades, algorithmic adaptation	Flexibility vs. process automation
4	The role of the human factor	Critical (developers, validators, token holders)	Minimal (mostly algorithmic control)	Requirements for management competencies
5	Reaction to crises	Community discussion, emergency meetings, voting, possible hard forks	Automatic protocol adaptation, temporal optimization	Predictability vs. Responsiveness
6	Scalability of solutions	Limited by the speed of achieving social consensus	Limited by technical parameters and throughput	Growth Potential and Limitations
7	Ability to innovate	High through community suggestions and experiments	Limited by the built-in algorithms	Innovative potential of the platform
8	Transparency of processes	Full transparency of discussions and voting	Code is transparent but difficult to understand	Stakeholder trust
9	Cost of adaptation	High (time, coordination, voting gas)	Low (automatic processes)	Economic efficiency

An analysis of Table 6 demonstrates that each approach is optimized for different use cases and governance contexts. Ethereum's institutional antifragility provides deep, fundamental adaptability to the system, allowing it to evolve in response to long-term challenges and changes in the external environment. This is especially valuable for projects where the legitimacy of decisions, community engagement, and the ability to radically change the course of development are critical. An example is Ethereum's transition to Proof of Stake (PoS), which required years of preparation and community consensus, but ultimately fundamentally changed the economics and ecological profile of the network.

Solana's temporal antifragility, on the other hand, enables rapid adaptation to short-term fluctuations and stress loads. The temporal approach, in contrast to the institutional one, emphasizes the importance of the speed of reaction to external signals, which is especially noticeable in conditions of market volatility, as demonstrated by the stock market analysis (Pavlov et al., 2019). If Ethereum can be compared to a democratic state capable of constitutional changes through citizen consensus, Solana is more like a highly automated governance system that instantly reacts to changes through embedded algorithms, which makes Solana an ideal platform for high-frequency financial applications, where even millisecond delays can lead to significant financial losses.

It is important to note that each approach has its own limitations, which stem from its fundamental principles. Ethereum's institutional approach can be too slow to respond to rapidly changing market conditions, as we see during periods of high gas price volatility, when the network becomes virtually unusable for small transactions. Decision-making processes through DAOs can drag on for months, which in a dynamic crypto market can mean missed opportunities.

Solana's temporal approach, in turn, may not be flexible enough to handle fundamental architectural changes, since changing the underlying temporal protocols requires stopping the entire system. The high degree of optimization for certain temporal patterns may create vulnerabilities when faced with unexpected use cases. In addition, the minimal role of the human factor in management may lead to situations where the system is technically functional, but does not meet changing user needs or regulatory requirements.

These limitations are not flaws, but rather reflect the inevitable trade-offs that come with choosing an architectural philosophy. Understanding these trade-offs is critical for managers and entrepreneurs when choosing a blockchain platform for their projects. DeFi projects that require high execution speed and predictability will find Solana's temporal antifragility an optimal solution. Projects focused on long-term community development, social tokens, or DAOs will do better on platforms with strong institutional antifragility.

The synergistic potential of the two approaches opens up prospects for the future development of blockchain technologies. It seems possible to create hybrid systems where temporal mechanisms provide operational adaptation at the micro level, and institutional structures manage the strategic evolution of the system. Such integration can lead to the emergence of new-generation blockchain platforms that combine the high performance and instant adaptability of Solana with the flexibility and democratic governance of Ethereum. An example of movement in this direction is the development of Layer 2 solutions for Ethereum, which are trying to add elements of temporal optimization to the institutionally antifragile base network.

The theoretical significance of the comparative analysis of the two approaches goes beyond blockchain technologies. It demonstrates that antifragility as a systemic property can be achieved in fundamentally different ways, each of which is optimal for a certain class of problems and operating conditions. This extends to some extent Taleb's (2012) theory of antifragility by showing that in digital systems the temporal dimension can be no less important than the institutional one in ensuring the system's ability to improve under stress.

An important aspect of the comparison is also the question of the long-term sustainability of each approach. Institutional antifragility, based on human coordination, can evolve along with changes in social norms and values, which ensures its relevance in the long term. Temporal antifragility, being more rigid in its foundations, may face challenges when the technological landscape changes radically. On the other hand, the automated nature of temporal antifragility makes it more predictable and reliable in the short and medium term, which is critical for financial applications. Thus, temporal and institutional approaches to antifragility are not competing, but complementary paradigms. Their comparative analysis enriches our understanding of ways to create resilient and adaptive decentralized systems, opening new horizons for theoretical research and practical developments in the field of blockchain technologies.

DISCUSSION

This study finds that Solana's temporal antifragility, based on PoH, temporal consensus layering, and micro-temporal feedback loops, allows the system to not only withstand stress loads but also improve its performance under high volatility. The use of multiple time horizons to assess the resilience of systems has parallels in the traditional financial sector. Khmarskyi and Pavlov's (2016) work on ranking Ukrainian banks based on their financial health demonstrates the importance of a multi-criteria approach to assessing the resilience and adaptability of financial institutions. These findings extend the concept of antifragility proposed by Taleb (2012) by highlighting the importance of temporal characteristics in high-frequency blockchain systems.

Comparisons with other academic literature reveal both similarities and differences. For example, a study on institutional antifragility of Ethereum found that the system's resilience and adaptability are achieved through social consensus and decentralized governance (Pavlov et al, 2024). In contrast, this paper demonstrates that Solana's antifragility is driven by algorithmic optimization and instantaneous adaptation, which represents a different approach to achieving resilience and adaptability.

Our results extend the findings of Liu et al. (2025) on the role of temporal coordination in distributed systems. While their work focused on consensus, we demonstrated how temporal coordination can serve as the basis for system-wide antifragility. The study of microtransaction business models complements the work of Zhou et al. (2021) on high-frequency trading on DEXs. However, our analysis goes beyond financial applications, demonstrating the applicability of microtransaction models in areas such as streaming payments, micro-staking of computing resources, and automated supply chain management.

Despite the significance of our results, we must acknowledge a number of limitations that limit the applicability of our findings. First, the exclusive focus of the study on Solana limits the generalizability of our findings to other high-frequency blockchain platforms such as Avalanche, Algorand, or Aptos; a comparative analysis with these systems could reveal universal patterns of temporal antifragility, expanding the scope of our results. Second, the lack of quantitative metrics for measuring temporal antifragility hinders an objective comparison of different systems, which is a significant barrier to further development and practical use of this concept in blockchain technologies. In the future, the integration of AI with high-frequency blockchain systems such as Solana may facilitate the development of innovative strategies for sustainable development. AI can automate decision-making and improve feedback mechanisms, which enhances temporal antifragility and allows economic systems to adapt to global challenges such as climate change or resource constraints. These limitations highlight the importance of broader and deeper research in this area.

CONCLUSIONS

This study presents a systematic conceptualization of temporal antifragility in the context of high-frequency blockchain systems using Solana as an example. The results demonstrate that in digitally distributed systems, the temporal dimension can be as important as the institutional dimension in ensuring the system's ability to improve under stress.

The key theoretical contribution of the paper is the identification of four fundamental mechanisms of temporal antifragility: temporal stratification of consensus, a system of temporal cascades, fractal temporal organization, and microtemporal feedback loops. These mechanisms, working synergistically, allow Solana not only to withstand extreme loads but also to optimize its performance in the process of adaptation to stressful conditions. This approach is fundamentally different from the institutional antifragility characteristic of traditional blockchain systems and opens up new prospects for the design of resilient decentralized systems.

The practical significance of the study lies in the development of a typology of microtransaction business models that become economically feasible due to Solana’s temporal antifragility. Models of continuous micropayments, high-frequency arbitrage, microstaking, and microtemporal smart contracts demonstrate how entrepreneurial structures can use volatility and uncertainty as a source of competitive advantage. This is especially relevant for the development of the digital economy, where the speed of adaptation and the ability to innovate are becoming critical success factors.

A comparative analysis of the temporal and institutional approaches to antifragility revealed their complementary nature. While institutional antifragility ensures long-term adaptability through social mechanisms and democratic governance, temporal antifragility provides instant response to changes through algorithmic optimization. Understanding such differences is critical for managers and entrepreneurs when choosing a blockchain platform to implement their projects.

The proposed conceptual model of temporal antifragility has potential for application beyond blockchain technologies. The principles of multi-level temporal organization, adaptive protocols, and cascade coordination can be used in the design of other high-frequency control systems, from automated production lines to smart city control systems.

The results of the study open up several promising directions for future work. First, it is necessary to develop quantitative metrics for measuring temporal antifragility, which will allow for an objective comparison of different systems. Second, empirical validation of the proposed model is required through an analysis of Solana's behavior under extreme conditions. Third, it is of interest to study the possibilities of creating hybrid systems that combine the advantages of temporal and institutional antifragility.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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Павлов Р., Заруцька О., Павлова Т., Гринько Т., Левкович О., Сокол П.

SOLANA ЯК ВИСОКОЧАСТОТНА МОДЕЛЬ УПРАВЛІННЯ: ТЕМПОРАЛЬНА АНТИКРИХКІСТЬ І МІКРОТРАНЗАКЦІЙНІ БІЗНЕС-МОДЕЛІ

Дослідження спрямоване на концептуалізацію темпоральної антикрихкості високочастотних блокчейн-систем і виявлення потенціалу мікротранзакційних бізнес-моделей на прикладі Solana. На відміну від традиційного розуміння антикрихкості як здатності системи поліпшуватися під впливом стресу, робота фокусується на часовому вимірі цього феномена, що є новим підходом до аналізу стійкості децентралізованих систем. Актуальність дослідження зумовлена зростанням ролі високочастотних взаємодій у цифровій економіці, де швидкість ухвалення рішень та адаптивність стають критичними факторами успіху.

Методологія дослідження включає теоретичний аналіз і синтез, порівняльний аналіз блокчейн-платформ, кейс-стаді мікротранзакційних моделей і концептуальне моделювання. На основі аналізу технічної документації Solana та наукової літератури виявлено чотири ключові механізми темпоральної антикрихкості: темпоральне розшарування консенсусу, систему часових каскадів, фрактальну темпоральну організацію та мікротемпоральні контури зворотного зв'язку. Такі механізми працюють синергетично, створюючи систему, здатну до самовдосконалення в умовах стресу.

Основні результати показують, що завдяки механізмові Proof of History та високій пропускній здатності Solana забезпечує миттєву адаптацію до змін на мікросекундному рівні. Розроблено детальну типологію мікротранзакційних бізнес-моделей, що включає безперервні мікроплатежі, високочастотний арбітраж, мікростейкінг і мікротемпоральні смартконтракти. Такі моделі стають економічно виправданими завдяки винятково низьким транзакційним витратам.

Порівняльний аналіз виявив фундаментальні відмінності між темпоральною антикрихкістю Solana та інституційною антикрихкістю традиційних блокчейнів. Запропонована концептуальна модель темпоральної антикрихкості демонструє, як багаторівнева часова організація дає змогу системі не лише витримувати стресові навантаження, а й удосконалюватися під їхнім впливом. Результати дослідження відкривають нові перспективи для створення інноваційних підприємницьких стратегій, здатних використати волатильність і невизначеність як джерело конкурентних переваг у цифровій економіці, що має важливе теоретичне й практичне значення для розвитку високочастотних бізнес-моделей.

Ключові слова: блокчейн, Solana, моделі підприємництва, децентралізоване управління, управління ризиками, стратагеми, розвиток, антикрихкість, філософія інформації, цифрова онтологія

JEL Класифікація: G14, L26, P40, O31