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CROSS-CHAIN FINANCIAL BUSINESS MODELS BASED ON STRUCTURAL ANTIFRAGILITY: EVIDENCE FROM THE POLKADOT ECOSYSTEM

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 Logistics, Oles Honchar Dnipro National University, Dnipro, Ukraine;
ORCID: 0000-0001-9217-9869

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ABSTRACT

The modern blockchain industry is characterized by the presence of numerous isolated, specialized platforms, which create critical barriers to interaction and call into question the effectiveness of decentralized infrastructure. Comprehending the mechanisms of structural antifragility is essential for designing systems that do not merely adapt to stressors and volatility but actively benefit and grow stronger from them. The goal of this study is to develop a conceptual model of structural antifragility as a specific type of systemic adaptability implemented through the modular architecture of heterogeneous multi-chain networks, using the Polkadot ecosystem as an example. This study operationalizes the concept of structural antifragility in relation to blockchain systems and identifies its differences from institutional and temporal forms of antifragility.

Four mechanisms of Polkadot's structural antifragility have been identified: a) heterogeneous multi-chain architecture; b) shared security; c) Cross-consensus messaging (XCM); d) Hardfork-free updates. The OpenGov decentralized governance system with conviction voting and multi-role delegation tools is analyzed. A typology of cross-chain business models is developed, highlighting their antifragile properties: structural risk decomposition, modular adaptation, cascading diffusion of innovations, economies of specialization, and shared security. The identified business models demonstrate the potential for creating innovative entrepreneurial strategies based on interoperability. A conceptual model is constructed demonstrating the relationship between modular architecture, fault isolation principles, and the antifragile properties of the system.

Structural antifragility is conceptualized as an independent dimension of blockchain system antifragility, complementing the institutional and temporal forms. The triad of antifragility paradigms represents complementary approaches, each optimized for specific business challenges and operating conditions. The developed conceptual model is applicable as an architectural pattern for building adaptive business ecosystems, enabling the isolation of experimental risks, scaling of successful solutions, and evolution without disruptive restructuring. The research results contribute to the development of innovative strategies for the sustainable and adaptive development of economic systems, providing a conceptual foundation for the creation of modular organizational structures capable of transforming stress factors into competitive advantages.

Keywords: blockchain, Polkadot, business model, business ecosystem, decentralized governance, stratagems, risks, antifragility philosophy, interoperability, digital transformation

JEL Classification: L26, M21, O31, G23

INTRODUCTION

The fragmentation of the blockchain ecosystem, where dozens of specialized networks operate in isolation, has exacerbated the problem of interoperability and raised the question of new architectural approaches to organizing decentralized systems. This diversity has stimulated active development of scientific research on various aspects of blockchain systems, but the attention of scientists is distributed unevenly. A significant portion of modern research focuses on the institutional aspects of decentralized governance (e.g., Davidson et al., 2018; De Filippi & Wright, 2018), as well as on scalability issues (e.g., Rao et al., 2018; et al., 2024) and security (e.g., Reno & Roy, 2025). However, aspects of interoperability and modular organization, despite their critical importance for the development of the digital economy, remain relatively understudied.

Polkadot, developed by Gavin Wood, co-founder of Ethereum and author of the Solidity language, implements a fundamentally different approach to scaling decentralized systems (Wood, 2016; Web3 Foundation, 2020). Instead of optimizing a single blockchain, Polkadot creates a heterogeneous ecosystem of specialized chains (parachains), each optimized for specific tasks but integrated into a common security and inter-chain communication infrastructure. This architecture eliminates the tradeoff between specialization and security inherent in isolated blockchains.

Building on Taleb's (2012) fundamental concept of antifragility, our study is a logical extension of work on the institutional antifragility of Ethereum (Pavlov et al., 2024) and the temporal antifragility of Solana (Pavlov et al., 2025). While Ethereum exhibits antifragility through social consensus mechanisms, DAOs, and governance evolution, and Solana through the optimization of temporal processes and microtemporal adaptation, Polkadot offers a third dimension of antifragility–a structural one based on a modular architecture, shared security, and cross-chain interoperability. Thus, Taleb's (2012) ideas serve as a primary foundation for extending the analysis to new dimensions, allowing for the adaptation of general antifragility theory to the specifics of blockchain architectures and emphasizing the evolution from institutional and temporal aspects to structural ones.

The relevance of this work stems from the growing fragmentation of the blockchain ecosystem, where numerous specialized networks operate in isolation, creating barriers for users and developers. Polkadot offers a solution to this problem through an architecture that ensures interoperability without compromising security or specialization. Exploring the mechanisms of structural antifragility is especially vital for designing systems that not only withstand change but actively thrive on it, thereby unlocking new market opportunities amid the ongoing digital transformation of the economy.

LITERATURE REVIEW

The problem of interoperability in blockchain systems is attracting increasing attention from researchers. Belchior et al. (2021) present a systematic review of cross-chain communication solutions, classifying them by trust assurance methods and architectural approaches. The authors note that most existing solutions rely on tradeoffs between security, decentralization, and functionality. Zamyatin et al. (2021) analyze inter-chain communication protocols from a security perspective, identifying potential attack vectors and proposing formal models for assessing the reliability of cross-chain bridges.

Polkadot's architectural approach is described in detail in the works of its creators. Wood (2016) in the Polkadot whitepaper presents the concept of a heterogeneous multichain, where parachains are united by a common security and communication infrastructure. Burdges et al. (2020) describe a shared security model and validation protocol that ensures the security of all parachains by a single set of Relay Chain validators. Stewart and Kokoris-Kogia (2020) present a formal specification of GRANDPA, a block finality protocol that ensures fast and secure transaction finality in the Polkadot ecosystem.

Inter-chain communication in Polkadot is implemented through the XCM (Cross-Consensus Messaging) protocol, described in the Polkadot Developer Docs (2024). Unlike traditional bridges, XCM provides a universal language for transmitting messages between different consensus systems, not limited to blockchains within the Polkadot ecosystem. This creates the foundation for true interoperability, extending beyond simple token exchange.

The economic aspects of Polkadot's operation are explored in papers devoted to the specifics of parachain slot auctions. Gehrlein and Häfner (2021) analyze the candle auction model used to allocate slots, demonstrating its effectiveness in preventing manipulation and ensuring fair access to shared resources. The crowdloan system, which allows projects to raise community funds to participate in auctions, creates a unique model for decentralized infrastructure financing.

In terms of governance, Polkadot implements an advanced on-chain governance model. Kiayias and Lazos (2023) analyze the features of voting and decision-making in decentralized systems, noting Polkadot's innovative approach to addressing low voter participation through vote delegation and conviction voting. OpenGov, Polkadot's new governance system, eliminates centralized elements such as the Council and Technical Committee, delegating power directly to token holders (Polkadot Developer Docs, 2025; Valaštín, 2024). In the context of modular architectures, work on the composability of DeFi protocols is of particular interest. Werner et al. (2023) analyze the phenomenon of "money legos" – the ability of different protocols to integrate with each other to create complex financial products. Polkadot extends this concept to the cross-chain layer, allowing composite applications to leverage the capabilities of various specialized parachains.

Despite growing interest in interoperability issues, academic literature does not offer a comprehensive concept of structural antifragility as applied to modular blockchain systems. Existing studies primarily focus on the technical aspects of cross-chain communication, neglecting how modular architecture influences a system's ability to improve under stress. There is also a lack of a systematic classification of cross-chain business models and an analysis of their antifragility properties, which defines the research niche of this paper.

AIMS AND OBJECTIVES

The aim of this study is to develop a conceptual model of structural antifragility as a specific type of systemic adaptability, implemented through the modular architecture of heterogeneous multi-chain networks, using the Polkadot ecosystem as an example. To achieve this goal, the following research objectives are addressed:

1. Operationalization of the concept of "structural antifragility" in relation to blockchain systems by identifying its distinctive characteristics relative to institutional (Ethereum) and temporal (Solana) forms of antifragility.
2. Identification and systematization of mechanisms for the formation of structural antifragility in the Polkadot architecture: heterogeneous multi-chain structure, shared security, the XCM protocol, and fork-free updates.
3. Identification of the features of the OpenGov decentralized governance system as a tool for adaptive protocol evolution, including consideration of conviction voting and multi-role delegation tools.
4. Development of a typology of cross-chain business models highlighting their antifragile properties: temporal decomposition of risks, rapid feedback, and adaptive learning.
5. Comparison of three forms of antifragility of blockchain systems (structural, institutional, temporal) and determination of the conditions for their synergistic interaction.
6. Construct a conceptual framework that elucidates the interconnections among modular architecture, fault isolation techniques, and antifragile characteristics within the Polkadot ecosystem, positioning it as an architectural pattern for designing adaptive business ecosystems.

The solution to the set tasks will allow us to expand the understanding of the concept of antifragility by Taleb (2012) in the context of modular blockchain systems, as well as to formulate recommendations for companies in the context of creating adaptive business models based on the use of the advantages of interoperability and specialization.

METHODS

The methodological basis of the study is a comprehensive approach integrating qualitative and quantitative methods for analyzing blockchain systems. The choice of methods is driven by the multifaceted nature of the Polkadot platform as a sociotechnical system combining technological, economic, and governance components. The conceptual foundation of the study is Taleb's (2012) theory of antifragility, adapted to the analysis of distributed systems.

The method of theoretical synthesis is applied to integrate the concepts of modular architecture (Baldwin & Clark, 2000), complex adaptive systems theory (Holland, 1995), biological adaptation to stressors in ecosystems (e.g., Shulman et al., 2017), and decentralized governance (Ostrom, 1990). This approach allows us to operationalize the concept of "structural antifragility" by identifying its distinctive characteristics relative to the institutional and temporal forms of antifragility identified in the authors' previous studies (Pavlov et al., 2024, 2025).

To identify the specifics of Polkadot's structural antifragility, a comparative analysis of the architectural solutions of three platforms is used: Polkadot (a heterogeneous multichain architecture), Ethereum (a monolithic architecture with layer-2 solutions), and Solana (an optimized monolithic architecture). The comparison criteria include fault isolation components, innovation diffusion methods, change management models, and adaptation time characteristics. The methodology for comparative analysis of blockchain systems is based on the approaches proposed in the works of Belchior et al. (2021) and Zamyatin et al. (2021).

An analysis method of on-chain data from the Polkadot ecosystem was used. The following quantitative metrics were examined:

1. OpenGov statistics on referendum dynamics, delegation structure, and the proportion of rejected proposals.
2. Parachain slot auction and crowdloan results.

3. XCM message volumes between parachains.
4. Elastic Scaling stress testing results on Kusama.

Multiple case studies of parachain projects were conducted. Examples of cross-chain business models (cross-chain DeFi, composite dApps, multi-chain identity, specialized parachains) within the Polkadot ecosystem were analyzed in detail. A typology of cross-chain business models was proposed based on an examination of parachain throughput, as well as the features of shared security and the XCM protocol in the context of their impact on entrepreneurial strategies.

Based on the synthesis of results, a conceptual model of Polkadot's structural antifragility was developed in the context of substantiating cross-chain entrepreneurial business models that utilize interoperability as a catalyst for innovation. The model includes interactions at three levels:

1. Transactions and blocks.
2. Parachains and epochs.
3. Ecosystem and governance, identifying components of failure isolation and cascading innovation diffusion.

The conceptual modeling methodology is based on approaches from system dynamics (Sterman, 2000) and the theory of multilevel perspectives of technological transitions (Geels, 2002).

RESULTS

Polkadot's Structural Antifragility Mechanisms

Unlike Taleb's (2012) general concept of antifragility, which emphasizes system improvement through exposure to stressors, and distinct from institutional antifragility rooted in social consensus mechanisms (Pavlov et al., 2024) or temporal antifragility enabled by optimized timing processes (Pavlov et al., 2025), structural antifragility enables systems to not only adapt but actively evolve through modular design, component isolation, and efficient propagation of successful solutions.

In the Polkadot ecosystem, the source of antifragility (Taleb, 2012) is heterogeneity itself: architectural differences between parachains, load asymmetries, and local failures of individual components. Modular organization transforms potential vulnerabilities into systemic advantages. Problems are isolated at the level of individual parachains, without spreading to the ecosystem, while successful solutions – new financial primitives, runtime optimizations, governance patterns – can be adopted by neighboring chains through the shared Substrate infrastructure and the XCM protocol. Monolithic blockchains lack this property, since any architectural limitation becomes a systemic problem, requiring a coordinated hard fork to resolve.

This research identifies four core mechanisms underpinning Polkadot's structural antifragility, setting it apart from other blockchain platforms and forming the basis for modular governance. These mechanisms not only confer resilience against structural disruptions and isolated component failures but also enable the system to strengthen and evolve under stress – a feature of particular value to managers seeking rapid adaptation in volatile business landscapes.

The first mechanism, "heterogeneous multichain architecture", involves organizing an ecosystem of parachains united by a common infrastructure (Relay Chain). Unlike monolithic blockchains with a single execution logic, Polkadot allows each parachain to optimize its architecture for specific tasks (Wood, 2016). This creates structural diversity, increasing the overall resilience of the system: the failure of one parachain does not affect the functioning of others, and successful architectural solutions can be adopted by neighboring chains.

The second mechanism, "shared security", secures all parachains through a single set of Relay Chain validators (Burdges et al., 2020). This eliminates the need for each parachain to build its own security infrastructure, which would be cost-ineffective for small, specialized networks. This mechanism creates economies of scale in security and eliminates the "weakest link" problem characteristic of isolated blockchains with a small number of validators.

The third mechanism, the "XCM Interchain Communication Protocol", is a universal language for transmitting messages between different consensus systems (Polkadot Developer Docs, 2024). XCM goes beyond simply exchanging tokens and enables the transmission of arbitrary instructions between parachains, including smart contract invocations, access rights management, and complex multi-chain operations. This creates the foundation for composite applications that leverage the capabilities of multiple specialized chains.

The fourth mechanism, "forkless upgrades", allows parachains and the Relay Chain to upgrade without splitting the network (Web3 Foundation, 2020). The runtime logic is stored in the blockchain state and can be modified through governance elements. This ensures continuous system evolution, eliminating the risks and coordination costs associated with traditional hard forks. For governance, this means the ability to model adaptive systems capable of evolving without disruptive disruptions (Table 1).

Table 1. Comparison of Polkadot, Ethereum, and Solana architectures. *(Source: compiled by the authors based on analysis by Taleb, 2012; Buterin, 2014, 2021; Wood, 2016; Yakovenko, 2018; Solana Labs, 2020; Web3 Foundation, 2020; Liu et al., 2022; Ethereum Foundation, 2023; Polkadot Developer Docs, 2024, 2025; Pavlov et al., 2024, 2025; Mssassi and Abou El Kalam, 2025; Reno and Roy, 2025 and analysis of the Polkadot, Ethereum, Solana ecosystems)*

Item No.	Parameter	Polkadot	Ethereum	Solana
1	Architectural model	Heterogeneous multichain	Monolithic (with L2)	Monolithic high-performance
2	Security model	Shared security	Own (PoS)	Own (PoH + PoS)
3	Interoperability	Native (XCM)	Across bridges and L2	Across the bridges
4	Specialization	High (parachains)	Low (universal VM)	Low (universal VM)
5	Features of the updates	Forkless upgrades	Hard forks + EIP	Coordinated updates
6	Antifragile type	Structural	Institutional	Temporal

Polkadot employs a radically distinct architectural paradigm compared to monolithic blockchains like Ethereum or Solana. Its heterogeneous multichain design enables flexible handling of diverse workloads and optimal performance even under structural stressors. Whereas traditional blockchains depend on a single virtual machine and uniform consensus process, Polkadot's modular framework supports parallel execution across specialized chains, delivering superior efficiency and adaptability in high-demand, heterogeneous environments (Wood, 2016; Web3 Foundation, 2020).

OpenGov Governance System

In June 2023, Polkadot transitioned from Gov V1 to the OpenGov system, representing a radical transformation of decentralized governance (Oghenekaro, 2024; Simply Staking, 2024). Gov V1 included centralized elements, such as a 13-member Council and a Technical Committee, which controlled a significant portion of decision-making. OpenGov completely eliminated these structures, delegating all power to DOT token holders. The key differences between the two systems are presented in Table 2.

Table 2. Comparison of Gov V1 and OpenGov. *(Source: compiled by the authors based on analysis by Wood, 2016; Rikken et al., 2023; Polkadot Wiki, 2023, 2024a; Simply Staking, 2024; Oghenekaro, 2024)*

Item No.	Parameter	Gov V1	OpenGov
1	Centralized bodies	Council (13), Tech Committee	None
2	Parallel referendums	Only 1 at a time	Many at the same time (on different tracks)
3	Voting model	Adaptive Quorum Biasing with time-lock	Conviction voting (multiplier 0.1× – 6×)
4	Delegation	Uniform for all types of proposals	Multirole delegation (by separate tracks)
5	Technical expertise	Technical Committee	Technical Fellowship (ranks 0–9)
6	The proportion of rejected referendums	9%	40% (for the first 6 months)
7	Increased activity (first 6 months)	Basic level	+1.008% referendums

A key feature of OpenGov is conviction voting – a system of persuasive voting where the strength of a vote is determined not only by the number of tokens but also by the willingness to lock them up for a long period. The conviction multiplier ranges from 0.1x (no lockup) to 6x (224-day lockup), creating a tool for identifying long-term stakeholders (Polkadot Wiki, 2023). This approach solves the classic problem of plutocracy in blockchain governance: large token holders unwilling to make long-term commitments gain less influence than smaller but committed ecosystem participants.

OpenGov introduces a system of origins and tracks, where each referendum belongs to a specific origin, which determines its parameters, including deposit requirements, time periods, the maximum number of concurrent referendums, and approval/support curves. In total, the system defines 17 different origins, from Root (with maximum authority) to Small Tipper (with minimal authority). The Small Tipper track is intended for quick and low-risk decisions, such as approving relatively small payments from the treasury (up to 1,000 DOT), with a minimum deposit and accelerated review times.

The Root track, in contrast, is used for the most critical protocol changes (such as runtime upgrades), with a significantly higher deposit and significantly longer preparation, voting, and confirmation periods to ensure maximum security and community engagement (Polkadot Wiki, 2023).

Each track uses dynamic approval and support curves, which determine the thresholds for decision-making. The approval curve sets the minimum share of "yes" votes among voters, while the support curve sets the minimum share of the total token supply participating in the vote. Both curves decrease over time: a referendum that does not gain sufficient support initially can be adopted later at lower thresholds, creating a balance between urgency and the legitimacy of decisions (Polkadot Wiki, 2023).

According to Oghenekaro (2024), the first six months after the transition to OpenGov saw a significant increase in activity compared to the Gov V1 period. The number of referendums increased by an average of 1.008%; the number of votes by 1.981%; and the number of treasury proposals by 405%. Moreover, the share of rejected referendums increased from 9% to 40%, indicating a greater demand and diversity of opinion within the community. This trend suggests that OpenGov not only increased activity but also improved the quality of proposal filtering; the community has become more selective, rejecting low-quality or insufficiently substantiated initiatives.

OpenGov implements a liquid democracy model through Multirole delegation capabilities. Token holders can delegate their votes to different experts across different tracks, for example, technical decisions to one delegate and treasury decisions to another. According to Oghenekaro (2024), 66,602 addresses vote directly, and 65,508 through delegation. Notably, the ratio of direct and delegated votes is close to parity, indicating a healthy ecosystem where active participants combine personal involvement with trust in experts in specialized fields.

Technically, the Fellowship replaced the Technical Committee, introducing a meritocratic ranking system from level 0 to 9. Ranks are assigned solely based on proven technical contribution to the Polkadot protocol and directly determine the Fellowship member's voting weight in technical referendums (Polkadot Wiki, 2024a). Advancement through the ranks requires demonstrating sustained contributions: writing code, participating in security audits, and developing specifications. This creates a distributed structure of technical expertise without concentrating power in a fixed circle of individuals.

From a structural antifragility perspective, OpenGov represents a component that strengthens the system through diversity and competition of ideas. The high rate of rejected referendums (40%) is not a sign of dysfunction; on the contrary, it demonstrates the system's ability to filter out weak proposals, directing treasury resources to the most valuable initiatives. Each rejected referendum generates feedback for the proponents, improving the quality of subsequent proposals.

Polkadot 2.0 and the Agile Coretime Model

Polkadot 2.0 represents the evolution of the ecosystem through three interconnected upgrades: Async Backing (May 2024), Agile Coretime (September 2024), and Elastic Scaling (testing on Kusama). These changes fundamentally transform the network's resource access model (Parity Technologies, 2024). The main components of Polkadot are presented in Table 3.

Table 3. Polkadot 2.0 components. *(Source: compiled by the authors based on analysis by Wood, 2023; Polkadot, 2024; Polkadot wiki, 2024b, 2024c; Parity Technologies, 2024; Murthy et al., 2024; Ferrell, 2025, and analysis of the Polkadot ecosystem)*

Item No.	Component	Functionality	Status
1	Async Backing	6-sec blocks, 5-10x size	Active (May 2024)
2	Agile Coretime	Bulk (28 days) + On-demand	Active (Sep 2024)
3	Elastic Scaling	Multi-core processing	Testing Kusama
4	DOT Burning 2.0	Burning by Coretime	It is planned

Async Backing reduced parachain block production time from 12 to 6 seconds and increased block size by 5-10 times. This is achieved through asynchronous validation: parachain block candidates are processed in parallel with the main chain, rather than sequentially (Polkadot wiki, 2024 b). Technically, this is realized through the "unincluded segments" feature – parachains can build new blocks on top of unfinalized candidates, creating a processing pipeline. This approach represents a temporal element of structural antifragility, as the system adapts to load by optimizing temporal processes without changing the underlying architecture.

Agile Coretime replaces the two-year slot model with a flexible lease system for computing time (Wood, 2023). Derek Yoo, founder of Moonbeam, believes that Coretime solves the binary choice faced by developers, who previously had to either commit to a full parachain slot or forego building on Polkadot altogether (Polkadot, 2024). The transition from fixed slots to flexible coretime represents a paradigm shift: blockchain resources become a commodity with market pricing, rather than a scarce good distributed through auctions.

To create cost-effective entry points for startups and flexibility for mature projects, the model proposes two types of coretime (Polkadot wiki, 2024 c):

1. Bulk coretime (rent for 28 days with the possibility of division and resale on the secondary market).
2. On-demand coretime (purchase of individual blocks as needed.

The secondary coretime market creates an additional level of economic efficiency, allowing projects with excess resources to sell unused time, while projects with peak loads can acquire additional capacity without long-term commitments. This creates market signals about the real demand for the ecosystem's computing resources.

Elastic Scaling allows parachains to utilize multiple cores simultaneously to increase throughput. In December 2024, a "Spamming" stress test on Kusama achieved 143,343 TPS using 23 of the 100 available cores (Polkadot, 2024b). The theoretical maximum at full load is estimated at over 500,000 TPS (Ferrell, 2025). The fundamental difference from vertical scaling (as in Solana) is that each parachain can independently scale according to its needs without impacting the performance of other ecosystem components.

The Polkadot 2.0 economic model includes a DOT token burn where revenue from the coretime sale is partially burned, creating deflationary pressure in addition to the existing burn from transaction fees (Murthy et al., 2024). This feature links the economic value of the DOT token to the actual use of the network–the higher the demand for coretime, the more tokens are burned, creating a positive feedback loop between the ecosystem's utility and the value of the underlying asset.

The next stage of architectural evolution will be the JAM (Join-Accumulate Machine), presented in the Gray Paper (Wood, 2025). JAM proposes a generalized computation model, transforming the Relay Chain into a synchronous global computer capable of performing arbitrary computations, not just validating parachains. This will expand the ecosystem's capabilities beyond the current model of specialized chains.

In terms of structural antifragility, Polkadot 2.0 demonstrates the system's ability to undergo radical transformation without hard forks or disruption to existing parachains. All three components (Async Backing, Agile Coretime, and Elastic Scaling) were implemented through forkless upgrades, confirming the feasibility of on-the-fly evolution of modular systems.

Parachains as adaptive modules

A key element of Polkadot's structural antifragility is parachains connected to the Relay Chain and leveraging its security infrastructure (Wood, 2016; Burdges et al., 2020). Unlike monolithic blockchains, where all functions are implemented within a single architecture, Polkadot separates consensus and security (the Relay Chain) from application logic execution. The Relay Chain ensures parachain block finality and state validation through a shared security component, allowing all connected chains to achieve a security level equivalent to the main network without the need to form their own set of validators. Parachains are adaptive modules, each optimized for specific tasks but integrated into a unified ecosystem. This organization creates structural diversity, increasing the overall adaptability of the system.

The model plays a key role in ensuring the economic sustainability of the ecosystem. Parachain slots are allocated through candle auctions, which minimize the potential for manipulation by preserving the uncertainty of termination (Gehrlein & Häfner, 2021). Classic parachain slots can be leased for up to 96 weeks through candle auctions, but with the introduction of Agile Coretime (Wood, 2023; Parity Technologies, 2024; Polkadot, 2024; Polkadot Wiki, 2024c), the flexible purchase of computing time has become possible. This creates an economic selection of viable projects and aligns the incentives of participants with the long-term interests of the ecosystem.

Crowdloan participants provide their DOT tokens to the project for the duration of the slot lease, receiving parachain tokens or other rewards in exchange. After the lease ends, the DOTs are returned to their owners. This creates a unique infrastructure funding model where risks and rewards are shared between the project and the community.

The diversity of parachains in the Polkadot ecosystem reflects the potential for specialization within its modular architecture. Each parachain type is optimized for specific tasks, leveraging the benefits of its specialized architecture while maintaining access to a common security and communication infrastructure (Table 4).

Table 4 shows that the parachain typology demonstrates the potential for structural specialization in the Polkadot ecosystem. Each type is optimized for specific tasks. This specialization improves the overall efficiency of the system, allowing each component to focus on its strengths.

Table 4. Typology of parachains by functional purpose. *(Source: compiled by the authors based on analysis by Wood, 2016; Burdges et al., 2020; Li et al, 2023; Oghenekaro, 2024; Zhang et al., 2024; Polkadot Wiki, 2024c, 2025; Murthy et al., 2024; Ferrell, 2025; Parachains.info, 2025, and analysis of the Polkadot ecosystem)*

Item No.	Parachain type	Functional purpose	Project examples	Adaptive mechanisms
1	DeFi parachains	DeFi, lending, DEX	HydraDX, Bifrost (liquid staking), Acala	Optimization for financial transactions
2	Smart contract platform	Universal smart contract execution environment	Moonbeam, Astar, Unique Network	EVM/WASM compatibility
3	Infrastructure	Bridges, oracles, and data storage	Bridge Hub	Services for other parachains
4	Identity and data	Decentralized identity, privacy	KILT, Litentry	Specialized cryptography
5	Industry solutions	Specialized applications in specific industries	OriginTrail, Robonomics, NeuroWeb, Mythos	Industry optimization
6	System parachains	General ecosystem services (governance, staking)	Asset Hub, Bridge Hub, Collectives, People Chain, Coretime Chain	Slots are reserved through OpenGov without an auction.
7	AI and zero-knowledge computing	Decentralized GPU networks, machine learning, ZKML, inference	NeuroWeb (partially), Acurast	Optimization for TEE, off-chain compute, ZK-proof

System parachains play a special role, providing common services for the entire ecosystem and receiving slots for free through governance elements. An example is the Asset Hub, which enables token issuance and management without the need to deploy smart contracts, significantly lowering the barriers to entry for new projects. This demonstrates how a modular architecture allows for the extraction of common functions into specialized components, increasing the efficiency of the entire system.

Cross-chain business models

The structural antifragility inherent in Polkadot creates novel avenues for entrepreneurs to design and deploy cross-chain business models that harness the strengths of multiple specialized blockchains via seamless inter-chain communication protocols (Wood, 2016; Polkadot Developer Docs, 2024). Previously unattainable due to the constraints of siloed blockchain ecosystems, such as absent native interoperability and the vulnerabilities of centralized bridges, these models now enable distinctive strategies for streamlining governance and crafting entrepreneurial approaches rooted in specialization and interconnectivity.

Cross-chain business models built on Polkadot (Wood, 2016; Belchior et al., 2021; Polkadot Developer Docs, 2024) possess several defining traits that empower entrepreneurial actors to pioneer advanced methods of governance and value capture:

1. Service composability. Polkadot enables the creation of applications that combine the capabilities of multiple specialized parachains, for example, a DeFi protocol that leverages the liquidity of one parachain, the oracles of another, and the private computation of a third.
2. Eliminating security duplication. Thanks to shared security, new projects do not need to build their own validator infrastructure, significantly reducing entry barriers and operational costs.
3. Specialized optimization. Each parachain can be optimized for specific tasks without the compromises required in general-purpose platforms. For example, a parachain for high-frequency trading might sacrifice generality for speed.
4. Native interoperability. The XCM protocol enables secure message transfer between parachains without the need to trust centralized intermediaries, eliminating the risks associated with traditional bridges.

Drawing on a detailed examination of Polkadot's architectural and functional capabilities, the study constructs a typology of cross-chain business models that illustrates pathways for entrepreneurial organizations to incorporate these models into their broader strategic frameworks (Table 5).

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Table 5. Classification of cross-chain business models in the Polkadot ecosystem. *(Source: compiled by the authors based on analysis Wood, 2016; Belchior et al., 2021; Valaštin et al., 2024; Polkadot Developer Docs, 2024; Parachains.info, 2025, and analysis of the Polkadot ecosystem)*

Item No.	Business model type	Description	Example of application
1	Cross-chain DeFi	Financial protocols leveraging the liquidity and functionality of multiple parachains	A yield aggregator that collects optimal rates from DeFi parachains Acala, Parallel, and HydraDX
2	Composite dApps	Applications that combine specialized services from different parachains into a single product	A game that uses NFTs from one parachain, tokenomics from another, and private data from a third
3	Multi-chain identity	Decentralized identity systems operating across parachains	A single verified identity for accessing services across the entire ecosystem
4	Specialized bridges	Infrastructure services for connecting the Polkadot ecosystem with external networks	A bridge to Ethereum that enables two-way transfer of assets and messages
5	Cross-chain oracles	External data services available to all parachains in the ecosystem	A single source of price data for all DeFi protocols in the ecosystem
6	Industry ecosystems	Vertically integrated solutions for specific industries	Logistics ecosystem: tracking (OriginTrail) + payments (Acala) + identification (KILT)

The proposed typology of cross-chain business models aligns closely with contemporary frameworks in sustainable finance and strategic corporate management amid uncertainty (Makedon et al., 2024; Makedon et al., 2025). These models equip entrepreneurs with practical instruments to build adaptable organizational structures, automate operations, and scale processes tailored to cross-chain interoperability environments. Further examination of their antifragile attributes underscores the models' capacity to enhance the overall efficiency and resilience of entrepreneurial ecosystems (Table 6).

Table 6. Antifragile properties of cross-chain business models. *(Source: compiled by the authors based on analysis by Taleb, 2012; Taleb, 2018; Wood, 2016; Polkadot Developer Docs, 2024 (and analysis of the Polkadot ecosystem)*

Item No.	Business model type	Description	Example of application
1	Structural decomposition of risks	Distribution of functions between specialized parachains	Failure of one component does not lead to the collapse of the entire system; minimizing losses in crisis situations
2	Modular adaptation	The possibility of replacing or upgrading individual components without stopping the system	Rapid response to market changes; ability to test new solutions
3	Cascading diffusion of innovations	Successful solutions from one parachain can be adopted by others through XCM	Accelerating innovative development; reducing R&D costs
4	Savings from specialization	Each parachain is optimized for specific tasks without compromise.	Higher efficiency and productivity compared to universal solutions
5	Shared security	All parachains are secured by a single set of Relay Chain validators.	Eliminate the need to create your own security infrastructure; lower barriers to entry

These characteristics empower cross-chain business models to not only withstand intense volatility and uncertainty but to actively gain strength from such conditions, embodying the core tenet of antifragility (Taleb, 2012). The structural segregation of risks proves particularly critical within blockchain ecosystems, where a vulnerability in any single element has historically posed a systemic threat to the entire network.

Structural cascades and systemic adaptability

Polkadot's modular architecture generates a hierarchy of structural cascades–interconnected layers, each implementing specific models of system adaptation and improvement, which aligns with the concept of antifragility (Taleb, 2012). Unlike the temporal cascades of high-frequency blockchains, where temporal coordination plays a key role, Polkadot's structural cascades are defined by the spatial organization of components and their interactions:

1. Transaction and block level. Key elements include routing XCM messages between parachains, production and validation of candidate blocks by collators, and dynamic allocation of computing resources (including on-demand coretime within the Agile Coretime framework). This organization ensures rapid response to external disturbances, minimizing latency and increasing the efficiency of individual operations.

2. Parachain and Epoch Layer. The main components are validator set rotation, bulk coretime allocation (28-day regions), and optimization of economic parameters (e.g., secondary coretime markets). The flexibility of this layer allows the system to adapt to medium-term changes in load and market conditions, balancing efficiency, resilience, and adaptability.
3. Ecosystem and Governance Layer. This layer facilitates high-level strategic coordination, encompassing long-term resource distribution, protocol upgrades via community referendums, and ongoing architectural evolution of the ecosystem. Such an arrangement promotes gradual, evolutionary adaptation, enabling the seamless incorporation of major innovations and the resolution of core challenges without triggering widespread system disruptions.

An in-depth examination of Polkadot’s architectural framework and ecosystem dynamics has yielded a conceptual model of structural antifragility, illustrating how the interplay between modular elements and adaptive mechanisms creates a system inherently designed for continuous enhancement (Figure 1).

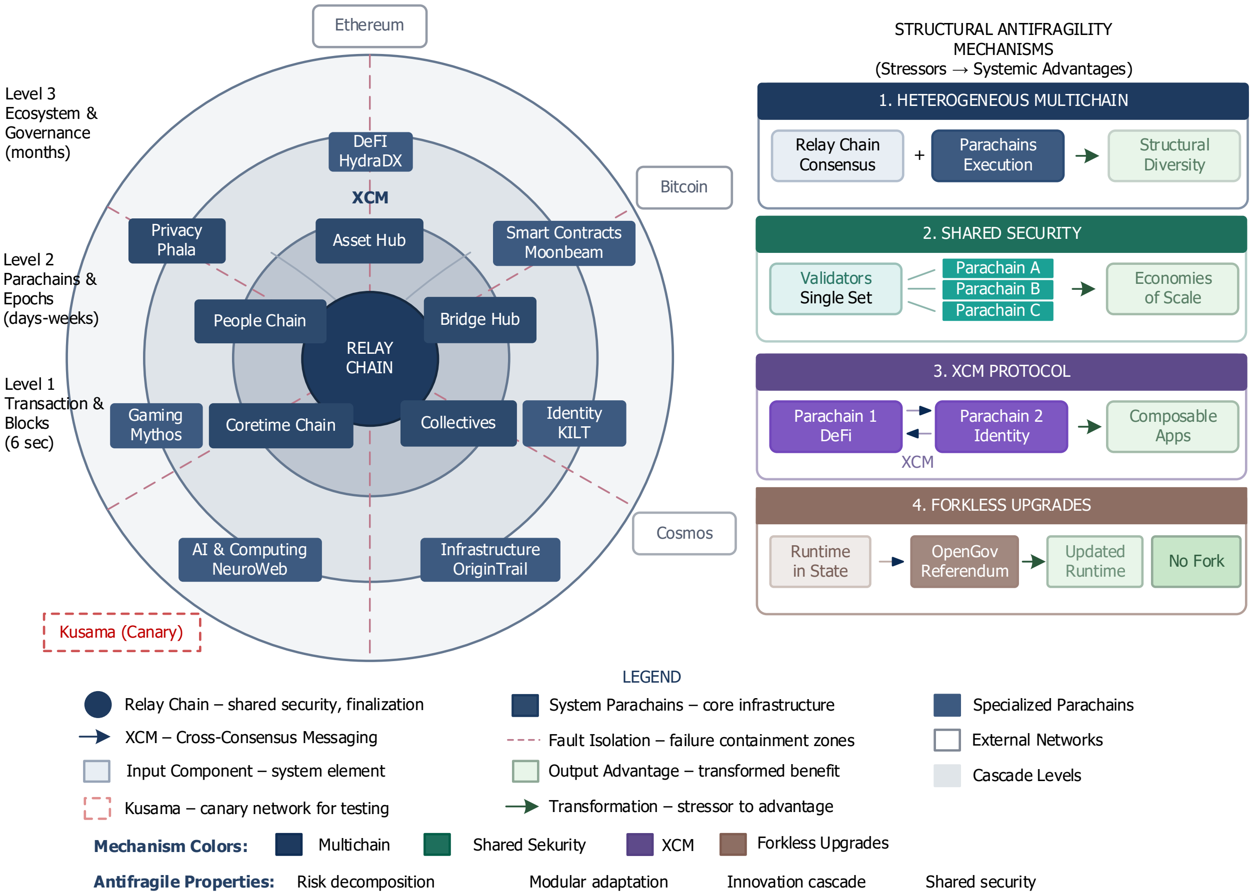

Figure 1. Conceptual model structural Polkadot's antifragility. *(Source: developed by authors on the basis of analysis Taleb, 2012; Wood, 2016; Burdges et al., 2020; Web3 Foundation, 2020; Polkadot Developer Docs, 2024, and analysis of the Polkadot ecosystem)*

The model's practical applicability extends beyond blockchain technologies. For entrepreneurs, it offers an architectural pattern for building business ecosystems where:

- the core provides a common infrastructure and standards (analogous to Relay Chain);
- specialized business units are optimized for specific market niches (analogous to parachains);
- interaction protocols ensure the composability of services without losing the autonomy of components (analogous to XCM).

This modular organization allows companies to isolate the risks of failed experiments, scale successful solutions through internal transfer, and evolve without disruptive restructuring, transforming external information stressors (e.g., Pavlov et al., 2019) into adaptive advantages, consistent with the fundamental principles of antifragility (Taleb, 2012). The primary innovation of the proposed model resides in its systematic framework for structural antifragility within the domain of modular blockchain architectures.

Comparative analysis of three paradigms of antifragility

The final element of the study is the triangulation of three antifragility paradigms: structural (Polkadot), institutional (Ethereum), and temporal (Solana). While previous studies (Pavlov et al., 2024, 2025) analyzed pairwise comparisons, this study considers all three dimensions within a single analytical framework, allowing us to identify not only the differences but also the potential for synergies between the approaches.

Ethereum's institutional antifragility (Pavlov et al., 2024) is based on social consensus as the primary adaptation mechanism. The DAO, the EIP (Ethereum Improvement Proposals) system, and the economic incentives for validators form a distributed decision-making structure capable of radical transformations. An example is the transition from Proof of Work to Proof of Stake (The Merge, September 2022), which required years of community coordination. The strength of this approach lies in the legitimacy of decisions and the ability to fundamentally change, while the limitation is the speed of response, measured in weeks and months.

Solana's temporal antifragility (Pavlov et al., 2025) is achieved through algorithmic optimization of temporal processes. The Proof of History protocol creates a cryptographically verifiable timeline, allowing the system to adapt at the microsecond level without human intervention. The strength of this approach lies in its speed of response and predictability; its limitations are the rigidity of the underlying protocols and the difficulty of fundamental changes requiring a coordinated shutdown of the network.

Polkadot's structural antifragility occupies a middle ground between these two extremes. Its modular architecture ensures fault isolation and horizontal scaling (the addition of parachains), while its forkless upgrade mechanism allows for faster evolution than Ethereum while maintaining legitimacy through OpenGov. The strength of this approach lies in combining component specialization with a shared security infrastructure. Its limitations include its dependence on the Relay Chain's throughput and the complexity of coordinating a heterogeneous ecosystem.

A clear grasp of the distinct paradigms of antifragility (Taleb, 2012) is essential for managers and entrepreneurs when selecting an appropriate blockchain platform for their initiatives. Table 7 summarizes recommendations for platform selection based on the characteristics of the business problem.

Table 7. Selecting a platform depending on business objectives. *(Source: compiled by the authors based on analysis by Taleb, 2012; Tamai and Kasahara (2024), Pavlov et al. (2024, 2025, and analysis of the Polkadot, Ethereum, and Solana ecosystems)*

Item No.	Business model type	Recommended platform	Justification
1	Characteristics of the business problem	Solana	Temporal antifragility ensures minimal latency and high throughput
2	Focus on long-term community development, DAO	Ethereum	Institutional antifragility supports democratic governance and evolution through consensus.
3	Industry-specific solution	Polkadot (native parachain)	Structural antifragility allows for the optimization of architecture to specific requirements
4	Integration of multiple blockchain services is required	Polkadot (a parachain-based dApp)	Native interoperability through XCM enables secure cross-chain composability
5	A broad ecosystem of smart contracts, DeFi	Ethereum or Moonbeam (Polkadot)	A mature developer and protocol ecosystem, Moonbeam brings EVM compatibility to Polkadot
6	Resilience to component failures is critical	Polkadot	Modular architecture isolates failures, preventing them from spreading throughout the entire system.

Practical synergies are already being realized in the Polkadot ecosystem. The Moonbeam parachain integrates institutional elements of Ethereum (EVM compatibility) with the structural advantages of Polkadot (shared security, XCM). The development of Polkadot 2.0 with Async Backing and Elastic Scaling introduces temporal optimizations, reducing block times to 6 seconds and increasing throughput to over 143,000 TPS. A promising direction is JAM, described in the Gray Paper (Wood, 2025), which envisions transforming the Relay Chain into a synchronous global computer – an architecture that potentially unites all three dimensions of antifragility in a single system. The antifragility triad of blockchain ecosystems represents complementary, rather than competing, paradigms. Each paradigm is specifically tailored to a distinct category of challenges and operational contexts (Figure 2).

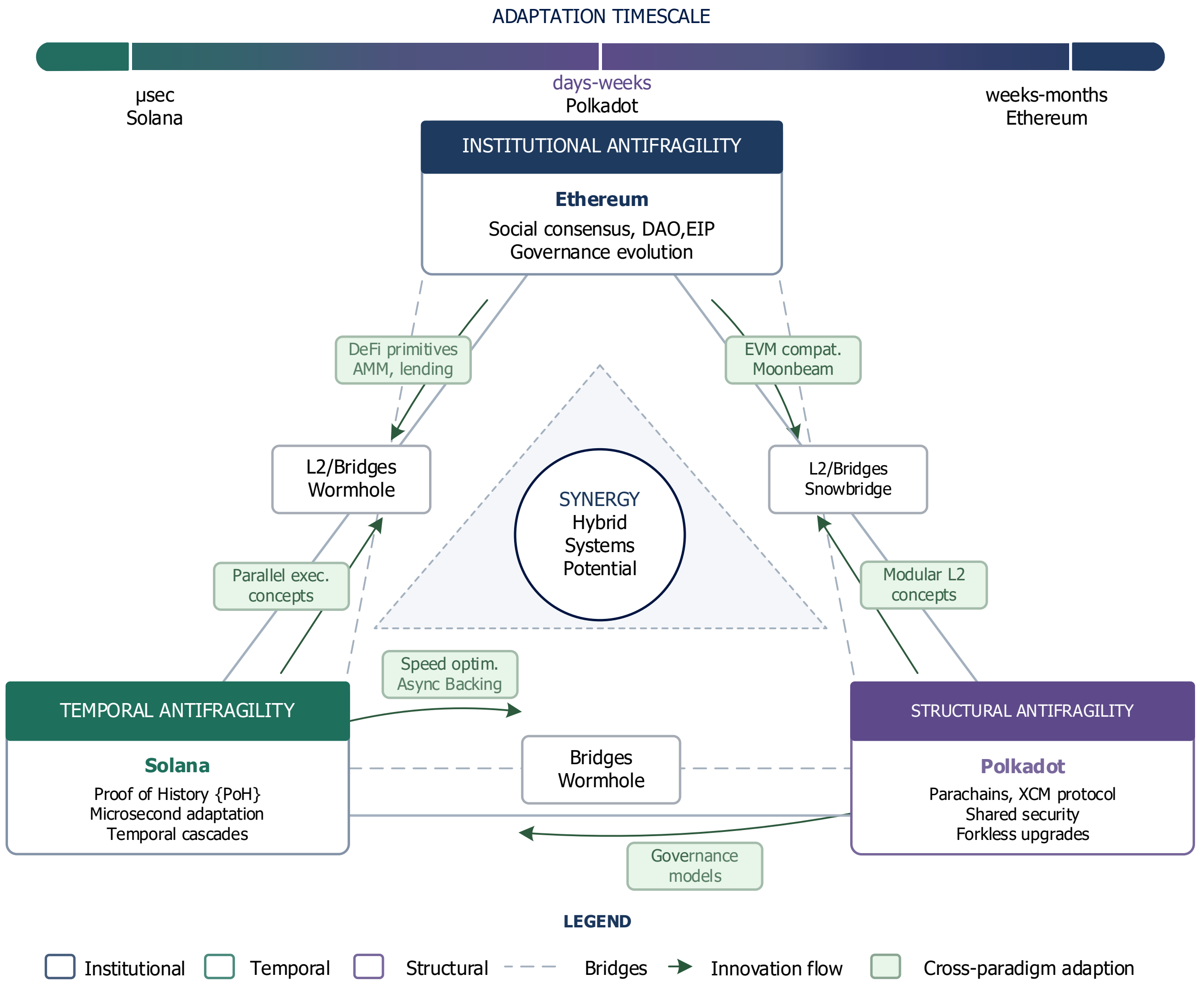

Figure 2. Antifragility triad of blockchain ecosystems. *(Source: developed by the authors based on the analysis of Taleb (2012), Wood (2016, 2025), Web 3 Foundation, 2020; Polkadot Developer Docs, 2024; Pavlov et al (2024, 2025 and analysis of the Polkadot, Ethereum, and Solana ecosystems)*

The triad of paradigms contributes to the development of Taleb's (2012) theory of antifragility as applied to distributed systems. Taleb's original concept does not differentiate the sources of antifragility, viewing it as a unitary property. The analysis demonstrates that in complex digital systems, antifragility has at least three independent dimensions, each with specific mechanisms and constraints. The structural dimension, identified in the Polkadot example, possesses a unique characteristic – the ability to horizontally scale antifragility, as the addition of a new parachain not only does not weaken but also potentially strengthens the ecosystem's resilience through diversification and new opportunities for the diffusion of innovations.

DISCUSSION

The obtained results allow us to expand our understanding of Taleb's (2012) concept of antifragility in relation to distributed systems and to substantiate structural antifragility as an independent dimension of the adaptability of blockchain architectures. The four identified mechanisms of Polkadot's structural antifragility (heterogeneous multichain architecture, shared security, the XCM protocol, and forkless upgrades) form a complementary system, where each component enhances the effect of the others. This complementarity distinguishes structural antifragility from institutional antifragility (Pavlov et al., 2024) and temporal (Pavlov et al., 2025) forms where the adaptation components operate relatively independently. The successful implementation of Polkadot 2.0 components (Async Backing, Agile Coretime, Elastic Scaling) through forkless upgrades without disrupting existing parachains confirms the practical feasibility of the identified mechanisms.

The obtained results are consistent with the findings of Belchior et al. (2021) on the inevitable trade-offs in blockchain interoperability solutions, including aspects of the classic blockchain trilemma. However, Polkadot's architecture significantly minimizes these trade-offs through a shared security model and native interoperability through parachains. Li et al. (2023) emphasize that cross-chain technologies are developing rapidly but generally remain in an early experimental stage without fully stable systems. Our results partially refute this general assessment for Polkadot, as the XCM mechanism demonstrates significant maturity and widespread adoption, especially after the implementation of Polkadot 2.0 in 2025. At the same time, the key challenges identified by Li et al. (2023), such as early detection of malicious node behavior, auditing cross-chain interactions, and optimizing incentive schemes, remain relevant for the Polkadot ecosystem.

Xu et al. (2024) emphasize that a modular approach facilitates the creation of scalable, flexible, and application-adaptable blockchain systems. Our results support this theoretical thesis: Polkadot's architecture implements modularity principles in practice, demonstrating how the decomposition of functions (consensus, execution, security, communication) among specialized components improves the overall adaptability of the system. Botros et al. (2024) presented the UNFRAGILE framework for transforming cloud systems into antifragile ones through chaos engineering and confirmed the ideas of Taleb (2012) that antifragile systems have the ability to overcome stressors and emerge stronger, while resilient systems focus only on reverting to a previous state. This is important for understanding our results: Polkadot's forkless upgrades mechanism ensures antifragile, not simply resilient, behavior, since the system evolves through upgrades rather than simply recovering from them.

The study's results offer prospects for developing innovative strategies for the sustainable and adaptive development of economic systems. However, the practical implementation of the identified principles of structural antifragility faces several challenges. First, modular architecture requires a high level of standardization of interfaces between components – a problem relevant not only to blockchain ecosystems but also to corporate structures striving for modular organization. Second, decentralized governance models (such as OpenGov) demonstrate high effectiveness in technological communities, but their applicability to traditional economic institutions requires adaptation, taking into account existing legal and regulatory frameworks. Of particular interest is the question of scalability: can principles effective for an ecosystem of several dozen parachains work at the level of national or global economic systems? A promising direction is the integration of modular blockchain architectures with artificial intelligence technologies to create intelligent adaptive systems: AI algorithms can use decentralized infrastructure to process data and coordinate decisions, while blockchain ensures verifiability, transparency, and democratic governance of critical infrastructure development. This synergy requires interdisciplinary research at the intersection of computer science, economics, and institutional theory, as well as new forms of popularization of complex concepts, including visual narratives (e.g., Hudoshnyk & Krupskyi, 2022).

As with any research, this study has certain limitations that readers should consider when evaluating its results and implications. Primarily, its predominantly conceptual orientation precludes empirical validation of the proposed structural antifragility model through rigorous quantitative approaches. Although the presented on-chain statistical data support certain propositions, a comprehensive empirical verification of the model requires the development of specialized metrics and long-term observation. Second, the Polkadot ecosystem is still in active development: Polkadot 2.0 components have only recently been implemented, and JAM currently exists only as a specification (Wood, 2025). This limits the ability to assess the long-term effects of structural antifragility and creates a risk of some conclusions becoming outdated as the platform evolves. Third, the analysis of cross-chain business models is based primarily on the technical capabilities of the architecture rather than on empirical data on real-world business practices. The number of active cross-chain applications that fully realize the potential of XCM remains limited, complicating the verification of the proposed typology.

CONCLUSIONS

Structural antifragility is conceptualized as an independent dimension of blockchain system adaptability, complementing institutional (Ethereum) and temporal (Solana) forms. Unlike institutional antifragility, which relies on social consensus and governance evolution, and temporal antifragility, which is achieved through the optimization of temporal processes, structural antifragility is realized through modular organization, spatial isolation of failures, and the cascading propagation of successful solutions between system components. This triad of paradigms extends Taleb's (2012) theory of antifragility to distributed digital systems.

A typology of cross-chain business models with antifragile properties has been developed:

1. Structural decomposition of risks between specialized components.
2. Modular adaptation allowing for the modernization of elements without system downtime.

3. Cascading diffusion of innovations through a common infrastructure.
4. Economies of specialization while maintaining integration.
5. Shared security, reducing barriers to entry.

These attributes allow entrepreneurial structures not only to endure conditions of uncertainty but to actively derive competitive advantages from them.

The antifragility triad of blockchain ecosystems (structural, institutional, and temporal) represents complementary rather than competing paradigms, each optimized for a specific class of problems and operating conditions. The potential for synergy observed in hybrid solutions opens up prospects for creating next-generation systems that integrate the benefits of all three dimensions of antifragility.

Polkadot's conceptual model of structural antifragility has applicability beyond blockchain technologies, proposing an architectural pattern for building business ecosystems where a centralized core provides a common infrastructure and standards, specialized modules are optimized for specific market niches, and interaction protocols ensure service composability without losing component autonomy. This organization allows for the isolation of experimental risks, the scaling of successful solutions, and evolution without disruptive restructuring.

Promising areas for further research include the development of quantitative metrics of structural antifragility for empirical verification of the proposed model, as well as a longitudinal analysis of the evolution of the Polkadot ecosystem to assess the long-term effects of the implementation of Polkadot 2.0 components. Of significant interest is an empirical study of cross-chain business models based on real-world entrepreneurial data and an analysis of the potential of JAM as an architecture that potentially integrates all three dimensions of antifragility. A comparative study of structural antifragility in other modular blockchain ecosystems will allow us to verify the universality of the identified patterns, while an examination of the social and political factors influencing the evolution of decentralized systems with modular architectures will complement the technological analysis with an institutional dimension.

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.

КРОС-ЧЕЙН ФІНАНСОВІ БІЗНЕС-МОДЕЛІ НА ОСНОВІ СТРУКТУРНОЇ АНТИКРИХКОСТІ: ДОСВІД ЕКОСИСТЕМИ POLKADOT

Сучасна блокчейн-індустрія характеризується наявністю безлічі ізольованих спеціалізованих платформ, що створює критичні бар'єри для взаємодії та ставить під сумнів ефективність децентралізованої інфраструктури. Розуміння механізмів структурної антикрихкості має вирішальне значення для створення систем, які не просто адаптуються до стресорів і невизначеності, а активно зміцнюються й розвиваються завдяки їм. Метою дослідження є розробка концептуальної моделі структурної антикрихкості як специфічного типу системної адаптивності, що реалізується через модульну архітектуру гетерогенних мультичейн-мереж, на прикладі екосистеми Polkadot. Дослідження операціоналізує поняття структурної антикрихкості стосовно блокчейн-систем і виявляє її відмінності від інституційної та темпоральної форм антикрихкості.

Виявлено чотири механізми структурної антикрихкості Polkadot: a) гетерогенна мультичейн-архітектура; b) роздільна безпека; c) протокол крос-консенсусних повідомлень (XCM); d) оновлення без хард-форків. Проаналізовано систему децентралізованого управління OpenGov з інструментами conviction voting і мультирольового делегування. Розроблено типологію крос-чейн бізнес-моделей із виділенням антикрихких властивостей: структурна декомпозиція ризиків, модульна адаптація, каскадне поширення інновацій, економія від спеціалізації, роздільна безпека. Ідентифіковані бізнес-моделі демонструють потенціал створення інноваційних підприємницьких стратегій на основі інтероперабельності. Побудовано концептуальну модель, що демонструє взаємозв'язок модульної архітектури, принципів ізоляції збоїв і антикрихких властивостей системи.

Структурна антикрихкість концептуалізована як самостійний вимір антикрихкості блокчейн-систем, що доповнює інституційну та темпоральну форми. Тріада парадигм антикрихкості представляє комплементарні підходи, кожен із яких оптимізований для певних бізнес-завдань та умов функціонування. Розроблена концептуальна модель застосовується як архітектурний патерн побудови адаптивних бізнес-екосистем, що дозволяє ізолювати ризики експериментів, масштабувати успішні рішення та еволюціонувати без руйнівних реструктуризацій. Результати дослідження вносять вклад у розробку інноваційних стратегій сталого та адаптивного розвитку економічних систем, забезпечуючи концептуальну основу для створення модульних організаційних структур, здатних трансформувати стресові фактори в конкурентні переваги.

Ключові слова: блокчейн, Polkadot, бізнес-модель, бізнес-екосистема, децентралізоване управління, стратегеми, ризики, філософія антикрихкості, інтероперабельність, цифрова трансформація

JEL Класифікація: L26, M21, O31, G23