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FINANCIAL AND INFORMATIONAL INTEGRATION THROUGH ORACLE NETWORKS

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ABSTRACT

Oracles are software components that enable data exchange between siloed blockchains and external environments, enhancing smart contract capabilities and platform interoperability. Oracles play key roles in decentralized finance and blockchain applications in centralized finance. We find that integration into decentralized oracle networks is positively associated with key measures of economic activity such as Total Value Locked, triggered by positive network effects in adoption and usage. Our study reveals symbiotic gains from enhanced interoperability and network effects across protocols on a given chain and among integrated chains. Oracle integration appears to improve risk-sharing and mitigates contagion, increasing resilience during turbulent periods in crypto markets. Overall, oracles emerge as a crucial component to enable informational and economic integration in decentralized finance ecosystems.

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"Me and other people in this room believe that the crypto, blockchain, and Web 3 infrastructure is the next iteration of the financial system."—Sergey Nazarov, Chainlink CEO.[1]

1 Introduction

Blockchain technology has evolved beyond facilitating simple cryptocurrency transactions to serving as an engine for powering decentralized finance (DeFi), decentralized applications (DApps), and the development of non-fungible tokens (NFTs), among other Web3 ecosystems. The technology is also gaining broader traction in centralized finance (CeFi), facilitating innovations in tokenization as well as interbank and cross-border payments (Harvey and Rabetti, 2024).[2] Blockchain technology has spurred various financial innovations, with most use cases relying heavily on smart contracts—computer code and programs that specify the terms of transactions and execute automatically when the contracting parties meet predetermined conditions. However, blockchains have a fundamental limitation, they cannot automatically interact with data and systems outside their native network environments.

To provide bridges across blockchains or between on-chain and off-chain systems, smart contracts require access to an additional infrastructure referred to as "oracles"—node(s) maintaining and updating the system states using information and data external to the native blockchain or smart contract. The inherent inability of blockchains to access external data in the absence of this additional piece of software is known as the "oracle problem." Oracles are essential for triggering smart contract execution based on off-chain or cross-chain events that are relevant to the terms and conditions specified in the contract. For instance, DeFi protocols, such as decentralized lending or exchanges for crypto-derivative trading, rely on price feeds from asset markets. Oracles also convey weather information for insurance products, randomness for gaming, IoT sensors for supply chain management, and ID verification for governments. Reliable oracles are integral to expanding the functionality of blockchains by offering a universal gateway to off-chain sources of information and synchronizing multiple distributed ledgers to facilitate financial activities while maintaining privacy, autonomy, and security in the networks and the broader ecosystem.

In principle, any node in a network can serve as an oracle. However, a centralized setup to deliver data to a smart contract introduces a single point of failure and concentration of market power, counteracting the security and competition benefits of the decentralized architecture of blockchain and DeFi applications (Cong and He, 2019). A unitary centralized oracle (CO) that goes offline, transmits inaccurate data, or is corrupted can cause financial losses

[1] While discussing the importance of oracles in integrating decentralized finance with traditional finance and financial institutions ("Crypto Summit at the White House, March 7, 2025" — See https://tinyurl.com/284j7vdr).

[2] For instance, JP Morgan's blockchain platform Onyx has generated hundreds of billions of dollars in repo transactions (https://tinyurl.com/2s3vrwps). The Monetary Authority of Singapore (MAS) has been piloting a unified financial sector for portfolio management, foreign exchange trading, and the issuance of tokenized assets (https://tinyurl.com/5fuhv5yy). HSBC recently launched tokenized gold on the London Exchange, and other banks and non-bank initiatives have been gaining ground worldwide (https://tinyurl.com/yc2694bx).

to users and network instability, given how blockchain transactions and smart contracts are automated, immutable, and irreversible. The vulnerabilities of COs and the imperative of maintaining a decentralized architecture have led to the development of decentralized oracle networks (DON), which authenticate data using multiple oracles and aggregate their input before feeding the data to smart contracts.

We conduct the first comprehensive empirical analysis of how informational and financial integration through oracle networks affects blockchain and DeFi ecosystems. At a first glance, the benefits of DON integration seem obvious. For instance, asset price feeds through oracle integration would allow a DeFi lending protocol to permit users to incorporate assets not native to its blockchain, thereby expanding its locus of borrowing and lending activities. However, oracles also introduce vulnerabilities, in addition to incurring costs. Integration through a CO introduces various risks—such as single point of failure—and even DON integration exposes the smart contract to cyber risks generated in the oracle integration process.[3] Therefore, whether DeFi protocols benefit from oracle integration and whether the type of integration matters remains an open empirical question.

To address these questions, we collect data on thousands of DeFi protocols spanning several types of financial services and their respective oracle integration. We augment our dataset with key variables, such as the total funds raised from venture capital and other early investors, whether the protocol has undergone an audit by a reputable firm, the specific type of service it provides (e.g., lending, exchange, or yield farming), and its native blockchain type.[4] These factors help control for pre-launch characteristics that may influence the outcome variables in our analysis. In addition, we incorporate millions of lines of coding activity from DeFi protocols' open-source repositories on GitHub to account for platform development. We capture community engagement by the number of followers of each DeFi protocol on the social media platform X.

We begin our analysis by examining the determinants of DON integration, estimating logistic regressions on whether a DeFi protocol adopts DON before launch, with all independent variables lagged to address reverse causality concerns. Our findings suggest that fundraising has a weak association with DON integration, likely because oracle administrators ease adoption for resource-constrained protocols through revenue-sharing models.[5] Audited protocols are more likely to adopt DON, indicating that concerns about smart contract security influence this decision. Moreover, code production is strongly correlated with DON integration, suggesting that protocols expanding their services require external data sources beyond their native blockchain. Finally, we find stronger effects of DON integration for protocols in Derivatives, Lending, Options, and Prediction markets due to their reliance on external data, such as price feeds and real-world event outcomes. Adoption is also higher on newer blockchains

[3] According to defillama.com, about three billion dollars have been lost due to such smart contract vulnerabilities arising from bridging services such as oracles. See https://defillama.com/hacks.

[4] See the appendix for detailed descriptions of each DeFi industry and a list of the 200 most popular blockchains.

[5] For instance, decentralized exchanges may allocate a small percentage of revenue fees to oracle providers based on price feed usage.

like Arbitrum and Avalanche, highlighting the greater benefits for smaller chains as expanded market access drives cross-chain user activity.

Next, we provide initial insights into the economic implications of oracle integration. We use total value locked (TVL)—the total value of digital assets locked or staked in a particular DeFi protocol or DApp—as our key outcome variable. Such assets include cryptocurrencies that are staked, loaned, or otherwise committed to a DeFi platform and actively participate in the platform's economic activities.[6] By representing the total capital committed to a protocol or blockchain, TVL provides a useful proxy for assessing the scale and engagement of its ecosystem—much like deposits function in traditional financial institutions.[7] We document rapid TVL growth following DON integration, particularly over longer time horizons, DON-integrated protocols achieving statistically significantly higher TVLs than their peers. On average, DON-integrated protocols exhibit 33%, 42%, and 82% higher TVL than their peers within the first month, quarter, and year from launch, respectively. This finding suggests that DON integration facilitates service expansion, attracts demand, and enhances economic activity as the protocol ecosystem matures. Interestingly, the TVL growth gap between DON-integrated protocols and those relying on centralized oracles (COs) widens over time. This pattern indicates that DON not only enables access to a broader range of services but also enhances reliability and security, mitigating integration risks such as single points of failure—a vulnerability to which COs are more exposed.

We also document a surge in post-integration TVL correlations among integrated chains, especially for young chains such as Avalanche, reflecting enhanced interoperability among integrated protocols. We also examine symbiotic gains among integrated protocols to mitigate selection effects that could drive the observed correlations. We conjecture that, by integrating through DON, DeFi protocols potentially gain value from enhanced interoperability between integrated protocols and between chains—depending on the mass of integrated protocols. Our empirical analysis of Ethereum, the largest smart contracting platform and a blockchain with the largest number of integrated protocols, supports this conjecture. TVL correlations among DeFi protocols on the Ethereum blockchain are increasing in the mass of integrated protocols, while the volatility of these correlations decreases.

Finally, we examine the mechanisms underlying potential risk-sharing benefits. A plausible channel is that as more protocols integrate, liquidity becomes more interconnected, reducing idiosyncratic shocks that would otherwise impact individual platforms. Yet, the increased correlations within and across blockchain networks may also engender greater systematic risk. To examine these conjectures, we investigate whether DON integration and interoperability improve ecosystem resilience during crises. Specifically, we investigate whether a recent event that

[6] Such activities include lending and borrowing, liquidity provision, yield farming, or participating in a decentralized exchange. The assets are generally locked in smart contracts and generate financial returns through interest, staking rewards, or governance tokens.

[7] Market participants often use TVL as a proxy for economic activity (e.g., https://docs.defipulse.com/metrics/tvl) and this proxy has also been used in the nascent DeFi literature (e.g., Landsman et al., 2023; DeSimone et al., 2025).

triggered a significant meltdown in crypto markets—the Terra-Luna crash—differentially affected the economic activity of integrated versus non-integrated protocols. Although the entire DeFi market crashed during this event—exhibiting a high level of contagion across the ecosystem—we document that integrated DeFi protocols experienced faster recovery in their economic activities than non-integrated protocols, suggesting that DON integration also fosters market resilience through more efficient risk-sharing.

Our findings suggest that DON integration benefits DeFi protocols through enhancing adoption and interoperability. However, since oracle integration is voluntary for many DeFi protocols, we avoid causal interpretations. Still, we conduct various tests to address endogeneity concerns. Our main results hold, particularly over longer time horizons post-integration, when applying Heckman correction for selection bias (Heckman, 1979, 1990) and matched-sample analysis. Additionally, as DON integration carries fewer risks than CO integration, our comparison of integration types—especially during crises—further strengthens robustness.

Our study advances the emerging literature on blockchain economics and DeFi. Harvey et al. (2021), John et al. (2022), Mik (2023), and Harvey and Rabetti (2024) offer general introductions to the topic. An emerging literature in computer science focuses on the technical aspects of oracle networks (e.g., Breidenbach et al., 2021; Zhang et al., 2020). Adams et al. (2022) study the difficulty, potential cost, and likelihood of oracle manipulations on Uniswap v3 under Ethereum PoS while Braun et al. (2023) uncover severe collusion vulnerabilities in decentralized autonomous organizations in general. Complementing these conceptual discussions, we present the first economic analysis of oracle integration in the DeFi space, establishing a foundation for future research in this space.

Our study yields insights relevant to both practitioners and regulators.[8] In addition to serving as the breeding ground for prominent FinTech start-ups, the DeFi market alone has become the largest alternative financing market worldwide, amassing several billions of dollars in funds raised, investments, and transaction volume. Blockchain-based Web3 infrastructures are beginning to play roles in supply chain management, environmental, sustainability, and governance (ESG) projects, and differential privacy.[9] Just as the study of "tokenomics" has emerged as the backbone for the successful valuation of effective token system designs for blockchain-based ventures, our study informs entrepreneurs, investors, DeFi communities, and regulators regarding decisions related to platform interoperability, information aggregation, and smart contracting in this vibrant emerging space.[10]

[8] Our study is pertinent to the current debate about crypto regulation (e.g. Amiram et al., 2022; Cong et al., 2023; Landsman et al., 2023; Cong et al., 2023). Our paper complements the work of Amiram et al. (2024), who argue that self-regulation and industry initiatives are potentially more effective than government regulation.

[9] See Lee et al., 2024 and Luo et al., 2024 for blockchain adoption benefits in the corporate setting.

[10] Tokenomics, the economics of token categorization, functionality, and valuation, is introduced and developed in a series of articles (e.g. Cong et al., 2021; Li and Mann, 2024; Cong et al., 2022; Malinova and Park, 2023). The tokenomics of staking (Cong et al., 2025) is particularly relevant for DONs; DON providers such as Chainlink have introduced staking programs to incentive desirable reporting.

2 Institutional Background and Data

2.1 Oracles and the DON Approach

Web3 and blockchain oracles. Web2 (i.e., Internet-based platform) primarily comprises user data and real-world information stored on centralized servers, making these databases vulnerable to data loss and manipulation. In contrast, Web3 purports to offer greater access, transparency, and user ownership through decentralized and trust-minimized public blockchains. The aim is to give users more control over their data and enable their participation in decentralized applications and peer-to-peer interactions without having to rely on conventional centralized platforms or intermediaries that may possess concentrated market power.

However, the blockchain oracle problem remains a significant challenge for smart contracting. While oracles can provide access to off-chain or cross-chain data and computation, there are concerns about the quality and reliability of that data because smart contracts cannot verify the accuracy of external data sources, which could result in errors or even malicious manipulation of contract contingencies and outcomes. Ensuring data reliability and preventing data manipulation are both crucial for successfully adopting Web3 and smart contract technology.

Information reporting, manipulation, and a DON solution. The data manipulation issue in smart contracts arises when unreliable or centralized oracles are used as a gateway to off-chain or cross-chain data sources, leading to inaccurate or tampered information being fed into the contract. Consequently, the contract may not be able to execute its functions with the same degree of determinism as the underlying blockchain.

The data manipulation problem can be divided into two parts: the risk of a single point of failure due to the use of a centralized oracle node for information retrieval and the inability of an insecure oracle to validate real-world data accurately. Centralized or insecure blockchain oracles undermine the trust minimization property of blockchains, as they allow individual participants or institutions to control the data inputs fed into the blockchain, exposing the system to manipulation.

DON offers a potential solution to the data manipulation problem by enabling secure validation and verification of off-chain data through a decentralized consensus mechanism. Unlike COs, DON require multiple nodes to reach a consensus, reducing the risk of data manipulation. To illustrate how DON solve the problems inherent to COs, consider Chainlink, the leading DON service, as an example. Chainlink allows off-chain data and computation to interact with smart contracts on various blockchains. The network uses a distributed pool of oracles run by several enterprises, data providers, and DevOps teams to enable information transfer and computation between blockchains and external systems. Chainlink's DON leverages security techniques similar to the consensus mechanisms that power blockchain technology and decentralization, requiring multiple independent nodes to validate

an oracle report before submitting it on-chain. In addition, Chainlink's system considers data quality, historical reliability, and average response time.

Note that current DON are not panaceas. Achieving decentralization, scalability, and truthfulness at the same time is difficult, if possible at all (Garratt and Monnet, 2023; Cong et al., 2025). Some DON may appear decentralized, but if, for instance, one oracle copies another or use the same data provider, they behave like a CO. The governance structure of DON has raised concerns (e.g., Appel and Grennan, 2023; Benhaim et al., 2024; Das et al., 2023; Goldberg and Schär, 2023; Han et al., 2023) and some recent studies discuss a variety of collusion problems (e.g., Cong and He, 2019; Braun et al., 2023). Moreover, existing DON services often entail centralized DON administrators, though they are shifting to decentralized systems where multiple DON administrators can participate and compete. In that sense, the DON we refer to in this study can be considered hybrid setups where DON retain some centralized elements but are more decentralized than COs.

DON services and use cases. DON integration currently involves deploying a network of oracle nodes on the blockchain on which the focal DeFi protocol resides, and setting up mechanisms for the oracle network to get compensated for the services provided. The integration potentially helps the DeFi protocol to thrive by providing the architecture needed for the efficient execution of its services while supporting a growing user base. Some of the main DON functions include data feeds, verifiable random number (VRF) generators, APIs to external data sources, and smart contract automation (e.g., keepers). DONs have been widely used in cross-chain asset transfers, real-world asset (RWA) tokenization, gaming, supply-chain management, prediction markets, etc.

Smart contracts frequently need to act upon the prices of assets in real-time. For example, Synthetix, a platform for trading of synthetic assets, uses data feeds to determine prices on its derivatives platform.[11] Lending and borrowing platforms such as AAVE use data feeds to validate the total value of posted collateral. DON data feeds are potentially the quickest and most secure way to connect smart contracts to the real-world market prices of assets.[12] In addition, DON enables smart contracts to access an external data source in a decentralized manner. Whether the contract requires sports results, the latest weather, or publicly available data, the DON contract library provides crucial tools for DeFi contracts.

Another DON service, the VRF, is a provably fair and verifiable random number generator that enables smart contracts to access random values without compromising security or usability. VRF generates one or more random values and provides cryptographic proofs of how those values are determined for each request. The proof is published and verified on-chain before any applications can use it. This process ensures that results cannot be tampered

[11] Synthetix is a DeFi protocol that enables the creation and trading of synthetic assets (Synths) on the Ethereum and Optimism blockchains. These Synths track the value of real-world assets like cryptocurrencies, fiat currencies, commodities, and stocks without requiring direct ownership.

[12] Data feeds enable smart contracts to retrieve the latest pricing data for an asset in a single call.

with or manipulated by any entity, including oracle operators, miners, users, or smart contract developers.

Finally, DON can provide decentralized smart contract automation services known as Keepers. Keepers allow smart contracts to outsource regular maintenance tasks in a decentralized manner. The network aims to provide a mechanism for incentivizing execution and governance of execution within the Keeper ecosystem. Relying on Keepers can help DeFi protocols reach the market faster and save gas fees (transaction fees) by offloading expensive on-chain automation logic to the decentralized Keepers Network.

2.2 Data Collection

We gathered data on DeFi protocols from early 2021 to November 2024 on several key variables, including TVL, staking activity, fundraising, code development, and social media activities—resulting in the largest sample on DeFi protocols to date. Information concerning DeFi protocols mainly comes from DefiLlama, which we complement with time series data on price and market capitalization from a combination of coingecko.com and coinmarketcap.com, code production (e.g., commits) from github.com, social media interactions from twitter.com, and on-chain (e.g., transactions and ownership) data from ETHplorer.com, EtherScan.com, and chains nodes such as Avalanche, Binance, Arbitrum, and others. This extensive dataset covers 4,988 DeFi protocols spanning dozens of distinct DeFi industries, such as decentralized exchanges, lending, and yield farming. Finally, we acquired information on hundreds of oracle integrations from publicly available information on the Chainlink network, data aggregators such as Defillama, and DeFi protocol disclosures on various social media platforms. Our database, therefore, constitutes the most comprehensive effort to date for empirical analyses of the economics of oracles and DONs.

2.3 Patterns and Trends

The market for oracles has grown tremendously in recent years with rapidly rising demand due to the evolution of the DeFi marketplace. Some oracles, such as CoinGecko price feeds, are centralized and provide specific services. While they offer speed and efficiency, they introduce a single point of failure and potential manipulation risks. Others, such as Chainlink and Pyth, are administrators that manage the operation of third-party oracle networks.[13] These networks aggregate data from multiple sources to enhance security, accuracy, and reliability, reducing the risk of manipulation.

[Table 1 about here]

[13] See Appendix A for a brief description of the main oracles.

Table 1 shows that the market for oracles has secured over $63 billion in TVL for 1,030 DeFi protocols across 69 blockchains, as of November 2024. Chainlink has become the most prominent DON administrator, with over half the current market share. Of the 68 oracles currently in operation, 30 have successfully secured at least four million dollars in TVL.

Figure 1 breaks down the number of DeFi protocols, their respective TVL, and the number of unique blockchains served per oracle. Chainlink leads in the number of integrated protocols (39.5%) and TVL in these protocols (51%). Among the top five DON sorted by TVL, Chronicle, WINkLink, and Pyth, follows Chainlink with 14%, 11%, and 11% respectively. These four oracle administrators account for 86.3% ($54.4b) of the market in terms of TVL.

[Figure 1 about here]

The DeFi landscape. Table 2 reports the characteristics of DeFi protocols grouped by industries. Liquid Staking protocols have the largest TVL ($28.98 billion), while Chain protocols have the largest market capitalization ($6.17) among all categories. Decentralized Exchanges (DEXs) category are the largest group of DeFi protocols, accounting for about a third of the market (438 protocols). Other industries such as *Lending* ($19.41 billion) and *Bridge* ($17.55 billion) have also amassed significant TVL. Notably, the average TVL is often smaller than the total market capitalization, except for categories where staking is an essential aspect of tokenomics (e.g., rewards or voting rights), such as *Bridge*, *Lending*, and *Liquid Staking*. Together with *DEX*, these industries constitute the core of DeFi market functioning.

[Table 2 about here]

Table 2 reports the distribution of DeFi protocols grouped by industry.[14] Although *DEX* and *Yield* are the largest industries with 1,486 and 529 protocols, respectively, the percentage of DON-integrated protocols within these two industries is only 1.5% and 11.25%, respectively. This is a counter-intuitive finding since both types of protocols depend on pricing information, implying that DON integration could yield sizable benefits. Other DeFi protocols with high demand for price feeds, such as *Derivatives*, *Lending*, and *Options*, feature much higher levels of integration, with about half of such protocols being DON-integrated. On average, across 5,123 DeFi protocols in our database, only 16.5% utilize decentralized oracles.

These insights suggest two direct implications. First, there is still considerable room for decentralized oracles services growth in the DeFi landscape. This is especially true for decentralized exchanges and yield farming, which account for about 40% of the market in terms of the number of protocols launched. Second, if it were indeed the case that DON integration confers benefits such as operational enhancement, interoperability gains, and price

[14] See Appendix A for a brief description of each industry mentioned in this table.

resilience for integrated protocols, then the overall DeFi market would be operating at sub-optimal levels of integration. We now examine these propositions through an empirical investigation of DON integration.

3 Determinants and Consequences of DON Integration

We begin by assessing the timing and determinants of DON integration. In a baseline analysis, we examine the relationship between measures of success of DeFi protocols and DON integration. We also address endogeneity concerns and formally test for differences across DeFi industries in the extent of DON integration.

3.1 Dataset

Our full sample, conditioned on data availability for all variables of interest, yields 4,664 DeFi protocols of which 640 have implemented DON integration and 187 have implemented CO integration. Table 3 depicts the summary statistics for the variables used in the empirical analysis. *TVL* is the total value of digital assets locked or staked in a particular DeFi protocol or DApp—including cryptocurrencies that are staked, loaned, or actively committed to the platform's economic activities. *Staking* is the total amount of staked cryptocurrencies expressed in millions of dollars. *Fundraising* is the total amount of funds raised expressed in millions of dollars. *MCap* is the total market capitalization expressed in millions of dollars. *# Chains* is the total number of listed blockchains. *Auditing* is an indicator of whether a Big 3 auditor audited the DeFI protocol (as per Landsman et al., 2023). *Open-Source* is an indicator of whether a DeFi protocol is coding open source on the GitHub platform. *Coding* is the number of commits at the DeFi protocol Github repositories (e.g., Gefen et al., 2024). *Followers* is the number of followers in the DeFi protocol social media channel. All variables in this panel are captured within 90 days before the DeFi protocol launch, except for those denoted with superscript [1], which are captured a month from the protocol launch date.

We start by presenting statistics on the pre-launch characteristics of DeFi protocols. On average, a typical DeFi protocol in our sample accumulates approximately $16.5 million in total value locked (TVL), $6.9 million in staked assets, and $9.9 million in market valuation within the first month after launch. Before launch, DeFi protocols raise an average of $6.52 million, with 23% undergoing audits by popular auditors and 7% being open-sourced. Additionally, they generate approximately 1.6 thousand GitHub commits and attract nearly 30 thousand followers on the social media platform *X*. In relative terms, protocols integrating DON have, on average, slightly higher TVL and staking but lower fundraising and market capitalizations than those integrating CO. Additionally, protocols with DON integration are listed on more blockchains, tend to be more open-source, and have greater social media

engagement—in terms of followers—compared to protocols with CO integration. Interestingly, however, protocols with DON integration undergo fewer audits by popular auditors than their centralized counterparts.

3.2 Determinants of DON Integration

To assess the determinants of DON integration, we estimate the following logit model:

$$DON_{it} = \alpha + \beta Fundraising_{i,t-1} + \gamma Auditing_{i,t-1} + \mu Coding_{i,t-1} + \delta Followers_{i,t-1} + \Lambda + \epsilon, \quad (1)$$

where dependent variable *DON* in Equation 1 is an indicator variable taking the value of one for a DeFi protocol with DON integration and zero otherwise. *Fundraising* is the total value raised with venture capital and other early investors in fundraising rounds. *Auditing* is an indicator variable denoting whether the protocol was audited by a popular auditor as per Landsman et al. (2023); *Coding* is the total number of commits available across all repositories for an open-sourced protocol. *Followers* is the total number of followers on the protocol's social media platform X. All variables are lagged and capped at the period ending at the protocol launch. Λ represents a vector of year-month, blockchain, and DeFi industry fixed effects (e.g., Wooldridge, 2010; Abadie and Kasy, 2020); ϵ is the error term. Subscript i indicates cross-sectional regressions at the DeFi protocol level and t is a time subscript.

[Table 4 about here]

Table 4 reports the main determinants of DON integration and provides several insights. We begin by describing the set of pre-launch characteristics of the protocols. First, we find weak evidence that financial resources play a role in determining DON integration. This suggests that even resource-constrained DeFi protocols can adapt to DON integration through various shared revenue schemes. However, protocols that undergo audits by well-known smart contract auditors are significantly more likely to integrate DON. This indicates that such protocols are more likely to offer financially complex products that require access to data outside the native blockchain environment, thereby necessitating greater scrutiny in smart contract coding. Similarly, open-source protocols exhibit a high likelihood of DON integration. This suggests that the decision to open their codebase to a broad spectrum of developers not only fosters collaboration but also facilitates further service extensions through shared code and forks. Since expanding a DeFi protocol's capabilities requires data and information integration, DON become a necessary tool for these protocols. Finally, social media engagement is also positively associated with the likelihood of DON integration. This implies that protocols with a rapidly expanding user base may need to enhance their services by bridging to other blockchain ecosystems or accessing data beyond their native environments.

Next, we examine how the nature of DeFi protocol services influences their decision to integrate DON. We find that DeFi protocols in the Derivatives, Lending, Options, and Prediction markets are significantly more likely to

adopt DON integration than those in other industries. There are at least two reasons for this positive relationship. First, these protocols require access to price feeds for assets outside their native blockchain. For example, DeFi lending platforms need constant price updates on non-native crypto assets used as loan collateral. Second, these protocols offer complex financial products that depend on real-world information. For instance, prediction markets providing betting services on sports outcomes need access to external data sources to accurately determine match results and settle bets. Interestingly, decentralized exchanges (DEXs) are less likely to incorporate DON compared to protocols in other industries. This finding is somewhat puzzling, given that some DEXs facilitate swaps between assets on different blockchains. This suggests that many DEXs rely on in-house bridging solutions rather than third-party DON—a risky approach, as users may struggle to assess whether these protocols can reliably maintain real-time price information.

In addition, we examine the association between blockchain type and DON integration. We find that protocols operating on newer blockchains like Arbitrum and Avalanche are more likely to integrate DON than those on mature blockchains like Ethereum. This outcome is driven by at least two key factors. First, younger blockchains have a higher demand for external data feeds since their native ecosystems are still developing. Unlike Ethereum, which has a well-established infrastructure with numerous integrated services, newer chains often lack deep liquidity, robust price discovery mechanisms, and comprehensive on-chain data. As a result, DeFi applications on these platforms—especially lending protocols—rely more heavily on DON to obtain accurate pricing for non-native assets used as collateral. Without these external data feeds, lending markets would struggle to function efficiently, as price inaccuracies could lead to improper liquidations and increased systemic risks. Second, protocols on emerging blockchains must compete aggressively to attract users and liquidity, often necessitating integration with mature networks like Ethereum. Many DeFi users prefer the security and deep liquidity of established ecosystems, making cross-chain compatibility essential for newer blockchains to gain traction. By integrating DON, protocols can enhance interoperability with Ethereum, facilitating seamless asset transfers, price feeds, and risk management tools. This integration is particularly crucial for protocols aiming to bridge liquidity across chains or provide services that depend on external market data. Overall, the need for reliable off-chain data and the strategic imperative of cross-chain connectivity drive DON adoption among DeFi protocols on newer blockchains, reinforcing their role in fostering blockchain interoperability and ecosystem development.

Finally, we examine how the timing of their launch influences DeFi protocols' decision to integrate DON. Using 2024 as the base category, we find that protocols launched in the early years of DeFi development were more likely to integrate DON than those launched in subsequent years, with this trend reversing in more recent years. Our interpretation is that early adopters were primarily visionaries and well-established blockchain enterprises, such as the pioneering DeFi lending platforms Compound and Aave. However, following the DeFi boom of 2021—a

period characterized by a surge in new platform launches—DON integration became less prevalent. This suggests a potential inverse relationship between DON adoption and the irrational exuberance often observed during market booms. As the DeFi market matured, particularly after major industry crises such as the Luna-Terra collapse and the FTX fallout, protocols launched in later years returned to integrating DON into their networks. Overall, our findings suggest a pattern of market learning, coupled with the natural maturation of the DeFi ecosystem over time, and a plausible demand for DON services as a response to market-wide risks.

3.3 Integration and Economic Growth

We next explore the incentives for DON integration and its economic implications at the blockchain and DeFi-protocol levels.

Blockchain level. Blockchain developers must access various external resources to create advanced smart contract applications. These resources include key DeFi primitives such as money markets, decentralized stablecoins, and synthetic asset prediction markets. Beyond DeFi primitives, as noted earlier, the provisioning of verifiable random number generators may also create value by boosting the development of on-chain gaming applications. Moreover, DON allows the automation of some development tasks, thereby minimizing costs and enhancing user experiences.

Take Avalanche as an example—its successful integration of price feeds demonstrates how DON adoption can drive ecosystem growth.[15] Before the deployment of DON, the Avalanche ecosystem faced significant limitations in developing automated market makers (e.g., decentralized exchanges) and yield aggregators (e.g., decentralized lending). Following DON integration, various money markets and other oracle-powered applications emerged, enhancing liquidity and accelerating ecosystem expansion. Notably, Avalanche's total value locked (TVL) surged 88-fold within the first few months following DON adoption.

[Figure 2 about here]

Figure 2 illustrates the evolution and implications of DON integration for several chains. The first (left) panel of the figure reports the evolution of the number of oracles in these chains. Ethereum, Matic, and BSC have the most growth in the number of oracles, reaching over 100 oracle networks deployed in the first three months following integration. The panel on the right illustrates gains in TVL at the chain level economy after integration. Using TVL scaled by a chain's TVL at its integration date as a measure of these gains, we document rapid growth for

[15] Avalanche is a high-performance, scalable, and decentralized blockchain platform designed for smart contracts and decentralized applications (dApps). Developed by Ava Labs and launched in 2020, Avalanche aims to overcome key limitations of earlier blockchain networks, such as slow transaction speeds, high fees, and scalability constraints.

Arbitrum—growing more than 300% in the first ten days after integration—and significant growth for Avalanche and Ethereum in the first three months after integration.[16]

DeFi-protocol level. Next, we examine the economic implications of DON integration at the DeFi protocol level, particularly in the period following a protocol's launch. The potential benefits of DON integration vary across protocols and blockchain networks, influenced by several factors, including the demand for real-time data from smart contract developers, the adoption of oracle-enabled applications by users, and the relative competitiveness of the newly supported blockchain compared to already integrated blockchains.

As a blockchain-agnostic infrastructure, DON can extend its support to any network, facilitating data availability, off-chain computation, and cross-chain interoperability. By providing reliable external data and computational resources, DON enables developers to create more advanced and sophisticated DeFi protocols, such as algorithmic stablecoins, decentralized derivatives, and automated asset management platforms. Moreover, the availability of oracle services fosters innovation and enhances network effects within blockchain ecosystems. As protocols gain access to accurate, secure data, they can offer more efficient financial products, improving market liquidity and attracting institutional and retail participation. This, in turn, strengthens the competitive positioning of the blockchain, increasing its adoption and overall market activity. Ultimately, DON integration acts as a catalyst for ecosystem expansion, reducing barriers to entry for developers and unlocking new economic opportunities and applications.

In short, we expect that the effects of DON integration on TVL and market capitalization will be more salient when a DeFi protocol goes live. To test this proposition, we estimate the following regression specifications:

$$TVL_{it} = \alpha + \beta(DON)_{it} + \gamma(CO)_{it} + \Theta_{i,t-1} + \Lambda_{it} + \epsilon_{it}, \tag{2}$$

where the dependent variable TVL in equation 2 represents the TVL expressed in logarithms over horizons of a week, month, quarter, or year. The equation has two variables of interest: DON, an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise; and, CO, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise. The base category includes DeFi-protocols without oracle services provided by external parties. Θ is a vector of DeFi protocol pre-launch characteristics listed in equation 1. Similarly, as in the previous specification, all variables are captured within 90 days before the DeFi protocol launch, except *Staking*, the total amount of staked cryptocurrencies expressed in millions of dollars, which is captured at the protocol launch date—note that staking is not available before the protocol launch as users need access to specific on-chain address to stake their cryptocurrencies. Λ represents a

[16] Arbitrum is a Layer 2 (L2) scaling solution for Ethereum, designed to enhance transaction speed, reduce fees, and improve scalability while maintaining Ethereum's security. It was developed by Offchain Labs and launched in 2021. Arbitrum competes with Optimism (OP), zkSync, and StarkNet, all of which offer different scaling solutions for Ethereum.

vector of industry, blockchain, and year-month fixed effects. ϵ is the error term. The subscript i indicates cross-sectional regressions at the DeFi protocol level at launch-date t. Note that, although we use industry and blockchain fixed effects to control for industry and blockchain-specific characteristics likely to influence TVL growth on DeFi-protocol's post-launch windows, there could be residual concerns regarding unobserved protocol characteristics or market conditions at the time of smart contract launch. This is why we also add year-month fixed effects across all specifications to potentially mitigate concerns that unobserved characteristics or market conditions at launch drive our main results.

[Table 5 about here]

The regression results, reported in column (a) of each panel of Table 5, indicate a strong positive relationship between DON integration and the TVL of DeFi protocols, particularly over longer time horizons. On average, DeFi protocols that integrate DON experience supplementary TVL growth of 21%, 33%, 42%, and 82% in the first week, month, quarter, and year, respectively, following their on-chain launch.

These findings yield two key insights. First, the economic effects of DON integration become more statistically robust as the DeFi protocol matures. This suggests that protocols leveraging DON are better positioned to expand their service offerings over time, attracting greater user demand. Second, the gap between DeFi protocols that integrate DON and those relying on alternative oracle solutions widens over time. This indicates that DON not only provides access to a broader range of services but also offers enhanced reliability and security, mitigating integration risks such as single points of failure.

Taken together, these results highlight DON integration as a key catalyst for the expansion of DeFi protocol services and a potential safeguard for users exposed to the risks associated with more complex financial products dependent upon access to financial data and information outside the protocol's native blockchain.

3.4 Endogeneity Concerns

A potential concern in interpreting our results entails endogenous selection—protocols that undertake DON integration could systematically possess ex-ante characteristics that lead to better outcomes. To address this concern, we undertake two additional econometrics tests.

First, we employ the two-step methodology to correct for selection effects (Heckman, 1979, 1990). In the first step, the dependent variable is whether a protocol has adopted an oracle. We run a Logit regression on the full sample, including control variables, as well as year-month, blockchain, and DeFi industry, fixed effects as in equation 2. Notably, the *IMR* (inverse Mills ratio) is calculated as the ratio of the probability density function (PDF) to the cumulative distribution function (CDF) of the standard normal distribution derived from the first-stage regression

results. Then, we run the second-stage outcome regression using the full sample of DeFi-protocols, including the inverse Mills ratio or λ included as an additional control variable to account for unobservable factors that influence both the probability of selection and the outcome of interest.

Column (b) in each panel of Table 5 presents the second-stage results. Notably, the estimates for our variable of interest DON, remain virtually identical to those in the corresponding column (a) which does not include Heckman correction for selection bias. This suggests that potential confounders influencing a DeFi protocol's decision to integrate DON are adequately controlled for in the previous specification. However, the statistically significant λ in longer time windows indicates that the proposed approach does introduce some additional robustness. In particular, we observe that potential sources of selection bias stem from specific pre-launch characteristics of DeFi protocols, including fundraising outcomes, auditing by well-known smart contract auditors, and coding activity in open-source repositories, as these variables are the most affected in the second-stage estimates.

Our second approach, to addressing endogeity concerns, entails a matched-sample analysis that uses the observed characteristics of all of the protocols in our sample to pin down the effects of DON integration by comparing outcomes for pairs of integrated and non-integrated protocols matched on other characteristics.

Specifically, we use Nearest Neighbour (NN) propensity score matching (PSM), a common method for estimating treatment responses from observational data. We use multivariate weighted k-nearest neighbors-based control group selection within industries and chains for clustering, pairing the elements of the treatment (i.e., protocols with DON integration) and control groups in the original vector space of the covariates (protocol characteristics, including staking, fundraising, auditing, open-source coding, and number of followers in social media channels). The dissimilarities of the protocols are calculated as the weighted distances of the subjects. The weights are calculated from a logistic regression model fitted to the status of the treatment assignment. We use $k = 3$, meaning each treated observation is matched to three controls, to improve the overall balance between the two groups.

[Table 6 about here]

Table 6 reports summary statistics for the matching exercise. Panel A displays the mean values for the characteristics of DeFi protocols with DON integration, others (including CO integration), and their mean differences.[17] The last column, which reports the percentage improvement of the matching procedure, indicates that the propensity matching score successfully improved the distance between the two groups' characteristics by an overall 133%. The significant improvement in the balance of pre-launch characteristics between groups is consistent with our previous finding that these covariates are the primary source of selection bias observed in the longer-window results.

[17] We use the Kolmogorov-Smirnov (K-S) test, a non-parametric test that compares two independent samples (two-sample K-S test), to measure the maximum absolute difference between the cumulative distribution functions (CDFs) of the treated and control samples. At a significance level of $\alpha = 0.05$, we fail to reject the null hypothesis, meaning we do not have sufficient evidence to conclude that the two samples come from different distributions.

Panel B reports the number of matched observations within analysis clusters across groups. As expected, matched control protocols decrease when conditioning on data availability of the treated group. To improve matching outcomes, we match three observations from the control group to each observation in the treatment group.

Column (C) in each panel of Table 5 presents the matched-sample results. The estimates for the our variable of interest *DON* as per equation 2 but conditioned on matched samples yields similar results as in previous specifications in columns (a) and (b). These results further validate our previous assessment that DON integration significantly impacts TVL of DeFi protocols, particularly over longer time horizons. Interestingly, ceteris paribus, the results of CO integration on TVL are stronger (at some horizons) in this specification, suggesting that the decision to choose a CO integration is more likely to be prone to omitted pre-launch characteristics than the decision to choose DON integration.

Altogether, the results from both approaches—with correction for selection and use of matched samples—alleviate endogeneity concerns. Nevertheless, we do not claim that our results completely establish causality.

3.5 Extended Discussion and Analysis

Next, we briefly summarize the results of several additional tests to expand the discussion on DON integration at the DeFi protocol level (for detailed results and discussions see Appendix B). All the tests in this section condition DON integration only to the major player, as this is the only decentralized oracle in which we have access to additional granular data.[18]

Our extended analysis presents additional key insights. First, protocols integrating DON before launch experience more pronounced economic effects, signaling a more reliable and fully developed service to users. In contrast, protocols integrating oracles post-launch may face vulnerabilities and weaker effects on total value locked (TVL). Additionally, DON integration is most significant for price feed services, with early adopters integrating these feeds before going live. However, other services like Verifiable Random Functions (VRF) or Proof of Reserves show less impact on TVL. Moreover, we examine the spillover effects of DON integration, particularly in the relationship between DeFi lending protocols and decentralized exchanges (DEXs). Lending protocols benefit from price feeds, and their integration can positively impact DEXs by attracting arbitrage opportunities, thus enhancing the overall blockchain ecosystem. Altogether, these extended findings further highlight the importance of timely and strategic DON integration in maximizing the economic outcomes of DeFi protocols.

[18] We are thankful to ChainLink Labs for providing detailed information.

4 Interoperability and Resilience in Times of Crisis

We now examine how DON integration facilitates symbiotic gains at both the blockchain and individual protocol levels, utilizing the major DON integration event involving Avalanche, a leading alternative to Ethereum for smart contracting. Moreover, we also analyze whether interoperability benefits or hurts the DeFi sector as a whole.

In particular, as the mass of integrated protocols increases, users have more efficient options to diversify risk through accessing more investment and DeFi transaction choices. In addition, as users become more risk-averse during times of crisis, protocols with DON integration may attract demand from protocols with alternative integration solutions with less risk-sharing. But on the other hand, network outcomes being more correlated via oracle integration may facilitate the transmission of shocks to the entire market, thereby increasing systemic risk. To shed light on the relative importance of these opposing forces, we conduct an initial investigation on the net effects of enhanced interoperability among integrated protocols in the context of market-wide crises.

4.1 Interoperability Effects: Network Symbiosis

Interoperability at the blockchain Level. As an illustration of whether blockchains experience symbiotic gains from DON integration, we examine how Avalanche's DON integration affects the correlations of its TVL with those of other chains.

[Table 7 about here]

Panel A of Table 7 reports the Spearman correlation coefficients showing the association between Avalanche's TVL and the TVLs of other chains in the 60-day periods (or longer periods in cases where data are available) before and after Avalanche's DON integration.[19] Panel B, which reports the changes in the correlations after integration, shows that correlations between Avalanche's TVL and those of other chains increase in the post-integration period in all cases except that of Binance. The TVL correlations with respect to Ethereum, Fantom, Harmony, Heco, and xDai, increased by 0.21, 0.57, 0.44, 0.31, and 1.13, respectively.

[Figure 3 about here]

Figure 3 illustrates how the correlations increased post-integration, possibly reflecting positive symbiotic gains arising from increased interoperability between chains.[20] For instance, the correlation between the TVLs of Avalanche and Ethereum increased by 36% post-integration.

[19] Source: defillama.com and messari.io.

[20] All changes in correlations, except that for Binance, are significant at the 99% confidence level.

Adopting DON offers several benefits for new blockchain platforms such as Avalanche. First, DeFi protocols launched in the chain post-adoption are easier to integrate. Second, the chain also benefits from increased interoperability, as the mass of integrated protocols increases because some protocols are multichain or share standard DON services. Together, these two factors affect protocol adoption and growth. Avalanche's successful DON implementation exemplifies how integration into DON can promote growth within the chain (i.e., at the protocol level) and among integrated chains.

Interoperability at DeFi protocol level. As protocols within a given chain implement DON integration, are there symbiotic gains among integrated protocols? Table 8 reports the Spearman correlations for protocols on the Ethereum blockchain. *Mean* represents the mean differences for TVL correlations before and after protocols integrate. *Sd* represents the average differences in standard deviations for TVL correlations before and after integration. *Protocols* is the number of matched protocols (in time) for which correlations are obtained.

[Table 8 about here]

The positive differences in mean correlations among integrated protocols (Panel A) indicate that interoperability increases as the mass of integrated protocols expands within a given chain. The post-integration increase in correlation coefficients is 0.01, 0.05, and 0.20 for fewer than 7, between 7 and 14, and between 14 and 21 integrated protocols, respectively. Interoperability effects continue to increase, but at a lower rate, when the number of integrated protocols exceeds 21. Independent of the number of integrated protocols within a given chain, interoperability effects are positive on average. Coupled with increases in TVL correlations between protocols, TVL volatility between protocols—captured as the standard deviation of the correlations—decreases by 0.06 on average. Panel B reports the results for all protocols (including non-integrated protocols). Interoperability effects remain positive, with a smaller increase in mean correlations and a smaller decrease in volatility than when only integrated protocols are considered.

Altogether, the results suggest that DON integration leads to increased TVL correlations and decreased volatility of TVL correlations among integrated protocols, supporting the view of symbiotic gains through integration and interoperability effects among integrated protocols in a given chain. However, our findings should be interpreted with caution. Our results are based only on the Ethereum blockchain, the largest chain in number and significance (as measured, for instance, by market capitalization) of DeFi protocols. Chain-specific effects may also affect correlations, such as overall growth in the number of users due to market conditions.

4.2 Resilience in Times of Crisis

Next, we investigate whether DON-integrated protocols show more resilience in crises. Anecdotal evidence suggests that DON integration could contribute to price stability during a market crisis. When the Curve Finance protocol was hacked on July 30, 2023, the price of its native token crashed to near zero on decentralized exchanges. However, since the centralized exchange Binance kept its price at $0.6 and Chainlink assigns a large weight to Binance in its price feed, there was a floor on the price of the token, which prevented further deterioration or even liquidation. The market recovered subsequently.[21] Motivated by this example, we looked for more general empirical evidence as to whether DON integration improves resilience.

To do so, we exploit the largest market-wide event in the DeFi space that shook the cryptocurrency market—the unraveling of the TerraLuna algorithmic stablecoin in May 2022. The plunge in Luna's value was instigated by its ties to TerraUSD (UST), the algorithmic stablecoin of the Terra network. On May 7, over $2 billion of UST was unstacked (removed from the Anchor Protocol) and hundreds of millions of dollars worth of coins were swiftly liquidated. This colossal sell-off drove the price of UST down from $1 to $0.91. As large volumes of UST were unloaded, the stablecoin began to lose its peg. This sparked a panic sell-off of UST, triggering the creation of more Luna and boosting its circulating supply. In the aftermath of the crash, crypto exchanges began delisting Luna and UST pairings. Essentially, Luna was discarded as it lost value and became worthless. This event led to substantial and broad-based declines in cryptocurrency valuations, accompanied by spikes in price volatility.

Figure 4 depicts daily standardized market capitalization coefficients around these two events for DeFi protocols with DON integration (Treat) and without DON integration (Control). All continuous predictors are mean-centered and scaled by one standard deviation. Standard errors (reported in confidence intervals) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain* level.

[Figure 4 about here]

Our empirical analysis indicates that DeFi protocols with DON integration rebounded more quickly from this market downturn than those without DON integration.[22] Overall, the examination of the Luna-Crash event, the largest recent negative shock in the cryptocurrency landscape, suggests that DeFi protocols with DON integration exhibit greater resilience than those without DON integration in times of crisis. This finding indicates that additional interoperability benefits of integration help mitigate market-wide shocks.[23]

[21] See https://cointelegraph.com/news/cex-price-feed-curve-price-collapse-100m-vulnerability.

[22] Our results provide additional support for the model in Uhlig (2022) by showing that integrated protocols have a faster market recovery after participants' suspension of convertibility's threshold is reached.

[23] This parallels evidence from the literature on globalization that countries more integrated into global trade and finance tend to be more resilient to crises and also recover more quickly from crises (both country-specific and global) that do occur. In particular, trade openness

5 Conclusion

We provide the first comprehensive description of the DeFi oracles market and document benefits accruing to DeFi protocols that integrate DON. These benefits appear in the post-launch phase of DeFi protocols, and include overall increased activity and enhanced interoperability, and, particularly, improved risk-sharing in times of crises. Our results suggest that DON integration facilitates economic and financial growth through symbiotic gains from enhanced interoperability between protocols in a given chain and—depending on the mass of integrated protocols—among chains. Despite concerns about systemic risks arising from integration, integrated protocols experience more resilient than non-integrated protocols during recent periods of turbulence in crypto markets. Yet, despite our efforts to mitigate endogeneity concerns, our findings should be interpreted with caution. The DeFi market is nascent and fast-evolving. Innovative protocols and upcoming crypto regulations may disrupt the current market structure. Additionally, more mature and stable markets with alternative channels for information and value exchange with other (conventional) markets are outside the scope of our analysis. Moreover, as the space of oracles administrators expands, it will be worthwhile to study how interactions among administrators affect the market for DeFi protocols.

Oracles seem to be poised to play a crucial role in the development and operation of Central Bank Digital Currencies (CBDCs) and other tokenized financial assets, bridging the gap between traditional financial systems and blockchain networks.[24] As governments and financial institutions explore CBDCs, oracles can enhance their functionality, interoperability, and security in several key ways. For CBDCs, oracles can provide real-time exchange rate data, facilitating seamless currency conversions and cross-border transactions. They can also support smart contract automation, enabling programmable monetary policies that respond dynamically to macroeconomic conditions such as inflation, employment rates, and interest rate changes. Furthermore, oracles can integrate with regulatory databases to ensure compliance with anti-money laundering (AML) and Know Your Customer (KYC) requirements while preserving privacy through zero-knowledge proofs.

Oracles are essential for the growing ecosystem of tokenized financial instruments, including securities, bonds, commodities, and real estate. Tokenized assets require accurate, real-time pricing data, which oracles aggregate from multiple sources to prevent manipulation and enhance liquidity. Smart contracts for tokenized bonds and equities can leverage oracles to automate interest payments, dividend distributions, and corporate actions based

is seen to have these benefits for emerging markets and developing economies.See Calvo et al. (2004), Frankel and Cavallo (2004), Cavallo (2007), and Edwards (2008).

[24] CBDCs and asset tokenization were central topics during our presentation and discussions on the implications of DeFi oracles with financial regulators and monetary policymakers, including at the Bank of Canada, Bank of Finland, Bank of Italy, Bank of Israel, Bank of Japan, the European Banking Authority, the European Systemic Risk Board, the Federal Reserve, the International Monetary Fund, the Monetary Authority of Singapore, the Office of the Comptroller of the Currency, the Securities and Exchange Commission, and the Swiss National Bank.

on real-world financial events. Additionally, oracles enable dynamic risk assessment by providing credit ratings, volatility measures, and settlement confirmations, ensuring efficient collateral management and lending practices in DeFi. The rise of cross-chain oracles, privacy-preserving technologies, and AI-enhanced data validation will further strengthen their role in shaping the future of programmable finance, unlocking new possibilities for both decentralized and institutional financial markets.

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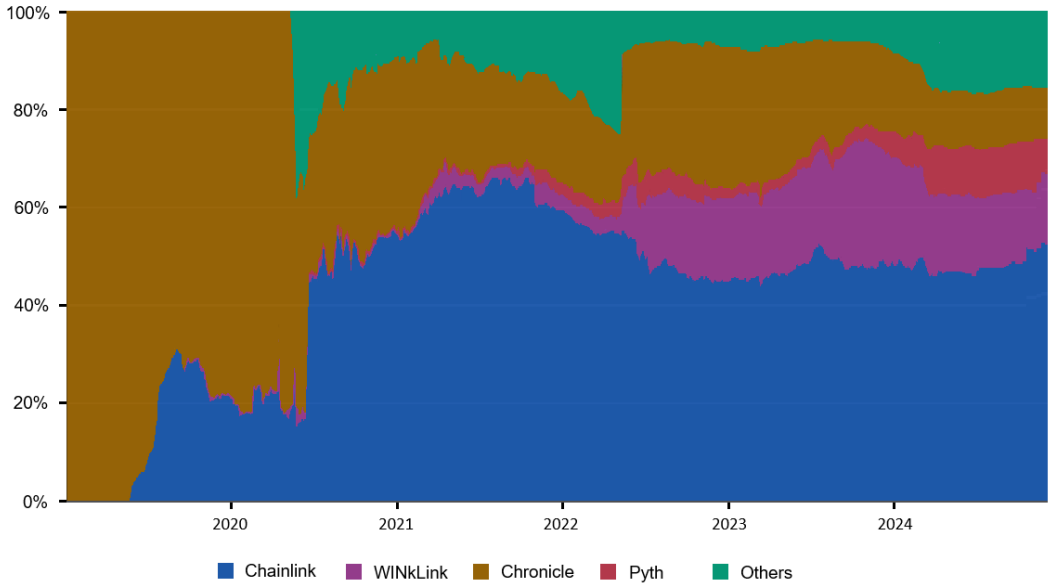
Figure 1. The market of oracles: These figures depict the evolution of market share in the oracle markets (9) Panel A) and their total market share as of November 2024 (Panel B). Market share is calculated based on the TVL of integrated protocols. In panel A, the Y-axis represents the percentage share of the market for the four largest oracles—Chainlink, WINkLink, Chronicle, and Pyth—as well as all remaining oracles categorized under 'Others.' Our TVL measure excludes values generated from staking, pool 2, and governance transactions. The data used to generate this plot is available at https://defillama.com/oracles.

Panel A: Market Evolution



Panel B: Largest Oracles (by total TVL secured)

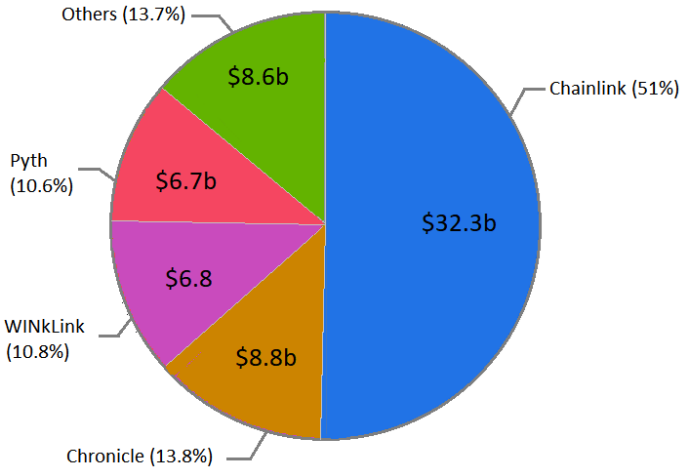


Figure 2. Decentralized oracle networks' evolution: This figure depicts the evolution of oracle networks deployed across blockchains and their respective TVL. The X-Axis captures the days from the first deployed oracle. The Y-Axis captures the number of deployed oracles in the left-hand-side figure, and the TVL Growth (measured in percentage) in the right-hand-side figure.

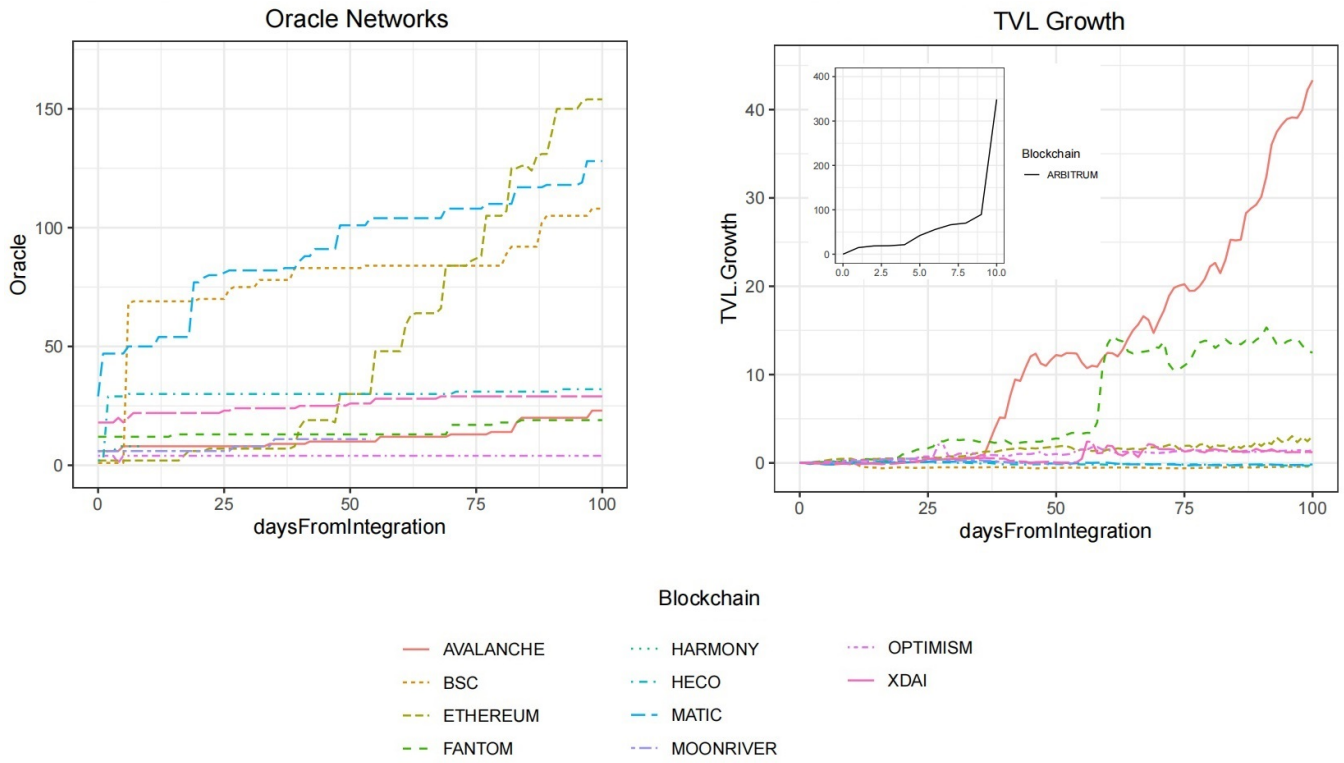


Figure 3. TVL correlations (Avalanche): This figure depicts Spearman correlations for TVL among chains. The left-hand-side (right-hand-side) figure depicts correlations among chains before (after) Avalanche integration. Spearman correlations among chains are presented in the range −1 (dark red) to +1 (dark blue).

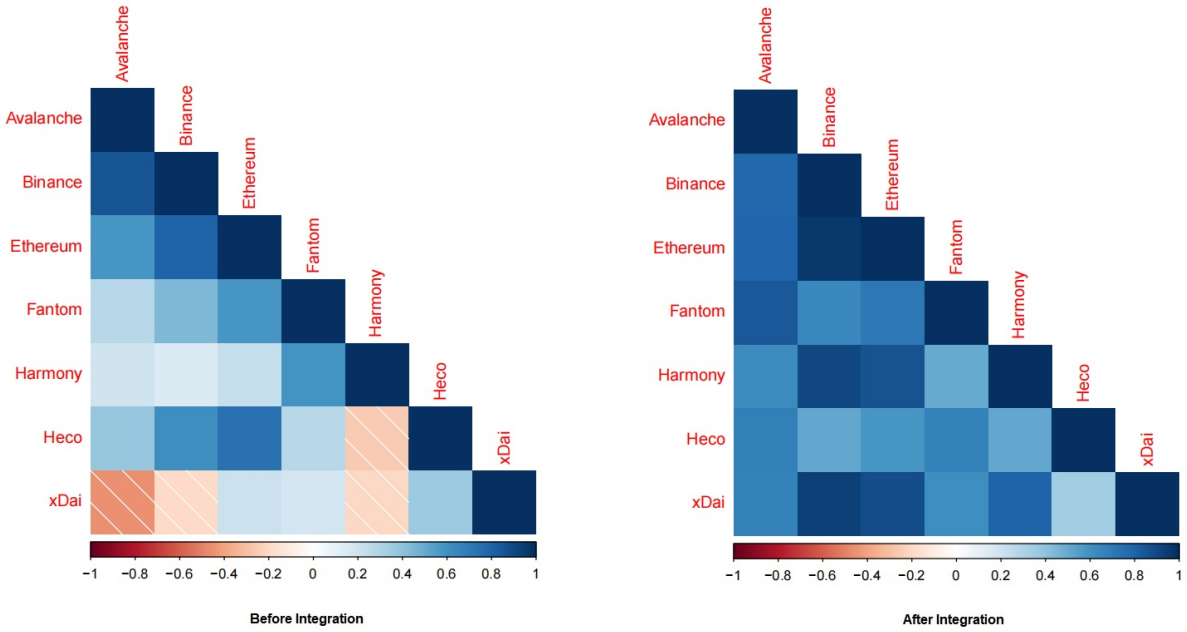


Figure 4. Resilience in times of crisis: This figure depicts daily standardized total value locked coefficients for DeFi protocols with DON integration (*Treatment group*, in light blue) and without DON integration (*Control group*, in orange), around the Terra-Luna crash event. All continuous predictors are mean-centered and scaled by 1 standard deviation. Standard errors (reported in confidence intervals) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*.

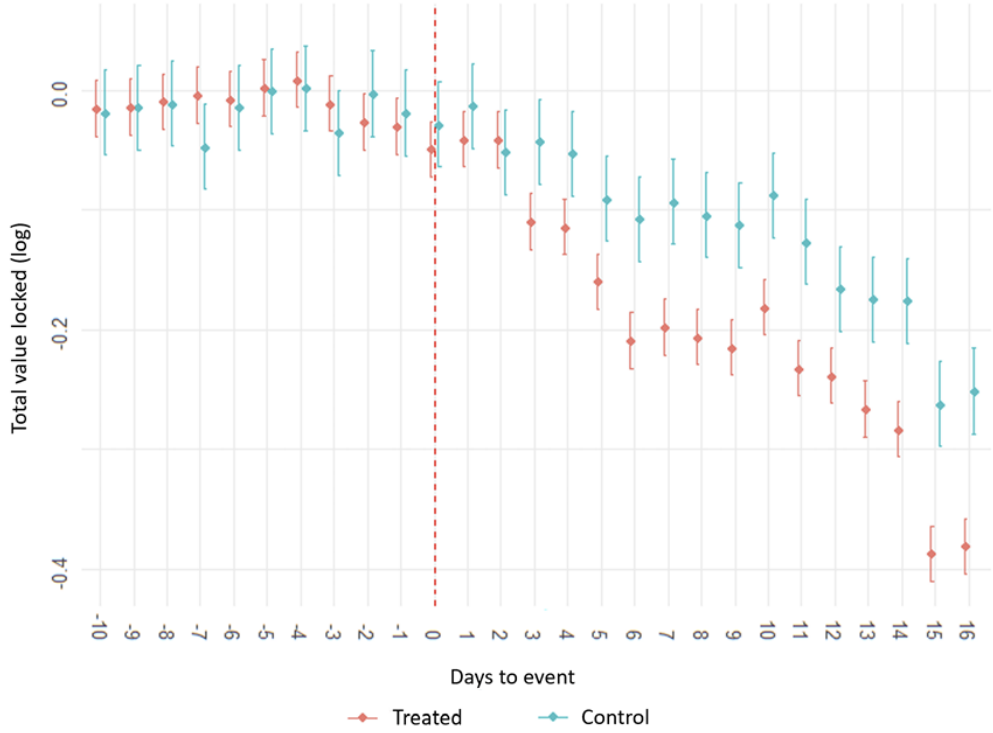


Table 1. The market of oracles: This panel depicts the market share of oracles, including the number of DeFi protocols, their TVL expressed in dollars, and the number of unique served blockchains. This table reports information collected as of November 2024. *Others* category includes 38 oracles whose number of protocols and TVL are expressed as the sum of their total values. *Total* category represents the entire market.

Oracle	Protocols (#)	Protocols (%)	TVL ($ million)	TVL (%)
Chainlink	407	39.5	32,198.71	51.1
Chronicle	5	0.5	8,747.39	13.9
WINkLink	2	0.2	6,839.33	10.8
Pyth	227	22.0	6,670.52	10.6
RedStone	51	5.0	1,632.51	2.6
Internal	43	4.2	1,619.86	2.6
Edge	1	0.1	1,304.03	2.1
Switchboard	13	1.3	1,021.68	1.6
Supra	11	1.1	600.92	1.0
API3	28	2.7	487.63	0.8
TWAP	90	8.7	430.67	0.7
UMA	8	0.8	313.67	0.5
Stork	12	1.2	246.69	0.4
Pragma	10	1.0	181.44	0.3
Price Oracle	1	0.1	178.47	0.3
Band	21	2.0	136.14	0.2
cLabs	2	0.2	100.56	0.2
Binance Oracle	3	0.3	79.14	0.1
eOracle	1	0.1	68.17	0.1
Balancer Pool LP token	1	0.1	38.04	0.1
Acurast	3	0.3	37.73	0.1
DIA	29	2.8	28.75	0.0
COTI's Oracle	1	0.1	26.59	0.0
Uniswap	1	0.1	20.46	0.0
NFTOracle	1	0.1	19.46	0.0
ReserveOracle	1	0.1	19.46	0.0
Charli3	1	0.1	7.54	0.0
Money On Chain	1	0.1	6.54	0.0
Oracles.Cash	1	0.1	4.86	0.0
Harbinger	2	0.2	4.11	0.0
Others	52	5.0	0.01	0.0
Total	1,030	100.0	63,071.08	100.0

Table 2. DeFi protocols per industry: This table depicts the distribution of DeFi protocols per category. All columns are expressed in numerals, except TVL and Mcap, which are expressed in billions of dollars. All data points as of November 2024. Centralized exchanges (CEX) and layer 1 (chains) are excluded. See Appendix A for the description of each industry. See Appendix B for the original data values.

Category	Protocols	TVL ($m)	Mcap ($m)	Chains	Integrated (%)
Algo-Stables	117	119.96	279.72	41	30.8
Bridge	99	30,944.01	2314.45	74	4.0
CDP	160	8,305.50	1507.34	87	41.9
Cross Chain	36	942.59	434.05	31	16.7
Decentralized Stablecoin	11	131.29	111.70	9	54.5
Derivatives	284	4,230.79	366.44	132	62.0
DEX Aggregator	58	6.14	2,392.64	10	1.7
Dexes	1,486	268,43.16	12,014.97	502	1.5
Farm	182	4,255.01	635.12	63	2.2
Gaming	65	20.31	1,928.06	33	4.6
Indexes	63	755.13	468.06	28	27.0
Insurance	26	309.04	238.50	14	26.9
Launchpad	75	890.29	1759.92	43	8.0
Lending	461	36,944.32	5,958.02	231	54.2
Leveraged Farming	33	556.67	136.06	21	42.4
Liquid Restaking	26	12,467.74	66.47	10	11.5
Liquid Staking	194	523,97.43	3,013.07	104	5.7
Liquidity manager	43	427.68	75.23	37	14.0
NFT Lending	29	87.49	5.07	10	24.1
NFT Marketplace	41	88.58	2,773.16	20	0.0
Options	61	106.62	81.05	37	49.2
Payments	21	534.66	443.41	19	4.8
Prediction Market	60	213.47	48.04	33	31.7
Privacy	17	634.36	209.60	14	0.0
Reserve Currency	123	9.41	319.30	28	5.7
Restaking	13	18,236.05	590.10	11	0.0
RWA	71	7,097.96	2,371.18	42	14.1
RWA Lending	9	3.69	298.42	7	11.1
Services	200	7,840.84	20,150.54	57	4.0
SoFi	56	21.18	89.17	20	0.0
Staking Pool	30	677.19	328.97	24	0.0
Synthetics	40	360.17	46.39	30	42.5
Uncollateralized Lending	10	12.25	360.24	8	0.0
Yield	529	6,380.02	2,647.09	178	11.5
Yield Aggregator	157	2,013.57	417.14	83	19.1
Others	102	6,549	3,619	3	15.7
Total	4,988	231,413.69	68,497.69	2,094	17.0

Table 3. Summary Statistics: This table depicts the summary statistics for the variables used in the empirical analysis. *TVL* is the total dollar value of all transactions that go through the DeFi protocol smart contracts. *Staking* is the total amount of staked cryptocurrencies expressed in millions of dollars. *Fundraising* is the total amount of funds raised expressed in millions of dollars. *MCap* is the total market capitalization expressed in millions of dollars. *# Chains* is the total number of listed blockchains. *Auditing* is an indicator of whether a Big 3 auditor audited the DeFI protocol. *OpenSource* is an indicator of whether a DeFi protocol is coding open source on the GitHub platform. *Coding* is the number of commits at the DeFi protocol Github repositories capturing code production. *Followers* is the number of followers in the DeFi protocol social media channel. All variables in this panel are captured within 90 days before the DeFi protocol launch, except for those denoted with superscript [1], which are captured one month from the launch date.

Full Sample (Obs = 4,664)									
	TVL[1]	**Staking**[1]	**Fundraising**	**MCap**[1]	**# Chains**	**Auditing**	**OpenSource**	**Coding**	**Followers**
Q1	0.02	0.01	2.00	2.76	1.00	0.00	0.00	0.00	11.00
Median	0.33	0.05	3.40	11.17	1.00	0.00	0.00	0.00	1,467.00
Mean	15.51	9.62	6.52	9.86	1.80	0.23	0.07	1,677.34	29,883.42
Q3	3.44	0.92	6.00	40.47	1.00	0.00	0.00	0.00	11,052.50
Sd	58.59	61.83	12.48	8.21	2.53	0.42	0.26	19,601.22	334,877.50
Decentralized Oracles (Obs = 640)									
	TVL[1]	**Staking**[1]	**Fundraising**	**MCap**[1]	**# Chains**	**Auditing**	**OpenSource**	**Coding**	**Followers**
Q1	0.03	0.04	1.92	1.97	1.00	0.00	0.00	0.00	286.50
Median	0.39	0.38	3.50	7.21	1.00	0.00	0.00	0.00	3380.00
Mean	16.64	11.50	6.33	7.48	1.97	0.31	0.12	2000.93	17408.25
Q3	3.37	1.90	5.55	21.27	2.00	1.00	0.00	0.00	13878.00
Sd	62.63	60.67	11.07	7.97	2.01	0.46	0.32	8466.11	43125.61
Centralized Oracles (Obs = 187)									
	TVL[1]	**Staking**[1]	**Fundraising**	**MCap**[1]	**# Chains**	**Auditing**	**OpenSource**	**Coding**	**Followers**
Q1	0.02	0.01	2.00	2.96	1.00	0.00	0.00	0.00	38.00
Median	0.33	0.03	3.25	12.72	1.00	0.00	0.00	0.00	861.00
Mean	15.32	9.43	6.57	10.41	1.56	0.33	0.08	691.99	11304.69
Q3	3.44	0.78	6.00	42.70	1.00	1.00	0.00	0.00	4912.50
Sd	57.88	61.99	12.88	8.24	1.34	0.47	0.27	4445.00	39499.01

Table 4. Determinants of DON integration: This table depicts the determinants of DON integration including *Raised Amount*, the total value of funds raised before protocol launch; *Auditing*, an indicator of whether a Big 3 auditor audited the DeFI protocol; *Coding*, the number of commits at the DeFi protocol Github repositories before protocol launch; and *Followers*, the number of followers at the DeFi protocol main Twitter account before protocol launch. Columns (2) to (4) also include indicators for DeFi protocol industries where all other industries are the baseline omitted category. Columns (3) and (4) also include indicators for main blockchains where all other blockchains are the baseline omitted category. Column (4) also includes indicators for the year of launch where 2024 is the baseline omitted category. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

	M1	M2	M3	M4	M5
Pre-Launch Characteristics:					
Fundraising	0.03 *	0.02	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Auditing	0.42 ***	0.39 ***	0.32 ***	0.31 ***	0.31 ***
	(0.14)	(0.11)	(0.11)	(0.11)	(0.10)
Coding	0.05 **	0.07 ***	0.06 ***	0.06 ***	0.05 ***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Followers	0.06 ***	0.03 **	0.02	0.03 *	0.03 **
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
DeFi Industry:					
Derivatives		2.34 ***	2.30 ***	2.29 ***	
		(0.21)	(0.33)	(0.33)	
Dexes		—2.18 ***	—2.12 ***	—2.14 ***	
		(0.31)	(0.25)	(0.25)	
Lending		1.82 ***	1.85 ***	1.87 ***	
		(0.27)	(0.19)	(0.19)	
Options		2.13 ***	1.99 ***	1.98 ***	
		(0.36)	(0.33)	(0.33)	
Prediction		1.38 ***	1.37 ***	1.40 ***	
		(0.28)	(0.27)	(0.29)	
Yield		—0.26	—0.30	—0.28	
		(0.22)	(0.24)	(0.25)	
Blockchain:					
Arbitrum			0.58 **	0.53 *	
			(0.29)	(0.29)	
Binance			0.33	0.32	
			(0.26)	(0.27)	
Ethereum			0.31	0.23	
			(0.29)	(0.30)	
Fantom			0.00	—0.01	
			(0.33)	(0.34)	
MultiChain			0.50 **	0.45 **	
			(0.22)	(0.23)	
Timing:					
2019				1.23 ***	
				(0.73)	
2020				1.05 ***	
				(0.33)	
2021				0.16	
				(0.20)	
2022				0.20	
				(0.26)	
2023				0.35 *	
				(0.19)	
Category	No	No	No	No	Yes
Blockchain	No	No	No	No	Yes
Year-Month	No	No	No	No	Yes
Obs.	4,664	4,664	4,664	4,664	4,664
Pseudo r^2	0.03	0.32	0.33	0.33	0.41

Table 5. Post-live economic responses to oracle integration: This table reports the regression results for equation 2 across several time windows (i.e., day, week, month, and quarter): (a) reports estimates from pooled OLS regression in the full sample. (b) reports estimates from 2nd-stage pooled OLS regression with Heckman correction for sample selection (e.g., Heckman, 1979, 1990). (c) reports estimates from the matched samples according to Table 6. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable. TVL is expressed in logarithm (levels) across the week, month, quarter, and year windows, and it is winsorized at [0.95–0.05] confidence interval. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; See table 3 for the description of the remaining variables. All specifications have fixed effects on the Category (e.g., Lending, Dexes), blockchain (e.g., Ethereum, Binance), and time. The Chi-Square test statistic for $H_0 : \beta_1 = \beta_2$ is reported in the last row of the table. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

	Panel A: Short Term						**Panel B: Long Term**					
	Week			**Month**			**Quarter**			**Year**		
	(a)	**(b)**	**(c)**	**(a)**	**(b)**	**(c)**	**(a)**	**(b)**	**(c)**	**(a)**	**(b)**	**(c)**
Oracles:												
Decentralized	0.21	0.22	0.35 *	0.33 **	0.36 **	0.47 ***	0.42 **	0.46 **	0.58 ***	0.82 ***	0.87 ***	0.90 ***
	(0.18)	(0.18)	(0.20)	(0.16)	(0.16)	(0.18)	(0.21)	(0.21)	(0.19)	(0.25)	(0.25)	(0.25)
Centralized	0.43	0.43	0.57 *	0.34	0.35 *	0.27	0.35	0.37 *	0.31	0.34	0.36	0.73 *
	(0.27)	(0.27)	(0.34)	(0.21)	(0.21)	(0.31)	(0.22)	(0.22)	(0.30)	(0.48)	(0.48)	(0.44)
Controls:												
Staking	0.07 ***	0.07 ***	0.05 ***	0.07 ***	0.08 ***	0.05 ***	0.08 ***	0.09 ***	0.07 ***	0.09 ***	0.11 ***	0.08 ***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Fundraising	0.03 *	0.02	0.01	0.03 **	0.01	0.02 *	0.03 *	0.00	0.01	0.03 *	−0.01	0.03
	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Auditing	0.06	−0.07	0.07	0.27 **	−0.19	0.24 *	0.29 **	−0.51	0.26 *	0.22	−0.61	0.17
	(0.12)	(0.37)	(0.13)	(0.12)	(0.35)	(0.14)	(0.12)	(0.41)	(0.15)	(0.14)	(0.43)	(0.15)
Coding	0.04	0.02	0.05 *	0.05	0.00	0.07 **	0.06 **	−0.02	0.08 **	0.11 ***	0.03	0.11 **
	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)
Followers	0.24 ***	0.24 ***	0.20 ***	0.29 ***	0.27 ***	0.24 ***	0.34 ***	0.29 ***	0.28 ***	0.36 ***	0.31 ***	0.35 ***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)	(0.03)
λ		−0.62			−2.28			−3.90 **			−4.09 **	
		(1.75)			(1.65)			(1.91)			(1.90)	
Category	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-Month	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4,197	4,197	2,176	4,110	4,110	2,176	3,910	3,910	2,176	2,837	2,837	2,176
Adj.r^2	0.26	0.28	0.25	0.31	0.33	0.31	0.34	0.35	0.36	0.39	0.41	0.40
Pr. > χ^2	0.53	0.47	0.83	0.45	1.00	0.11	0.16	0.22	0.02	0.01	0.02	0.03

Table 6. PSM-NN: This table reports the summary statistics of the matching procedure. We employ propensity matching scores (PSM) based on the nearest neighborhood. We use $k = 3$, meaning each treated observation is matched to three control observations, to improve the overall balance between the two groups. Panel A reports the mean values for the characteristics of DeFi protocols with DON integration, others (including CO integration), and their mean differences. The last column reports the percentage improvement of the matching procedure. Peers are matched within the industry and blockchain. Panel B reports the number of matched observations within clusters of analysis for TVL, market capitalization (MCap), number of unique users, and on-chain transfers.

Panel A: Matching Procedure

	Oracles	Others	Differences	Improvement
Staking	1.90	1.98	-0.08	73%
Fundraising	1.52	0.83	0.69	48%
Auditing	0.35	0.28	0.07	86%
Coding	1.21	0.87	0.34	60%
Followers	6.62	5.81	0.83	118%
Overall Distance	0.49	0.17	0.32	133%

Panel B: Samples

Sample Sizes	Control	Treated
All	2,217	544
Matched	1,632	544
Unmatched	585	0
Discarded	0	0

Table 7. Avalanche interoperability effects: This table reports Spearman correlations among chains. In Panel A, the coefficients are reported for the period before (after) Avalanche integration in the top-right (bottom-left) corner of the table. In Panel B, the changes between before and after correlations are reported for each chain in relation to Avalanche. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

Panel A - Spearman Correlations

After \ Before	Avalanche	Binance	Ethereum	Fantom	Harmony	Heco	xDai
Avalanche		0.85	0.58	0.27	0.20	0.38	-0.46
Binance	0.78		0.81	0.44	0.15	0.62	—0.19
Ethereum	0.79	0.97		0.59	0.23	0.74	0.22
Fantom	0.84	0.64	0.71		0.59	0.27	0.18
Harmony	0.64	0.91	0.86	0.51		—0.26	—0.20
Heco	0.69	0.52	0.59	0.67	0.51		0.36
xDai	0.68	0.93	0.88	0.62	0.80	0.34	

Panel B - Changes

	Avalanche	Binance	Ethereum	Fantom	Harmony	Heco	xDai
Change	-	—0.07	0.21***	0.57***	0.44***	0.31***	1.13***

Table 8. Between protocols interoperability (Ethereum): This table reports Spearman correlations for the TVL of DeFi protocols. Panel A reports the correlations among DeFi protocols with oracle integration. Panel B reports the correlations among all DeFi protocols. *Mean* represents the mean differences for TVL correlations before and after protocols integrate. *Sd* represents the average differences in standard deviations for TVL correlations before and after protocols are integrated. *Protocols* is the number of matched protocols (in time) for which correlations are obtained. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

Panel A - Integrated Protocols			
	Mean	**Sd**	**Protocols**
less than 7	0.01	−0.11***	3.55
between 7 and 14	0.05**	−0.06***	11.60
between 14 and 21	0.20***	−0.06***	18.50
more than 21	0.07***	−0.01	25.00
all	0.05**	−0.06***	13.71
Panel B - All Protocols			
	Mean	**Sd**	**Protocols**
less than 10	0.02	0.01	7.44
between 10 and 100	0.02	0.02	64.13
more than 100	0.01	0.02	130.09
all	0.02	0.03	69.69

Online Appendices
Appendix A: Oracles and DeFi Industries

Table A1. Main Oracles: This table briefly describes the main oracles based on their total market share as September 2024.

Oracle	Description
API3	API3 is a decentralized oracle platform that provides robust Oracle infrastructure to developers on Ethereum-based Layer 1 and Layer 2 networks. It allows developers to connect their decentralized applications (dApps) with real-world data streams through APIs (see https://api3.org/).
Binance Oracle	Binance Oracle is a decentralized oracle service provided by Binance, aiming to integrate external data with blockchain applications. It functions similarly to other oracle networks by supplying smart contracts with real-world data, such as asset prices, financial metrics, and other external information necessary for the operation of decentralized applications (dApps), supporting a wide range of use cases within the Binance ecosystem (see https://oracle.binance.com/).
Chainlink	Chainlink is a decentralized oracle network that provides real-world data to smart contracts on the blockchain. It facilitates the transfer of tamper-proof data from off-chain sources to on-chain smart contracts, enabling hybrid smart contracts and cross-chain interoperability. The network is built on Ethereum and allows smart contracts to connect to external APIs and leverage secure off-chain computations. The Chainlink Network refers to all decentralized oracle networks operating using the Chainlink protocol, including individual oracles, data providers running their own node, and node operators (see https://chain.link/faqs).
Chronicle	Chronicle is a decentralized oracle platform that delivers secure, real-time data feeds for smart contracts, particularly in enterprise and decentralized finance (DeFi) sectors. Like other oracle networks, Chronicle connects smart contracts with external, off-chain data, enabling blockchain applications to interact with real-world events and information. It was initially developed on Ethereum and is currently used within the MakerDAO ecosystem (see https://chroniclelabs.org/).
Pyth	Pyth Network is a blockchain oracle that provides real-time market data for various assets, including cryptocurrencies, equities, forex, and commodities. It aggregates data from over 110 major market participants, such as Jane Street, CBOE, Binance, OKX, and Bybit (see https://www.pyth.network/).
RedStone	RedStone Oracle is a decentralized oracle network designed to provide foff-chain data for blockchain-based smart contracts. It introduces an innovative approach by delivering real-time data directly to smart contracts, focusing on improving the speed and efficiency of data access (see https://redstone.finance/).
Supra	Supra Oracle is a decentralized oracle network designed to bridge real-world data with blockchain ecosystems. Built on the Telos blockchain, it aims to deliver accurate and secure data feeds for decentralized applications (dApps) across multiple blockchains (see https://supra.com/).
Switchboard	Switchboard is a decentralized oracle network that allows smart contracts to access reliable, off-chain data by crowdsourcing data feeds. It is primarily built for use in the Solana blockchain ecosystem. Like other oracles, Switchboard provides the infrastructure for smart contracts to securely interact with real-world data, but it stands out for its emphasis on flexibility and user control (see https://switchboard.xyz/).
TWAP	TWAP oracle (Time-Weighted Average Price oracle) is a type of decentralized oracle that provides the average price of an asset over a specific time period, using the TWAP method. Instead of providing real-time or instantaneous prices, a TWAP oracle calculates the average price of an asset by sampling its price at regular intervals over time. This helps to smooth out short-term volatility and reduces the risk of price manipulation (see https://blog.uniswap.org/uniswap-v3-oracles).
WINkLink	WINkLink is a decentralized oracle system built on the TRON blockchain. It functions similarly to other oracle networks like Chainlink but is explicitly designed for TRON-based decentralized applications (dApps). WINkLink connects these smart contracts with off-chain data sources, enabling them to access real-world information like asset prices, sports results, or weather data securely and reliably. It aims to make smart contracts on TRON more versatile by allowing them to interact with off-chain data (see https://winklink.org/#/home).

Table A2. DeFi Industries: This table provides a brief description, according to https://defillama.com/, of each DeFi industry reported on Table 2.

Industry	Description
Algo-Stables	Algo-Stables refers to a category of algorithmic stablecoins within the DeFi ecosystem. These stablecoins are designed to maintain a stable value using algorithms and smart contract protocols. Unlike traditional fiat-backed stablecoins that rely on centralized reserves, DeFi Algo Stables aims to achieve price stability through algorithmic mechanisms, often involving automated supply adjustments based on market demand.
Bridge	DeFi Bridge protocols are DeFi platforms that facilitate the seamless transfer of assets and liquidity between different blockchain networks. These protocols bridge separate blockchain ecosystems and allow users to transfer tokens or other digital assets across these networks. DeFi Bridge protocols typically utilize smart contracts to enable secure and trustless transactions between different blockchain platforms, enhancing interoperability and expanding the reach of decentralized applications (dApps) and decentralized exchanges (DEXs).
CDP	CDP protocols, or Collateralized Debt Position protocols, are integral to the DeFi ecosystem. These protocols enable users to create and manage CDPs, smart contracts that allow individuals to collateralize their digital assets in exchange for borrowing other cryptocurrencies or stablecoins. With DeFi CDP protocols, users can lock up their crypto assets as collateral, providing security and mitigating counterparty risk. Based on the value of the collateral, users can then borrow a certain amount of funds, which can be used for various purposes such as trading, investment, or liquidity provision. The borrowed funds are typically overcollateralized, meaning users must provide more value in collateral than the amount they borrow.
Cross Chain	Cross-Chain protocols are an essential component of the DeFi ecosystem that facilitates interoperability between different blockchain networks. These protocols enable the seamless transfer of assets and data across multiple blockchains, allowing users to access a broader range of decentralized applications (dApps) and utilize various tokens and services.
Derivatives	Derivatives protocols enable the trading and creating derivative products using blockchain technology. Without intermediaries or centralized exchanges, these protocols allow users to gain exposure to various financial instruments, such as futures, options, swaps, and synthetic assets. DeFi Derivatives protocols allow users to engage in decentralized derivatives trading, hedging strategies, and speculative investments. These platforms typically utilize smart contracts to create and settle derivative contracts, ensuring the trading process's transparency, security, and automation.
DEXs	DEX protocols, or Decentralized Exchange protocols, are a key component of the DeFi ecosystem. These protocols enable users to trade cryptocurrencies and other digital assets directly with each other on a peer-to-peer basis without intermediaries like traditional centralized exchanges. DEX protocols operate through smart contracts deployed on blockchain networks, which facilitate the matching and execution of trades transparently and decentralized. Many DEX protocols employ automated market-making algorithms and liquidity pools to ensure continuous liquidity and efficient trading.
Farm	Farm protocols are a DeFi platform that allows users to participate in yield farming or liquidity mining. These protocols enable users to earn rewards by providing liquidity to specific pools or participating in various farming strategies within the DeFi ecosystem. In Farm protocols, users can lock up their cryptocurrency assets in liquidity pools, which decentralized exchanges or lending platforms utilize to facilitate trading and lending activities. By providing liquidity to these pools, users can earn rewards through additional tokens or fees generated by the platform.
Gaming	Gaming protocols combine the features of DeFi with gaming, enabling users to interact with gaming platforms and earn rewards through blockchain technology. These protocols allow players to engage in various gaming activities such as in-game item trading, betting, and participation in decentralized virtual worlds. In addition, DeFi Gaming protocols may incorporate decentralized autonomous organizations (DAOs) to govern the gaming ecosystem, giving players a voice in decision-making and incentivizing their active participation.

Continue.

Industry	Description
Indexes	Indexes protocols are DeFi platforms offering curated and diversified token indexes within the DeFi ecosystem. These protocols enable users to gain exposure to a basket of DeFi assets and track the sector's overall performance. DeFi Indexes protocols typically create indexes by selecting and weighing a group of tokens based on predetermined criteria, such as market capitalization, liquidity, or project fundamentals. The indexes are designed to give users a diversified investment option representing the broader DeFi market rather than investing in individual assets.
Insurance	Insurance protocols are crucial components of DeFi that aim to mitigate risks and provide insurance coverage for various DeFi activities. Insurance protocols enable users to purchase coverage against risks such as smart contract vulnerabilities, hacking incidents, or protocol failures. Users can pay premiums to the insurance protocol and, in return, receive coverage in the event of a defined risk occurrence. These protocols often employ a peer-to-peer model, where coverage is provided collectively by a pool of participants who contribute funds to the insurance pool. The pool's funds are then used to compensate policyholders in the event of a valid claim. The coverage terms, premium rates, and claim processes are typically governed by smart contracts, ensuring transparency and automation of insurance operations.
Launchpad	Launchpad protocols are platforms within the DeFi ecosystem that facilitate the launch and initial offering of new tokens or projects. These protocols serve as a launchpad for blockchain-based projects to raise funds, gain exposure, and attract early investors. These protocols often utilize smart contracts to automate the token sale process. They may also incorporate token vesting schedules, governance rights, or tiered investment structures.
Lending	Lending protocols enable users to lend and borrow digital assets peer-to-peer without the need for traditional intermediaries, such as banks. Through DeFi Lending protocols, users can lend their idle cryptocurrency holdings and earn interest on their deposits. These protocols match lenders with borrowers, allowing borrowers to access funds while lenders earn a return on their capital. The lending process is typically facilitated by smart contracts, which automate the borrowing and repayment terms. Borrowers can provide collateral, such as cryptocurrencies or other digital assets, to secure their loans. Collateralized lending reduces credit risk and allows borrowers to access funds without needing credit checks or cumbersome loan approval processes. In default, lenders can liquidate the collateral to recover their funds. Lending protocols often implement mechanisms to determine interest rates dynamically based on supply and demand. Rates can be influenced by factors such as the availability of funds, the lending pool's utilization rate, or borrowers' creditworthiness.
Liquid Staking	Liquid Staking allow users to unlock the liquidity of staked assets while still participating in the staking process. These protocols enable users to earn staking rewards and maintain exposure to the benefits of staking, all while having the flexibility to use their staked assets for other purposes within the DeFi ecosystem. Traditional staking typically involves locking up tokens in a contract for a specific period, which restricts their liquidity and utility. However, DeFi Liquid Staking protocols address this limitation by creating synthetic representations of the staked assets, often referred to as "staking derivatives" or "staked tokens." These synthetic tokens represent the staked assets and can be freely traded or utilized within the DeFi ecosystem. By utilizing DeFi Liquid Staking protocols, users can stake their assets and receive staking rewards while still having the option to trade or use the staked tokens for other purposes. This flexibility provides additional liquidity and allows users to take advantage of other DeFi opportunities without sacrificing the benefits of staking. DeFi Liquid Staking protocols typically employ smart contracts and mechanisms to ensure the synchronization of rewards with the underlying staking process. Users can earn rewards through additional staked tokens or other assets, which can be claimed periodically based on the staking protocol's parameters.
NFT Lending	NFT Lending are protocols focusing on lending and borrowing Non-Fungible Tokens (NFTs). These protocols enable users to leverage their NFT assets to access liquidity or earn passive income through lending. Through DeFi NFT Lending protocols, NFT owners can deposit their NFTs as collateral and borrow assets such as cryptocurrencies or stablecoins. The value of the borrowed assets is typically based on a certain loan-to-value (LTV) ratio determined by the protocol. NFT collateral provides security to lenders, reducing the risk of default. Lenders can supply funds to the lending pools within these protocols and earn interest by lending their assets to borrowers. The interest rates are typically determined by the supply and demand dynamics within the lending market.

continuation.

Industry	Description
NFT Marketplace	NFT Marketplace protocols are decentralized platforms within the DeFi ecosystem that facilitate the trading, buying, and selling of Non-Fungible Tokens (NFTs). These protocols provide a decentralized and transparent marketplace where users can discover, list, and transact with NFTs. Through DeFi NFT Marketplace protocols, users can directly showcase and trade their unique digital assets, such as artwork, collectibles, virtual real estate, or in-game items, with other participants. DeFi NFT Marketplace protocols offer features like bidding, auctions, or fixed-price listings, allowing users to set their preferred pricing and engage in competitive or curated sales. These protocols often provide additional functionalities such as curation, community governance, or reward mechanisms to enhance the user experience and promote engagement.
Options	Options protocols are a specific DeFi segment focusing on options trading. These protocols enable users to trade options contracts decentralized and transparently without intermediaries. Options contracts give users the right, but not the obligation, to buy (call option) or sell (put option) an underlying asset at a predetermined price (strike price) within a specific time frame (expiration date). DeFi Options protocols facilitate the creation, trading, and settlement of these options contracts using smart contracts and blockchain technology. These protocols often offer a range of options types, including European or American-style options and various underlying assets, such as cryptocurrencies or other digital assets. They typically provide features like order matching, price discovery, and automated settlement of options contracts.
Oracle	Oracles are a fundamental part of DeFi that provides external data to blockchain-based applications and smart contracts. These protocols act as bridges, facilitating connections between on-chain and off-chain data sources. Oracles retrieve real-time data from various sources, such as price feeds, market data, or weather information, and make it available on the blockchain. Smart contracts can then utilize this data to make informed decisions, execute actions, or trigger events based on real-world conditions. They enable the automation of financial transactions, decentralized exchanges, lending platforms, and other DeFi applications that require real-time or external data inputs. To maintain integrity and prevent manipulation, DeFi Oracle protocols employ mechanisms such as data aggregation, consensus algorithms, or reputation systems. These measures ensure the reliability of the data provided and reduce the risks associated with relying on a single data source.
Payments	Payments protocols that facilitate seamless and secure peer-to-peer transactions using cryptocurrencies or digital assets. These protocols offer wallet integration, address management, and transaction tracking features, allowing users to manage their digital assets and initiate payments directly from their wallets. They often support multiple cryptocurrencies, giving users flexibility and choice in payment options. Furthermore, Payment protocols may incorporate additional functionalities such as recurring payments, payment splitting, or subscription services.
Prediction Market	Prediction Market are protocols that enable users to make predictions and trade on the outcomes of future events. Through these protocols, users can forecast various outcomes, such as election results, sports events, or the price movements of cryptocurrencies. Participants can purchase shares representing different predictions, with the share prices reflecting the perceived probability of the event occurring. The trading activity within these protocols creates a decentralized consensus on the likelihood of different outcomes. As more information becomes available or as the event approaches, the share prices adjust accordingly, reflecting the evolving market sentiment.
Privacy	Privacy protocols focus on enhancing the privacy and confidentiality of transactions and interactions within the blockchain network. These protocols aim to increase users' anonymity and protect sensitive information while engaging in DeFi activities. These protocols offer various privacy features, such as zero-knowledge proofs, ring signatures, or confidential transactions, which obfuscate transaction information and make it difficult to trace or link specific actions to individual users.
Reserve Currency	Reserve Currency protocols aim to establish stable and reliable reserve currencies within the decentralized ecosystem. These protocols enable users to hold and transact with stablecoins backed by collateral or algorithmic mechanisms to maintain their value and stability. Unlike traditional fiat currencies, which are typically issued and controlled by central banks, DeFi Reserve Currency protocols provide a decentralized alternative. These protocols offer stability by maintaining a collateral pool or implementing algorithmic mechanisms that adjust the stablecoin supply based on demand and market conditions. This stability is crucial for users to have confidence in the value of the reserve currency, allowing them to transact and store value within the DeFi ecosystem without being subject to the volatility of other cryptocurrencies.

continuation.

Industry	Description
Services	Service protocols are DeFi platforms that offer users a range of services and functionalities within the decentralized ecosystem. These protocols act as service providers, offering various tools, applications, or infrastructure to support the needs of participants in the DeFi space. These protocols provide a wide array of services, including but not limited to portfolio management, yield optimization, data analytics, liquidity aggregation, lending/borrowing facilitation, or smart contract auditing.
Staking	Staking protocols allow users to actively participate in the validation and security of blockchain networks while earning passive income. Through staking, users can lock up their digital assets in a staking contract, typically in cryptocurrencies. In return for staking their assets, users receive staking rewards, which are typically distributed in the form of additional tokens. The reward distribution and rate vary depending on the specific staking protocol and the staked network. Some protocols also offer additional features, such as delegation, where users can delegate their stake to a trusted validator to earn rewards without running their own infrastructure.
Synthetics	Synthetics allow users to replicate the value and performance of real-world assets using blockchain-based tokens, such as stocks, commodities, or fiat currencies. Through Synthetics protocols, users can create and trade synthetic assets known as "synths" that derive their value from an underlying asset. Synthetic assets are typically created through smart contracts and collateralized with other cryptocurrencies or digital assets. Users can lock up their collateral and mint synths in a protocol-determined ratio. The collateral guarantees the maintenance of the value and stability of the synthetic asset. These protocols often provide features such as price feeds, oracle integrations, and trading interfaces. Users can buy and sell synths on decentralized exchanges or utilize them for various purposes within the DeFi ecosystem, such as loan collateral or participation in yield farming.
Uncollateralized Lending	Uncollateralized Lending protocols are a specialized subset within the DeFi ecosystem that allows users to borrow funds without needing collateral. Unlike traditional lending systems that require collateral as a form of security, these protocols rely on alternative mechanisms to assess the borrower's ability to repay the loan. These mechanisms may include analyzing the borrower's transaction history, credit scores, or utilizing decentralized identity solutions. The interest rates are typically determined by market dynamics and the perceived risk associated with the borrower. These protocols often provide features such as loan terms, repayment schedules, and automated loan agreements through smart contracts. Uncollateralized lending introduces risks for lenders, as there is no direct collateral to recover funds in the event of default. To mitigate this risk, protocols may implement reputation-based lending, insurance pools, or risk assessment algorithms to protect lenders and incentivize responsible borrowing behavior.
Yield	DeFi Yield protocols focus on optimizing and maximizing the yield or returns on cryptocurrency assets. These protocols provide users with strategies, tools, or platforms to generate passive income by deploying their digital assets in various yield-generating opportunities within the DeFi ecosystem. Through Yield protocols, users can participate in liquidity provision, yield farming, lending, or staking to earn additional tokens or rewards. These protocols leverage smart contracts and algorithms to identify and allocate users' assets to the most favorable yield-generating strategies. They often offer features such as automated portfolio rebalancing, compounding of earnings, or integration with decentralized exchanges and lending platforms to enhance yield generation.
Yield Aggregator	Yield Aggregators aim to optimize and maximize user yield generation by aggregating and automating various yield-generating strategies within the DeFi ecosystem. These protocols act as intermediaries between users and multiple DeFi platforms, allowing users to deposit their digital assets into a single interface. To maximize returns, the Yield Aggregator protocol then allocates these assets across different strategies, such as liquidity provision, yield farming, lending, or staking.

Table A3. Blockchains: This table presents the top 200 blockchains ranked by total value locked as of November 2024. Total value locked represents the cumulative value in dollars of all assets either deposited or transacted through a smart contract. The notation (m) denotes million, while (b) denotes billion.

Name	Protocols	TVL	Name	Protocols	TVL	Name	Protocols	TVL	Name	Protocols	TVL
Ethereum	1,226	$60.996b	Kaia	61	$65.67m	Bifrost	3	$9.28m	Degen	9	$1.81m
Solana	182	$8.467b	BounceBit	13	$61.46m	ZetaChain	25	$8.75m	World Chain	5	$1.75m
Tron	34	$7.692b	Hydration	1	$58.66m	Doge	4	$8.37m	Velas	15	$1.73m
BSC	816	$5.198b	Metis	60	$51.79m	Ontology	3	$8.32m	AirDAO	4	$1.68m
Bitcoin	43	$4.351b	ICP	10	$50.95m	Canto	25	$8.22m	Wax	9	$1.67m
Base	390	$3.174b	Tezos	20	$46.51m	re.al	10	$7.8m	Persistence One	3	$1.56m
Arbitrum	734	$2.935b	Injective	24	$45.5m	Dogechain	45	$7.61m	HAQQ	5	$1.54m
Sui	44	$1.604b	Neutron	11	$45.12m	Onus	5	$7.11m	DeFiVerse	1	$1.52m
Avalanche	412	$1.271b	zkLink Nova	23	$42.03m	Venom	3	$6.74m	KCC	28	$1.51m
Hyperliquid	3	$1.234b	Manta	66	$40.85m	Ergo	10	$5.89m	Songbird	7	$1.51m
Polygon	582	$1.025b	Fraxtal	16	$39.94m	Dexalot	1	$5.62m	Meter	13	$1.42m
Aptos	49	$1.023b	Fuel Ignition	5	$38.59m	Oraichain	4	$5.47m	Elastos	3	$1.40m
CORE	49	$924.08m	Telos	41	$37.81m	GodwokenV1	7	$5.12m	Terra Classic	30	$1.31m
Optimism	274	$737.23m	Stellar	10	$33.59m	Terra2	14	$4.97m	Xai	3	$1.29m
Blast	142	$568.75m	Cronos zkEVM	11	$33.04m	Moonriver	57	$4.96m	XPLA	2	$1.24m
Mantle	107	$565.32m	IOTA EVM	8	$30.66m	Vite	4	$4.95m	IDEX	1	$1.22m
Cronos	115	$549.67m	Flow	11	$28.34m	DFS Network	1	$4.8m	Equilibrium	1	$1.14m
Bitlayer	22	$518.03m	Bifrost Network	4	$26.57m	Dymension	2	$4.77m	Milkomeda C1	21	$1.13m
PulseChain	44	$515.98m	Reya Network	3	$26.57m	Litecoin	4	$4.74m	Neon	11	$1.13m
Linea	124	$502.73m	Kujira	15	$25.26m	Astar zkEVM	11	$4.56m	Etherlink	6	$1.13m
Cardano	40	$483.95m	Moonbeam	61	$23.94m	Wanchain	9	$4.5m	Everscale	2	$1.11m
Scroll	110	$405.67m	Mayachain	1	$23.16m	Shibarium	16	$4.33m	Fuse	25	$1.11m
Thorchain	3	$398.08m	IoTeX	33	$21.69m	Carbon	4	$4.26m	Arbitrum Nova	10	$1.10m
dYdX	2	$331.44m	Flare	16	$21.46m	Proton	3	$4.24m	Rangers	2	$1.07m
Gnosis	75	$305.48m	K2	2	$20.92m	Nuls	4	$4.11m	CosmosHub	5	$1.03m
TON	44	$304.71m	Astar	43	$20.85m	Beam	2	$4.1m	RENEC	1	$992,040
Starknet	30	$271.67m	Radix	14	$20.01m	Vision	2	$3.98m	Lisk	2	$939,848
BSquared	21	$269.57m	Chainflip	1	$19.27m	DFK	2	$3.93m	Elysium	1	$916,220
Taiko	35	$264.53m	opBNB	40	$19.1m	Morph	4	$3.89m	Oasis Emerald	19	$914,002
BOB	21	$261.8m	MAP Protocol	9	$17.83m	Bahamut	6	$3.78m	Juno	10	$877,853
Near	28	$257.58m	Rollux	5	$17.37m	Polynomial	2	$3.7m	Kadena	6	$875,897
Rootstock	26	$231.71m	Aurora	60	$16.86m	Gravity	4	$3.56m	ShimmerEVM	7	$844,297
AILayer	6	$212m	WEMIX3.0	12	$16.54m	smartBCH	23	$3.41m	LaChain Network	2	$818,652
Sei	32	$187.92m	ApeChain	8	$15.84m	FunctionX	3	$3m	Obyte	7	$814,291
Zircuit	9	$176.22m	NEO	6	$15.33m	Eclipse	5	$2.97m	Sanko	3	$712,133
Kava	141	$170.14m	XRPL	6	$14.8m	BEVM	9	$2.96m	SatoshiVM	1	$711,370
Merlin	24	$154.41m	Waves	9	$14m	Acala	8	$2.96m	Stargaze	3	$689,068
EOS	21	$152.53m	Bitcoincash	3	$14.01m	Horizen EON	7	$2.76m	DeFiChain EVM	3	$667,668
Mode	70	$144.08m	Immutable zkEVM	3	$13.98m	UX	3	$2.68m	ThunderCore	10	$663,561
Ronin	4	$134.5m	Conflux	16	$13.67m	aelf	1	$2.67m	VeChain	2	$656,273
Mixin	10	$123.72m	Icon	6	$13.58m	Oasis Sapphire	5	$2.46m	Ultron	3	$651,439
Osmosis	17	$118.77m	FSC	1	$13.51m	Harmony	61	$2.38m	Starcoin	3	$611,535
Celo	53	$118.24m	DefiChain	3	$13.35m	Interlay	5	$2.28m	RSS3	1	$606,993
MultiversX	22	$111.59m	Secret	9	$13.14m	Oasys	4	$2.2m	Evmos	23	$588,575
Algorand	33	$106.2m	EOS EVM	8	$12.57m	Archway	6	$2.18m	Chihuahua	3	$579,362
Stacks	12	$102.94m	XDC	11	$12.57m	OKTChain	37	$2.16m	Energi	1	$577,400
Fantom	332	$97.22m	Alephium	5	$11.81m	Hydra	3	$2.11m	SKALE Europa	6	$573,779
Hedera	12	$93.07m	Chiliz	6	$11.29m	Zilliqa	7	$2m	NOS	1	$550,389
ZKsync Era	125	$88.14m	Polygon zkEVM	70	$10.07m	Boba	28	$1.87m	EthereumClassic	11	$539,530
Filecoin	22	$69.82m	X Layer	26	$9.3m	Theta	5	$1.87m	Bittorrent	16	$530,062

Appendix B: Extended Discussion and Analysis

We briefly summarize the results of several additional tests to expand the discussion on DON integration in this section. All the tests in this section conditions DON integration only to the major player, Chainlink, as this is the only decentralized oracle in which we have access to additional granular data.[1]

DeFi protocols whose DON integration occurs exclusively before their respective smart-contract launches, with no further post-launch oracle integration, may experience accentuated economic effects. A protocol's DON integration before launch likely signals that it is fully developed and can provide an extensive array of services that are more reliable, accurate, and less susceptible to manipulation due to the incorporation of a third party data provider for hybrid smart contracts (i.e., DON). Table B2, which presents results for DeFi protocols without post-launch integration, supports this conjecture. The coefficients are more significant and almost twice as large as those reported in our main specification, suggesting that the impact of DON integration is accentuated for protocols that are well developed before launch. In contrast, DeFi protocols that undertake oracle integration in the post-live phase may have been launched without being fully developed and tested, which could make them vulnerable to bugs and technical limitations. Table B3, which presents results for this subset of DeFi protocols, shows that DON integration has either no significant impact or, at longer horizons, even a negative effect on TVL.

DeFi protocols often adopt DON before their operations go live. Defining days to integration as the difference (in days) between DON integration and the go-live date, the mean (median) average days to integration is 35 (7) days before the protocol goes live. For early adopters—using price feeds as the main oracle service, the mean (median) average days to integration is minus 195 (minus 151) days. The mean (median) average days to integration for late adopters—those using other services beyond price feeds, the mean (median) average days to integration is 146 (102) days. A considerable variation in days to integration across oracle service suggests that while DON integration is crucial for some services to go live (e.g., price feeds for DeFi lending), an increasing spectrum of oracle services, such as VRF for gaming, also allows post-live integration. Using Chainlink as the focal DON, price feeds dominate oracle services with 76.47% of the integration—or early adopters before the protocol goes live. VRF, Keepers, and Proof of Reserve follow with 11.45%, 6.07% and 0.62%, respectively, of the post-live integration. Our study focuses exclusively on price feeds as the main service of Oracle integration in the next sections.

Another important aspect relates to the heterogeneity of DON services. As discussed earlier, DON integration includes other services beyond access to external data in the form of price feeds. These services are Keepers, external

[1] We are thankful to ChainLink Labs for providing detailed information.

entities (usually a data provider) that perform various tasks, such as data validation, submitting updates, triggering specific actions based on predefined conditions, and maintaining the integrity of the oracle network; VRF (Verifiable Random Function), a cryptographic method used to generate random numbers in a verifiable manner within a blockchain or decentralized network often used for gaming and NFT applications; and proof-of-reserves, a mechanism used to validate and provide evidence that a service or platform holds the assets it claims to have in reserve. These services are essential for the functioning and credibility of certain DeFi protocols. Indeed, certain protocols could not even exist without them. For instance, DeFi protocols providing weather insurance cannot operate without DON integration. For certain DeFi protocols, however, DON integration is helpful but not crucial. Some DeFi protocols incorporate various price feeds through DON integration in a manner that enables them to deploy and offer a new array of decentralized finance services. Therefore, the marginal effects of DON integration could be greater for protocols using price feeds, which enhance their capabilities, compared to other services. The results in Table B4 support this logic. The integration of DeFi protocols with DON that provide price feeds have large and statistically significant positive effects on TVLs at longer horizons while integration with other DON services has little effect.

Finally, besides the direct impacts on an integrating protocol, DON integration may have spillover effects on other protocols with which it has strong financial linkages. Consider the relationship between DeFi lending protocols and decentralized exchanges (DEXs). Lending protocols are highly dependent on DON to access price feeds to keep track of the current value of collateralized assets. By contrast, DEXs are not oracle-dependent as their prices derive directly from supply-demand interactions on their protocols. Nevertheless, DEXs might benefit from the DON integration of lending protocols as this attracts arbitrageurs who can liquidate undercollaterized positions in lending markets and sell the collateralized assets at a premium in a DEX in the same blockchain environment. Thus, DON integration of lending protocols could have positive spillover effects on to DEXs. Table B5 examines this conjecture. The results suggest that there are indeed spillover effects from DON integration of DeFi lending protocols on to the TVLs of local DEXs in the same blockchain. These indirect effects over longer time horizons are about three times larger than the direct effects on the TVLs of the integrating protocols themselves that were documented in our main specification. This adds to the other strands of evidence in this paper suggesting that DON integration is vital to the effective functioning and economic outcomes of all protocols within a blockchain environment.

Table B1. Post-live performance responses to oracle adoption (Economic and financial activities): This table reports the summary statistics for equation 2 in Panel A, and replacing TVL with market capitalization of traded tokens in Panel B. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable in Panel A. Market capitalization (i.e., aggregate value in dollars of total tokens in circulation times their price) is the dependent variable in Panel B. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

	Panel A: Total Value Locked				**Panel B: Market Capitalization**			
	Day	**Week**	**Month**	**Quarter**	**Day**	**Week**	**Month**	**Quarter**
DON	6.34	30.46	65.01 **	77.36 **	1.35	22.90	43.64 **	68.00 **
	(11.66)	(21.25)	(28.98)	(38.43)	(9.23)	(15.28)	(21.65)	(28.49)
CON	6.42	-15.27	-42.77	-33.61	-7.70	33.31	34.57	77.32
	(19.35)	(35.31)	(50.51)	(67.77)	(16.42)	(26.86)	(38.64)	(49.00)
log(1 + FDV)	1.17 **	2.04 **	2.49 *	4.73 ***	0.23	-0.28	1.38	2.46 *
	(0.55)	(1.00)	(1.37)	(1.80)	(0.47)	(0.77)	(1.09)	(1.46)
log(1 + Staking)	0.84	1.29	4.08 **	6.59 ***	0.92	0.28	0.93	5.63 ***
	(0.73)	(1.33)	(1.84)	(2.48)	(0.59)	(0.96)	(1.37)	(1.85)
log(1 + # Chains)	-1.24	-26.93	-40.53	-55.91	-5.05	1.96	-14.75	19.94
	(17.40)	(31.50)	(43.38)	(55.45)	(14.80)	(24.20)	(34.35)	(42.25)
log(1 + Oracles)	7.05	14.52	28.34	14.40	-13.26	-7.15	13.08	45.45
	(16.14)	(29.87)	(41.69)	(57.45)	(13.61)	(22.75)	(32.87)	(45.22)
Category	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	1373	1349	1273	1047	745	739	710	579
Adj.r^2	0.04	0.04	0.09	0.14	0.06	0.05	0.14	0.27

Table B2. Economic Effects Without Post-Live Adoption: This table reports the summary statistics for equation 2 but is conditioned to protocols with adoption before launch. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable across all specifications. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

TVL (Without Post-Live Adoption)				
	Day	**Week**	**Month**	**Quarter**
DON	28.02 **	59.76 **	129.82 ***	168.40 ***
	(13.62)	(24.72)	(33.61)	(42.62)
CON	-4.96	-43.52	-102.31 **	-114.35 *
	(19.64)	(35.76)	(50.85)	(68.22)
log(1 + FDV)	1.13 **	2.05 **	2.46 *	4.66 ***
	(0.54)	(1.00)	(1.35)	(1.78)
log(1 + Staking)	0.79	1.31	4.03 **	6.52 ***
	(0.73)	(1.33)	(1.83)	(2.45)
log(1 + # Chains)	-2.73	-28.53	-43.09	-62.12
	(17.37)	(31.45)	(43.16)	(55.12)
log(1 + Oracles)	5.77	18.27	34.93	16.77
	(15.59)	(28.86)	(40.21)	(54.65)
Category	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
Obs.	1,373	1,349	1,273	1,047
Adj.r^2	0.04	0.04	0.09	0.14

Table B3. Economic Effects With Post-Live Adoption: This table reports the summary statistics for equation 2 but is conditioned to protocols with adoption after launch. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable across all specifications. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

TVL (With Post-Live Adoption)				
	Day	**Week**	**Month**	**Quarter**
DON	-18.51	-17.93	-41.79	-79.88 *
	(13.34)	(24.42)	(33.84)	(45.11)
CON	11.88	-16.38	-43.61	-25.43
	(19.77)	(36.17)	(51.81)	(69.01)
log(1 + FDV)	1.28 **	2.28 **	2.96 **	5.48 ***
	(0.55)	(1.00)	(1.36)	(1.79)
log(1 + Staking)	0.93	1.54	4.53 **	7.55 ***
	(0.73)	(1.33)	(1.84)	(2.47)
log(1 + # Chains)	-0.29	-23.69	-32.10	-48.06
	(17.36)	(31.46)	(43.34)	(55.37)
log(1 + Oracles)	14.08	30.94	64.70	75.38
	(15.85)	(29.38)	(40.99)	(55.69)
Category	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
Obs.	1,373	1,349	1,273	1,047
Adj.r^2	0.04	0.04	0.08	0.14

Table B4. DON Characteristics: This table reports the summary statistics for equation 2 in the cross-section of DON services. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable across all specifications. The variables of interest include *DON(Price Feed)*, is an indicator variable that equals one for DeFi protocols with price feed integration and zero otherwise; *DON(Keeper)*, is an indicator variable that equals one for DeFi protocols with keeper integration and zero otherwise; and, *DON(VRF)*, is an indicator variable that equals one for DeFi protocols with verifiable random function (VRF) integration and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

TVL (DON Characteristics)				
	Day	**Week**	**Month**	**Quarter**
DON(Price Feed)	-4.50	25.37	68.72 **	73.56 *
	(12.36)	(22.54)	(30.90)	(40.89)
DON(Keeper)	49.17	-5.06	1.45	41.52
	(38.30)	(69.24)	(93.46)	(121.62)
DON(VRF)	7.22	-36.07	-40.82	-57.77
	(14.23)	(25.75)	(35.02)	(43.75)
DON(Proof-of-Reserve)	-30.51	-52.04	-62.78	-48.58
	(110.22)	(199.20)	(270.29)	(338.07)
Controls	Yes	Yes	Yes	Yes
Category	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
Obs.	1,373	1,349	1,273	1,047
Adj.r^2	0.03	0.04	0.08	0.13

Table B5. Spillover effects: This table reports the summary statistics for equation 2 but is conditioned to protocols in the decentralized exchange industry. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable across all specifications. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration and zero otherwise. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. All specifications have Blockchain and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

TVL (Decentralized Exchanges)				
	Day	**Week**	**Month**	**Quarter**
DON	18.69	120.67 ***	173.98 ***	226.44 ***
	(25.24)	(44.36)	(55.87)	(68.05)
CON	47.43	48.27	3.33	25.93
	(35.15)	(62.85)	(82.88)	(105.73)
log(1 + FDV)	-0.35	2.26	5.05 **	8.56 ***
	(1.08)	(1.91)	(2.40)	(2.86)
log(1 + Staking)	0.50	3.88	4.69	6.97 *
	(1.42)	(2.53)	(3.30)	(4.05)
log(1 + # Chains)	-2.65	-59.86	-106.74	-33.03
	(37.42)	(65.58)	(82.90)	(97.56)
log(1 + Oracles)	13.37	13.88	-41.85	-207.37 *
	(40.24)	(71.16)	(92.17)	(118.79)
Blockchain	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
Obs.	416	409	383	323
Adj.r^2	0.05	0.11	0.15	0.18

Table B6. Post-live performance responses to oracle adoption (On-chain activities): This table reports the summary statistics for Equation 2, but replaces TVL with the number of on-chain unique users (i.e., unique wallets with at least one token) in Panel A, and the number of on-chain transfers (i.e., the number of on-chain transactions) in Panel B. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the *Category* × *Blockchain*. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

	Panel A: Unique Users				**Panel B: Transfers**			
	Day	**Week**	**Month**	**Quarter**	**Day**	**Week**	**Month**	**Quarter**
DON	20.45	42.40 **	53.58 ***	42.47 **	20.07	55.92 **	60.99 **	57.24 **
	(21.62)	(19.75)	(20.15)	(20.71)	(30.79)	(27.60)	(28.27)	(28.15)
CON	43.77	38.76	40.68	54.44 *	25.80	40.99	32.83	64.17
	(34.64)	(31.65)	(32.29)	(32.60)	(49.35)	(44.23)	(45.29)	(44.30)
log(1 + FDV)	4.09 ***	4.38 ***	4.72 ***	4.38 ***	6.55 ***	5.14 ***	6.34 ***	5.51 ***
	(1.14)	(1.04)	(1.06)	(1.12)	(1.62)	(1.45)	(1.49)	(1.52)
log(1 + Staking)	2.00	1.68	1.18	1.03	2.93	1.60	1.45	2.17
	(1.29)	(1.18)	(1.21)	(1.28)	(1.84)	(1.65)	(1.70)	(1.74)
log(1 + # Chains)	12.44	8.18	-6.81	16.45	28.81	35.63	1.31	32.02
	(28.00)	(25.58)	(26.09)	(26.92)	(39.88)	(35.75)	(36.60)	(36.59)
log(1 + Oracles)	3.82	-8.89	-33.11	5.47	-7.80	10.05	-47.03	-12.49
	(29.71)	(27.15)	(27.69)	(29.71)	(42.32)	(37.94)	(38.84)	(40.38)
Category	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	312	312	311	282	312	312	311	282
Adj.r^2	0.26	0.28	0.30	0.29	0.29	0.31	0.30	0.30

Table B7. DeFi protocols per industry (original values as 2022): This table depicts the distribution of DeFi protocols per category. All columns are expressed in numerals, except TVL and Mcap which are expressed in billion of dollars. See Appendix A for the description of each industry.

Category	Protocols	TVL ($b)	Mcap ($b)	Chains	Audits
Algo-Stables	80	5.29	2.74	1.19	0.85
Bridge	21	24.46	11.63	6.43	1.29
CDP	35	16.46	2.33	1.57	1.56
Chain	9	10.19	8.85	1.00	0.89
Cross Chain	14	1.99	0.27	5.79	1.43
Derivatives	25	3.15	2.28	1.40	1.83
DEX	438	57.75	28.34	1.48	1.19
Farm	34	0.04	0.01	1.26	0.88
Gaming	17	0.02	2.93	1.53	0.94
Indexes	27	0.60	0.16	1.63	1.33
Insurance	19	1.20	0.66	1.47	1.56
Launchpad	21	0.05	0.42	1.19	1.20
Lending	143	44.88	6.83	1.69	1.61
Liquid Staking	26	19.11	2.09	1.46	1.23
NFT Lending	3	0.00	0.04	2.00	2.00
NFT Marketplace	7	0.04	0.37	1.57	0.57
Options	34	0.92	0.33	2.00	1.53
Oracle	3	0.00	0.18	1.33	1.33
Payments	8	0.84	1.13	2.00	1.25
Prediction Market	10	0.01	0.00	1.00	0.60
Privacy	7	0.58	0.23	1.29	1.43
Reserve Currency	116	0.96	0.65	1.08	0.25
Services	49	4.45	1.16	1.59	0.72
Staking	44	0.62	0.62	1.23	0.93
Synthetics	22	0.56	0.64	1.45	1.50
Yield	315	19.22	3.01	1.43	1.31
Yield Aggregator	48	4.28	1.00	2.44	1.31
Grand Total	1,575	217.67	78.91	1.58	1.17

Table B8. DeFi protocols per industry (market values as 2024): This table depicts the distribution of DeFi protocols per category as September 2024. All columns are expressed in numerals, except TVL and Mcap which are expressed in billion of dollars. See Appendix A for the description of each industry. * excludes Chain entries

Category	Protocols	TVL ($b)	Mcap ($b)	Chains	Audits
Algo-Stables	115	0.09	0.40	1.26	0.66
Bridge	81	22.53	1.05	6.11	0.95
CDP	150	7.79	1.93	1.62	1.15
Chain	77	27.46	1264.83	1.34	0.18
Cross Chain	35	0.80	0.36	9.03	0.97
Derivatives	259	3.54	0.74	1.66	0.99
Dexes	1382	16.43	6.01	1.62	0.80
Farm	164	3.68	0.42	1.28	0.55
Gaming	54	0.00	1.54	1.30	0.67
Indexes	59	0.54	0.26	1.56	1.24
Insurance	26	0.26	0.19	2.15	1.60
Launchpad	57	0.77	1.53	2.67	0.95
Lending	436	29.76	3.81	1.79	1.20
Liquid Staking	180	39.53	2.71	1.47	1.04
NFT Lending	30	0.08	0.01	1.40	1.03
NFT Marketplace	39	0.09	2.21	1.23	0.77
Options	58	0.17	0.08	2.02	1.31
Oracle	9	0.00	1.16	1.44	0.67
Payments	19	0.42	0.40	3.47	1.05
Prediction Market	49	0.10	0.03	1.84	0.67
Privacy	17	0.54	0.20	2.24	0.94
Reserve Currency	123	0.01	0.27	1.08	0.29
Services	208	0.80	13.48	1.51	0.56
Staking Pool	27	0.49	0.09	1.22	0.52
Synthetics	39	0.37	0.04	1.41	1.36
Yield	508	5.51	1.76	1.67	1.14
Yield Aggregator	141	1.55	0.26	2.41	1.16
Total	4,342	163.30	1305.76	2.14	0.91
Total*	4,265	135.84	40.92	2.17	0.93