Platform Co-opetition and the Blockchain Scalability Trilemma: An Empirical Investigation of User Preferences for Security, Scalability, and Decentralization

– EXTENDED ABSTRACT –

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Abstract

This study explores the dynamic interplay of competition and cooperation—co-opetition—between Layer 1 (L1) and Layer 2 (L2) blockchain platforms as a response to the scalability trilemma: balancing security, scalability, and decentralization. Using a dataset of 300 million decentralized application (dApp) transactions from Ethereum, Polygon, and Arbitrum, alongside adaptive choice-based conjoint experiments, we identify distinct user preferences shaping platform adoption and multihoming behavior. Our findings reveal that user priorities, from low fees to robust security, drive differentiation among L2 platforms while influencing their alignment with L1 ecosystems. This research offers actionable insights for designing scalable, user-centric blockchain platforms and advances understanding of how co-opetition underpins the growth and governance of Web3 technologies.

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1 Introduction

Blockchain technology has emerged as a potentially transformative force in markets, promising transparency, security, and decentralization. Among the foundational innovations of blockchain is the creation of "base layer" or Layer 1 (L1) blockchain platforms, such as Ethereum, which prioritize decentralization and security. These L1 platforms have laid the groundwork for decentralized finance (DeFi), fungible and non-fungible tokens, and various applications that underlie the promise of Web3—a vision of a transparent, inclusive, and democratic internet. The increasing adoption of these technologies, however, has exposed critical scalability limitations inherent in the architecture of L1 blockchains. This challenge originates from the trade-offs between scalability, security and decentralization due to the difficulty of optimizing all three simultaneously, and has come to be known as the blockchain scalability trilemma.

Layer 2 (L2) solutions have emerged as a critical evolution in blockchain technology to address these limitations. L2 platforms like Polygon and Arbitrum provide scalability enhancements to L1 blockchains by coordinating transactions off-chain while preserving security through periodic checkpoints and proofs anchored on the L1. These platforms enable blockchain ecosystems to scale and serve a broader user base by alleviating congestion and reducing transaction costs. In 2023, Ethereum's L2 platforms reached over 3.5 million monthly active users and amassed more than $6 billion in total value locked (TVL) within their DeFi protocols, marking a significant milestone in the adoption of L2 blockchains.

The interplay between L1 and L2 blockchains introduces a dynamic of platform co-opetition—a mix of competition and cooperation. While L2 platforms compete for users and decentralized application (dApp) providers, they simultaneously cooperate with L1 platforms to enhance scalability and security. This dynamic raises important questions about how L2 platforms govern this relationship, differentiate themselves to attract users, and how users' preferences influence their switching or multihoming decisions among L1 and L2 platforms. Understanding these dynamics is essential for shaping the future of blockchain ecosystems and ensuring their sustainability and growth.

Despite the growing adoption of L2 platforms, there is limited empirical research on how platform co-opetition shapes the blockchain ecosystem and influences user behavior. This paper helps to fill this gap by investigating user preferences for security, scalability, and decentralization and examining how these preferences affect switching and multihoming

decisions.

We constructed a novel dataset comprising 300 million dApp transactions from December 2022 to February 2024 for dApps that multihome across Ethereum, Polygon, and Arbitrum. This dataset enables us to analyze individual user behavior and identify patterns that can inform platform strategies. To understand the dynamic driving that behavior, we conduct an adaptive choice-based conjoint survey to estimate user preferences and we validate our findings with survey data.

Blockchain transaction data is pseudonymous, making it difficult to link transactions to individual users. To overcome this, we offered our survey participants an incentive to provide their wallet addresses in order to send them a commemorative non-fungible token (NFT) and we matched the addresses thus collected with user transaction histories. We also were able to use platform-level metrics and leverage quasi-natural experiments, such as Arbitrum's sequencer halt event, to isolate the impact of specific factors on user behavior.

Our preliminary findings indicate that users consider a platform's security, decentralization, and scalability when making multihoming decisions. Events that compromise security, such as Arbitrum's sequencer halt, have significant spillover effects on user behavior, highlighting the interconnectedness of blockchain ecosystems. Furthermore, our conjoint survey reveals distinct clusters of user preferences, providing insights into how L2 platforms can tailor their strategies to meet the needs of different user segments.

Our methodology demonstrates the potential of blockchain data to address questions that are difficult to answer in proprietary platform settings. The transparency and accessibility of blockchain data provide unique opportunities for researchers to analyze platform dynamics and inform policy decisions. This underscores the broader relevance of our work to the study of digital platforms.

2 Literature Review

Layer 1 platforms, such as Ethereum, were designed with a strong emphasis on decentralization and security. This design philosophy strives to prevent any single entity from controlling the network while aiming to make transactions immutable and verifiable. However, these advantages come with trade-offs: as the network grows, transaction fees rise, and confirmation times increase due to limited throughput. These scalability challenges have hindered the adoption of blockchain technologies in mainstream applications, where low latency and

high throughput are often prerequisites.

The *blockchain scalability trilemma* has been an important concept in understanding the limitations and potential trade-offs in blockchain architecture. This trilemma, which posits that scalability, decentralization, and security cannot be optimized simultaneously, is deeply rooted in the technical framework of blockchain technology as enhancements to one dimension need to come at the expense of the others. For example, increasing transaction throughput typically necessitate larger block sizes, which can reduce decentralization by making it harder for smaller nodes to participate in the network. Similarly, prioritizing decentralization and security often limits the system's ability to process transactions at scale. Introduced by Ethereum's co-founder Vitalik Buterin, the technical foundations of the trilemma have been the subject of extensive academic and industry research, exploring mechanisms to mitigate these trade-offs. This section examines the evolution of the trilemma, the development of Layer 2 (L2) solutions, and the dynamics of platform co-opetition within blockchain ecosystems.

2.1 The Blockchain Scalability Trilemma

The scalability trilemma has been extensively documented in the academic literature. Early foundational work by Nakamoto (2008) introduced Bitcoin's proof-of-work (PoW) consensus mechanism, which prioritized security and decentralization at the expense of scalability. Subsequent studies, such as those by Decker and Wattenhofer (2013), highlighted the scalability bottlenecks inherent in Bitcoin's architecture, particularly the limited number of transactions per second (TPS). Ethereum's introduction in 2015 expanded the capabilities of blockchain through its smart contract functionality, but it also inherited the scalability limitations of PoW. Research by Gencer et al. (2018) quantified Ethereum's decentralization by analyzing the geographic distribution of nodes, concluding that achieving higher TPS would require trade-offs with decentralization. These findings underscored the difficulty of addressing the trilemma within a single-layer architecture.

Emerging blockchain protocols have attempted to overcome these limitations. For instance, Dfinity's Internet Computer and Solana have pursued innovative designs to enhance scalability. However, critics argue that these protocols compromise decentralization, as seen in Solana's reliance on a smaller validator set (Yakovenko et al., 2020). Such trade-offs have led to renewed interest in Layer 2 solutions as a complementary approach.

2.2 Layer 2 Solutions: Enhancing Scalability

Layer 2 solutions represent a paradigm shift in addressing the scalability trilemma. By moving most transactions off-chain while relying on the underlying L1 for security and decentralization, L2 platforms – such as Polygona and Arbitum – significantly enhance throughput and reduce costs. Rollups, state channels, and sidechains are among the most prominent L2 technologies.

Rollups, which aggregate transactions into a single proof submitted to the Layer 1 (L1) blockchain, have gained widespread adoption. Optimistic rollups and zero-knowledge (zk) rollups are the two primary types, each with distinct trade-offs. Optimistic rollups, exemplified by Optimism, rely on fraud proofs to ensure security, while zk-rollups, used by StarkNet, leverage cryptographic proofs for enhanced efficiency (Ben-Sasson et al., 2014). Comparative studies, such as those by Croman et al. (2016), highlight the trade-offs between these approaches, noting that zk-rollups offer faster finality but require more computational resources.

State channels, another L2 solution, facilitate off-chain transactions by establishing a private communication channel between participants. Early implementations, such as the Lightning Network for Bitcoin, demonstrated significant scalability improvements (Poon & Dryja, 2016). However, state channels are less versatile than rollups, as they are limited to predefined participants and specific use cases.

Sidechains operate as independent blockchains that interact with the main chain via cross-chain bridges. Examples include Polygon's Plasma framework and the Loom Network. While sidechains enhance scalability and reduce transaction costs, they rely on their own consensus mechanisms, raising concerns about security and decentralization (Buterin, 2018).

2.3 Platform Co-opetition

The relationship between Layer 1 and Layer 2 platforms exemplifies the concept of platform co-opetition, a term coined by Brandenburger and Nalebuff (1996). This dynamic—where competitors collaborate for mutual benefit—is particularly pronounced in blockchain ecosystems. L2 platforms rely on L1 blockchains for security and decentralization, while L1 platforms benefit from the scalability enhancements provided by L2 solutions.

Empirical studies have begun to analyze the strategic implications of co-opetition in blockchain ecosystems. Cohen and Zhang (2022) explored the pricing strategies of L2 plat-

forms, finding that transaction fees significantly influence user adoption. Similarly, Chemaya and Liu (2022) investigated user preferences for security, scalability, and decentralization, concluding that these factors shape switching and multihoming behaviors.

The role of governance in co-opetition is another critical area of inquiry. L2 platforms must navigate complex governance structures to align incentives between stakeholders. For example, Arbitrum's sequencer halt incident in 2023 highlighted the challenges of maintaining operational reliability while scaling (Arbitrum Foundation, 2023). Such events underscore the need for robust governance mechanisms to mitigate risks and ensure ecosystem stability.

2.4 User Preferences and Behavior

Understanding user behavior is essential for designing effective blockchain platforms. Recent studies have employed adaptive choice-based conjoint analysis to quantify user preferences. Johnson and Orme (2007) pioneered this methodology, which has been adapted to blockchain contexts by researchers such as Obermeier et al. (2024). These studies reveal distinct clusters of user preferences, with some prioritizing security and decentralization while others value scalability and low transaction costs.

Multihoming behavior—the practice of using multiple platforms simultaneously—is another critical aspect of user behavior. Empirical evidence suggests that multihoming mitigates platform-specific risks but also increases competition among L2 platforms (Eisenmann et al., 2006, Bakos and Halaburda 2020). For instance, dApp providers often deploy their services on multiple L2 platforms to reach a broader audience, further intensifying competition.

2.5 Our contribution to the literature

Conceptual contribution:

- We contribute to the general platforms literature by studying coopetition without formal governance in a setting that allows us to test if user preferences in an open system can overcome platform dynamics.

- We contribute to the blockchain literature by studying coopetition between L1 and L2 blockchains as a solution to the scalability trilemma, which is key to the success of decentralized blockchain platforms

Empirical contribution:

- We contribute to the general platforms literature, multihoming between L1 and L2 blockchains provides the opportunity to test how user preferences interact with platform dynamics such as network effects or differentiation in platform characteristics.
- We contribute to the blockchain literature by showing the existence of user groups with heterogeneous preferences regarding possible solutions to the scalability trilemma. We thus provide early evidence that user preferences are important for the evolution of the L2 ecosystem.

3 Empirical Strategy

We adopt a multi-method approach to explore user preferences and behavior within Layer 1 (L1) and Layer 2 (L2) blockchain ecosystems. We study the factors driving platform adoption and multihoming behavior with dApp-side analysis utilizing blockchain transaction data and with survey-based data collected via adaptive choice-based conjoint surveys.

3.1 Data Collection and Sources

Our transaction dataset comprises over 300 million decentralized application (dApp) transactions conducted on dApps that multihome on Ethereum, Polygon, and Arbitrum between December 2022 and February 2024. This extensive dataset provides a granular view of user activity across multiple platforms, enabling us to track transaction volume, fees and execution over time. Additionally, we collected platform-level metrics such as token exchange rates, transaction fees, and measures of decentralization and security, which serve as independent variables in our econometric model.

We obtained data on individual user preferences using an adaptive choice-based conjoint survey as detailed below. To address the pseudonymous nature of blockchain data, we matched user survey responses with wallet addresses to link on-chain behavior to stated preferences. This approach enables a detailed analysis of individual user decisions and the ability to compare them with user preferences as revealed in the conjoint survey.

3.2 Adaptive Choice-Based Conjoint Survey

Adaptive choice-based conjoint (ACBC) survey is a methodology pioneered by Johnson and Orme (2007). This approach is well-suited for quantifying user preferences in complex decision-making environments. Our ACBC survey was designed to evaluate user trade-offs among decentralization, security and scalability, which comprise the blockchain trilemma. The conjoint survey was structured to reflect real-world platform attributes and their variations. Table 1 summarizes the attributes and levels included in the survey.

Attribute	Levels
Relation to L1	Optimistic roll-up, zk-roll-up, PoS sidechain
Likelihood of attack	Very unlikely, somewhat likely, very likely
Withdraw window	Instant, 2 days, 14 days, not possible
Sequencer failure mechanism	No mechanism, self-sequencing, L1 enforced
Nakamoto index	1, 2-5, 5-50, >50
Transaction latency	<5 seconds, 5-30 seconds, 30 seconds-5 min, 5-30 min
Transaction costs	<$0.001, $0.001-$0.01, $0.01-$0.10, $0.10-$1.00, $1.00-$10.00

Table 1: Attributes and levels included in the conjoin survey

Participants are presented with hypothetical L2 platforms featuring combinations of these attributes and asked to choose their preferred platform. The survey adapts to their responses, refining subsequent questions to focus on the most relevant trade-offs for each participant. Two pilot studies were conducted to validate the survey design and refine the methodology. The first pilot study involved 95 participants, 23 of whom shared their wallet addresses to receive a commemorative NFT reward. Analysis of these wallet addresses provided initial insights into user behavior, including the distribution of their transactions across Ethereum, Polygon, Optimism, and Arbitrum. The second pilot study identified preliminary user clusters and validated the heterogeneity of preferences across the participant pool. These findings informed certain design modifications for the full-scale survey.

3.3 On-Chain Data Analysis

The dApp-side analysis uses blockchain transaction data to examine user behavior and platform dynamics. To address the pseudonymity of blockchain data we collected over 80,000 smart contract addresses associated with 324 multihoming dApps. This dataset enables us to track user transactions across multiple platforms, linking activity to specific dApps and wallet addresses. For survey respondents that provide their wallet address, we are able to analyze the relationship between stated preferences and actual behavior.

To address the rapid pace of platform development and overlapping effects we collected multiple platform-level metrics so we can model the platform choice. These metrics include:

- **Token Exchange Rates**: Fluctuations in token prices, which can influence user behavior.
- **Transaction Fees**: Platform-specific costs associated with conducting transactions.
- **Decentralization and Security Measures**: Metrics such as the Nakamoto index and the number of validators, which provide insights into platform governance.

Additionally, we leveraged quasi-natural experiments to isolate the impact of specific events on user behavior. For instance, the Arbitrum sequencer halt event in June 2023 served as a case study to analyze the effects of platform reliability on transaction activity. Using a difference-in-difference (DiD) approach, we compared transaction volumes on Arbitrum before and after the event, using Ethereum and Polygon as control groups.

3.4 Choice Model

We model the relationship between user preferences, platform attributes, and platform choice as follows:

$$Y_{it} = \beta_0 + \beta_1 X_t + \beta_2 X_p t + \beta_3 X_i + \beta_4 X_i X_{pt} + \epsilon_{it}$$

Where: Y_{it} represents user i's platform choice at time t, X_t encodes general macro-economic factors of the crypto industry, X_{pt} is platform p's security, scalability, and decentralization features (e.g., transaction fees or number of validators) at time t, X_i user preferences for security, scalability, and decentralization, and ϵ_{it} is the error term.

We obtain X_i from our survey responses and the rest of the user-level variables by mining the transactions of these respondents on the L1 and L2 blockchains.

4 Results

Participants in the pilot version of our adaptive choice-based conjoint study were asked to evaluate hypothetical L2 platforms based on the seven most important attributes underlying the trilemma of decentralization, security and scalability. Analysis of the 95 responses determined the relative importance of these attributes (see Figure 1).

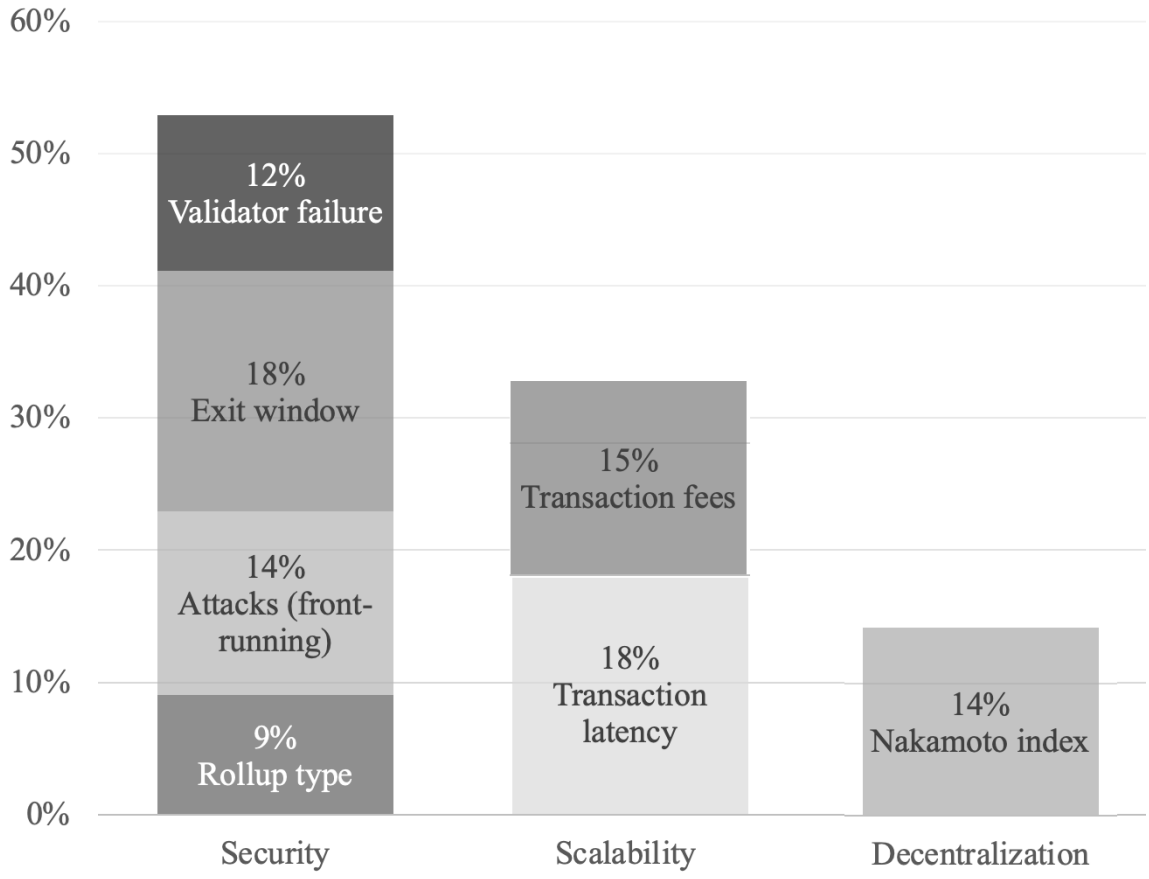


Figure 1: Attribute importance based on pilot study

The analysis also identified six primary user clusters and their associated priorities (see Figure 2):

- **Cluster 1**: Balanced Preferences: Users in this cluster demonstrated an even distribution of importance across all attributes, valuing security, scalability, and decentralization equally.

- **Cluster 2**: Latency and Cost-Sensitive Users: These users prioritized low transaction costs and minimal latency, indicating a preference for platforms with fast and inexpensive transactions.
- **Cluster 3**: L2 Reliability: This group emphasized robust failure mechanisms and reliability, showing a strong aversion to platforms with sequencer vulnerabilities.
- **Cluster 4**: Decentralization Advocates: Users in this cluster prioritized decentralization and exit options, reflecting concerns about platform governance and security.
- **Cluster 5**: Speed and Switching Flexibility: These users valued rapid transaction processing and the ability to switch platforms easily.
- **Cluster 6:** Speed at All Costs: This group prioritized transaction speed above all other factors, even at the expense of security and decentralization.

Cluster	L1 relation	Attacks	Exit window	Sequencer failure	Nakamoto index	Latency	Costs
1	14.28	14.28	14.28	14.28	14.28	14.28	14.28
2	15.38	11.52	9.40	4.29	10.64	22.66	26.07
3	3.91	16.06	22.30	21.19	12.31	9.89	14.29
4	4.51	11.99	26.62	6.50	23.21	12.47	14.66
5	6.79	15.50	21.18	9.65	12.93	19.70	14.21
6	0.29	0.92	0.64	0.90	1.21	94.42	1.57

Cluster 1: Balanced	Cluster 4: Decentralization and exit
Cluster 2: Latency & costs	Cluster 5: Speed and switching
Cluster 3: L2 reliability	Cluster 6: Speed at all costs

Figure 2: User clusters based on pilot study

The conjoint analysis also quantified the relative importance of each platform attribute. For example, transaction costs and latency emerged as critical determinants for cost-sensitive users, while security-conscious users placed a higher value on decentralization and robust failure mechanisms. The results are consistent with previous studies, such as Chemaya and Liu (2022), which emphasized the trade-offs users are willing to make between scalability and security.

Pereira et al (2023) report significant multihoming by both dApps and users. This was confirmed in our sample. Analysis of transaction data for respondents that provided us their wallet address revealed that these users engage with multiple L1 and L2 platforms leveraging each platform's characteristics consistently with their preferences as revealed in their conjoint study responses.

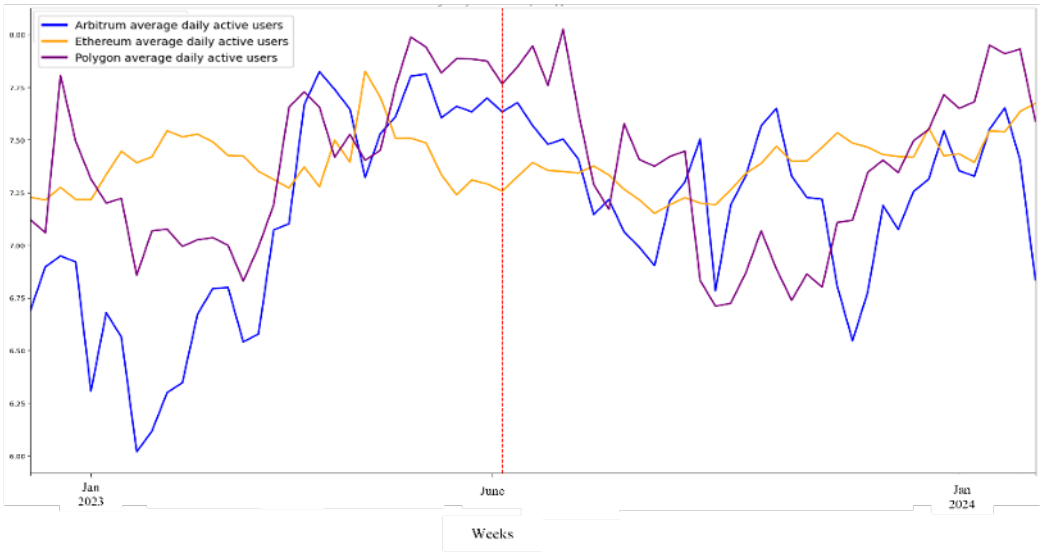


Figure 3: Transactions of multi-chain dApps before and after Arbitrumn sequencer failure

Our preliminary findings include:

- Clear differences in platform adoption based on user preferences. For example, latency-sensitive users favored Optimism, while security-conscious users gravitated toward zk-rollup-based platforms.

- Arbitrum's sequencer halt in June 2023 provided valuable insights into the impact of platform reliability on user behavior. A hardware failure in the main sequencer node forced Arbitrum to stop processing new transactions. The sequencer node was restarted after several hours with new redundancies to increase its stability. Following this incident, transaction activity of multihoming dApps (n=324) on Arbitrum declined compared to Ethereum, while there was a potential spillover effect on other L2s (e.g., Polygon PoS) as shown in Figure 3. This highlights the interconnectedness of the ecosystem and the importance of resilience in maintaining user trust.

5 Conclusion

Blockchain platforms represent a significant evolution in the realm of digital platforms, introducing a transformative combination of transparency, security, and decentralization. However, the blockchain scalability trilemma—the need to balance scalability, security, and decentralization—remains a persistent challenge. We investigated how blockchain ecosystems leverage co-opetition between Layer 1 (L1) and Layer 2 (L2) platforms to address this challenge, fostering a new paradigm of growth and innovation. By examining user preferences and their implications for platform design, our research sheds light on the critical factors shaping blockchain platform strategies and user behavior.

The interplay between L1 and L2 platforms exemplifies a unique form of co-opetition, wherein platforms simultaneously compete for users while cooperating to optimize scalability and security. L2 platforms, such as Polygon and Arbitrum, extend the functionality of L1 blockchains like Ethereum by offloading transactions and improving scalability without sacrificing the underlying security. This duality of competition and cooperation enables the blockchain ecosystem to grow and innovate, fostering a symbiotic relationship that benefits all stakeholders.

A key contribution of this study lies in identifying distinct user preferences and their influence on platform adoption. Through adaptive choice-based conjoint experiments and analysis of on-chain data, we identified six user clusters with diverse priorities:

- Balanced Preferences: Users who value security, scalability, and decentralization equally.
- Latency and Cost-Sensitive Users: Those who prioritize low transaction costs and minimal latency.
- L2 Reliability Advocates: Users emphasizing robust failure mechanisms and platform reliability.
- Decentralization Advocates: Individuals concerned about governance and seeking decentralized solutions.
- Speed and Switching Flexibility Seekers: Users favoring rapid transactions and platform interoperability.
- Speed at All Costs: Users prioritizing transaction speed above other factors.

These clusters highlight the heterogeneity of user preferences, emphasizing the need for tailored platform strategies. For instance, cost-sensitive users may gravitate towards platforms offering lower transaction fees, while security-conscious users prioritize decentralization and robust governance.

Our data revealed significant multihoming by both dApps and users, reflecting the match between user needs and the characteristics of different platforms. Multihoming also mitigates platform-specific risks, enabling users and dApps to navigate ecosystem disruptions, such as the Arbitrum sequencer halt in June 2023.

Our findings offer actionable insights for blockchain platforms seeking to enhance user satisfaction and drive adoption:

- Customization Based on User Clusters: Platforms can develop targeted strategies for different user segments. For instance, cost-sensitive users would benefit from platforms focusing on low fees and efficiency, while decentralization advocates require transparent governance and robust security.

- Innovative Features and Differentiation: Platforms can set themselves apart by addressing emerging user needs, such as instant withdrawals, enhanced interoperability, and failure-resistant mechanisms.

- Leveraging Co-opetition: L2 platforms must continue to align their strategies with L1 platforms, leveraging the symbiotic relationship to maximize scalability without compromising security.

- Resilience and Governance: Events like the Arbitrum sequencer halt highlight the importance of reliability and robust governance in maintaining user trust. Platforms should invest in redundancy, fail-safe mechanisms, and transparent governance structures to mitigate risks.

The diversity of user preferences underscores the importance of a multifaceted approach to blockchain design. Platforms must strike a delicate balance between scalability, security, and decentralization to meet the needs of diverse user segments. This balance is crucial for the sustainability and growth of blockchain ecosystems, particularly as they face increasing adoption and evolving user demands.

Furthermore, the transparency and accessibility of blockchain data provide unique opportunities for empirical research. Unlike proprietary platforms, blockchain ecosystems offer

unparalleled visibility into transaction dynamics, enabling researchers to analyze user behavior and platform strategies at a granular level. This transparency enhances our understanding of digital platforms and informs policy decisions, contributing to the broader discourse on platform economics.

This study highlights the role of user preferences in shaping platform dynamics and provides actionable insights for designing sustainable and user-centric blockchain ecosystems. Our findings are not only relevant to blockchain but also offer broader implications for digital platforms navigating the complexities of competition, cooperation, and user behavior in fast-evolving environments. By leveraging the transparency and accessibility of blockchain data, this research contributes to the ongoing dialogue on the future of decentralized technologies and their impact on society.

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