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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. Integration through oracle networks for blockchain and DeFi platforms allows them to be informationally and financially connected to other blockchain ecosystems and off-chain environments. Using hand-collected data on hundreds of DeFi protocols and data from the market for decenftralized oracle networks (DONs), we document that oracle integration has positive financial and economic ramifications. Additionally, our initial evidence suggests that symbiotic gains from enhanced interoperability between protocols on a given chain and, depending on the mass of integrated protocols, among integrated chains, translate to positive network effects. Moreover, oracle integration appears to improve risk-sharing without significant contagions; integrated protocols appear more resilient than nonintegrated protocols during times of crisis. We draw parallels between oracle integration and international economic and financial integration, offering insights for regulators, entrepreneurs, and practitioners in the emerging space blockchains, DeFi, and Web3 ecosystems.

JEL Classification: G15, G18, G29, K29, K42, O16

Keywords: DeFi, blockchain, smart contracts, interoperability, information aggregation, globalization, international economics, risk-sharing, financial crisis.

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1 Introduction

Blockchain technology has evolved beyond facilitating simple cryptocurrency transactions to serving as an engine for powering centralized finance (CeFi), decentralized finance (DeFi), decentralized applications (DApps), and the development of non-fungible tokens (NFTs), among other Web3 ecosystems.[1] Most use cases heavily rely on smart contracts — computer code and programs that specify the terms of transactions and execute automatically when the contracting parties meet predetermined conditions. But blockchains and smart contracts have a fundamental limitation — they cannot automatically interact with data and systems existing outside their native network environment. The inherent inability of blockchains to access external data is known as the "blockchain oracle problem," or simply the "oracle problem." To provide bridges across blockchains or between on-chain and off-chain systems, smart contracts require access to this additional "oracle" infrastructure—node(s) maintaining and updating the system states using information and data external to the native blockchain or smart contract—to trigger executions based on off-chain or cross-chain events, such as changes in market prices or weather conditions relevant to the terms and conditions specified in the contract.[2] Reliable oracles can therefore expand the types of digital agreements blockchains can support by offering a universal gateway to off-chain sources of information and synchronizing multiple distributed ledgers to facilitate financial activities, all while privacy, autonomy, and security in the networks and the broader economy.

We conduct the first comprehensive empirical analysis of how informational and financial integration through oracle networks affects the blockchain and DeFi ecosystems.[3] Just as international economic integration involves the exchange of capital, goods, information, assets, and services among different countries, oracle integration for blockchain and DeFi networks aims to provide seamless flows of information for smart contracting, crypto assets, and Web3 services across var-

[1] Web3, a.k.a. Web 3.0 or the decentralized web, refers to the next generation of internet built on top of blockchain technology and decentralized protocols.

[2] For instance, DeFi protocols such as decentralized lending or exchanges for crypto-derivative trading require price feeds from benchmark markets to function properly. Besides price feeds, oracles may also convey information from asset markets for financial contracts, weather information for insurance products, randomness for gaming, IoT sensors for supply chain management, and ID verification for governments.

[3] For theoretical studies and discussions see Harvey, Ramachandran, and Santoro (2021), Adams, Wan, and Zinsmeister (2022), Braun, Hä usle, and Karpischek (2022), John, Kogan, and Saleh (2022), Ali, S, T, and R (2023), and Mik (2023).

ious digital ecosystems. As such, the implications of oracle integration for system outcomes, such as total value locked, token market capitalization, and userbase growth, can be analyzed in a similar framework as that developed for understanding the impact of a country's economic and financial integration with other countries on international capital flows, GDP and consumption growth, contagion of financial crisis, etc. Conversely, insights from blockchain integration may help us understand findings in the extant international financial integration literature.

While any node in a network can serve as an oracle, a centralized setup to deliver data to a smart contract introduces a single point of failure and concentration of market power (Cong and He, 2019), contravening the decentralized architecture of many blockchain and Web3 applications. For example, if the centralized oracle on which it relies goes offline, a smart contract loses access to the data required for execution or executes with stale data, not to mention that a corrupted oracle node can cause tremendous financial losses to users and network instability given how blockchain transactions and smart contracts are automated, immutable, and irreversible. Instead of centralized oracles (COs), the most popular industry solution to the oracle problem has been to develop oracle networks, especially decentralized oracle networks (DONs), which authenticate data using multiple oracles and aggregate their input before feeding into smart contracts. Our goal is to understand the oracle market and investigate the impact of DON integration on the focal digital network and its symbiology with other ecosystems, blockchain-based or offchain.

We start by providing an overall description of the DONs market, which has evolved from having a sole provider (*MakerDAO*) in 2019 to having over thirty in 2022. While some oracles such as Coingecko price feeds are centralized and provide specific services, others are administrators responsible for managing third-party oracle inputs (e.g., *Pyth*). As of end-2022, Chainlink was the largest DON administrator and had integrated over a hundred DeFi protocols (52% of the market) and secured over $35 billion USD in total value locked (TVL). Decentralized exchange, decentralized lending, yield farming, and derivatives count for 65% of all networks and protocols integrated through oracles, consistent with their heavy reliance on accurate price information retrieved off-chain. Some protocols require oracles to go live (e.g., decentralized lending) but many protocols never undertake DON integration or delay it until well after going live, indicating that DON integration is typically neither immediate nor considered essential despite its many potential advantages in this early phase of the industry.

We examine two key metrics of DeFi protocols, total value locked (TVL) and market capitalization of tokens, to assess the effect of oracle integration. TVL refers to the aggregate value in dollars of all assets held in a DeFi protocol. These assets, which can include cryptocurrencies like Ether, Bitcoin, and various altcoins, are usually staked, loaned, or otherwise committed to a DeFi platform and actively participate in the platform's economic activities.[4] Market capitalization is the aggregated value in USD of total tokens in circulation times their price. It serves as a proxy for the DeFi protocol market valuation. We document rapid TVL growth in the first three months from integration at the chain level, especially among young chains such as Arbitrum and Avalanche. On average, DON integration positively affects TVL growth (average 75%) and market capitalization (average 43%) even within the first month of going live. These results suggest that DON enables the creation of more advanced and reliable DeFi protocols, boosting the blockchain ecosystem's growth and market demand.

The potential impact of DON integration are not limited to these adoption effects. Inspired by the international economics literature, we assess symbiotic gains for enhanced interoperability among integrated protocols. Using TVL correlations among integrated chains, we document a surge in post-integration correlations, especially for young chains such as Avalanche. For example, correlations between one's TVL and those of other chains increased following Avalanche's DON integration, reflecting enhanced interoperability. In particular, the correlation between the TVLs of Avalanche and Ethereum increased 36.21% post-integration. To mitigate selection that could drive the observed correlations, we also examine symbiotic gains among integrated protocols. We conjecture that, by integrating through DONs, DeFi protocols potentially gain value from enhanced interoperability between integrated protocols and between chains — depending on the mass of integrated protocols. Our empirical analysis on Ethereum, the blockchain with the largest number of integrated protocols, supports this conjecture, with TVL correlations among DeFi protocols on the Ethereum blockchain shown to be increasing in the mass of integrated protocols.

Next, we examine whether oracle integration and interoperability gains translate to network effects. Using on-chain variables to test userbase and on-chain activity growth, such as the num-

[4]Economic activities in this context could include lending and borrowing, liquidity provision, yield farming, or participating in a decentralized exchange. The assets are generally locked in smart contracts on a blockchain, and they generate returns for the user in the form of interest, yield, or governance tokens, depending on the specific platform's design and terms.

ber of unique wallets and on-chain transfers, both within specific DeFi protocol industries and blockchain ecosystems, we find substantial network effects/economy of scale. User base growth is positive across all on-chain proxies and time-window specifications. For instance, the average growth in the user base and on-chain transfers within the first month after DON launch is 56% and 76% higher for integrated protocols than for non-integrated protocols. We conclude that, beyond adoption and interoperability effects, DON integration fosters more rapid development of integrated protocols' on-chain activities.

These findings collectively suggest that integration through oracle networks benefits DeFi protocols through enhanced adoption and interoperability effects. These effects then translate into userbase growth and further development of on-chain activities. Our main results are preserved when we separate the effects of DON integration from integration through centralized oracles (CO) and also when we control for factors associated with the likelihood that a DeFi protocol will undertake DON integration, including fully diluted market capitalization, staking levels, number of listed chains and integrated oracles, and industry and blockchain fixed effects. It also holds in a sample excluding DeFi protocols with post-live integration and in restrictive analysis with matched samples and synthetic controls.

Our study contributes to several fields of academic and practitioner research. First, it is related to the literature on how international financial integration affects economic outcomes such as productivity, growth, and asset returns at the country level. We can think of blockchains as separate countries and international financial integration through various forms of cross-border capital flows as the equivalent of DON integration bridging ecosystems. The effects of financial integration on productivity and growth are generally found to be dependent on the form and extent of integration (Bekaert, Harvey, and Lundblad (2005) and Coeurdacier, Rey, and Winant (2020); Henry (2007) and Kose, Prasad, Rogoff, and Wei (2009), provide surveys of this literature). For instance, foreign direct investment and portfolio equity flows have been shown to be positively associated with higher output and productivity growth in recipient economies and better risk-sharing outcomes as well. Debt inflows (including bank loans and sovereign debt financed by foreign investors) yield few growth or risk-sharing benefits. The former types of flows also better convey the indirect benefits of financial globalization, such as technology transfers. In our setting, DON integration provides more robust and reliable informational and financial integration between blockchains (compared to CO integration or no integration), potentially generating both direct and indirect benefits.

In addition, there is evidence of threshold effects leading to nonlinearities in the relationships between these variables (Kose, Prasad, and Taylor, 2011). Financial integration is shown to influence the cross-country comovement of fluctuations in business cycle aggregates such as GDP and consumption (Kose, Prasad, and Terrones, 2003) as well as asset returns (Bekaert, Harvey, Kiguel, and Wang, 2016). Analogously, DON integration boosts local economies through adoption effects and enhanced interoperability among integrated protocols benefiting economic players (e.g., DeFi protocol users and service providers), especially as the mass of integrated protocols grows in the ecosystem.

This study provides insights into a broader literature on price discovery on digital platforms, especially in markets with high information asymmetries. For instance, price discovery has been established as a function of credibility signaling in the cryptocurrency (Sokolov, 2021), initial coin offerings (Lyandres, Palazzo, and Rabetti, 2022), and crowdfunding markets (Michels, 2012). Our work complements these studies by documenting how DON integration facilitates price discovery in DeFi markets.

This study also contributes to the current debate over crypto regulation (Foley, Karlsen, and Putnins (2019), Griffin and Shams (2020), Cong, Li, Tang, and Yang (2023), Amiram, Jørgensen, and Rabetti (2022), Cong, Landsman, Maydew, and Rabetti (2023), Rabetti (2023), and Cong, Grauer, Rabetti, and Updegrave (2023)), by highlighting that decentralized solutions can potentially replace certain aspects of regulatory oversight over DeFi markets, especially in the context of ensuring reliability and verifiability of financial information. Our paper complements the findings of Amiram, Lyandres, and Rabetti (2021) that industry-related initiatives are potentially more effective than regulation in preserving the industry while washing off bad actors. Our study joins Cong, Harvey, Rabetti, and Wu (2022) in helping to determine the parameters of a constructive approach toward a regulatory framework that facilitates such objectives while preserving the advantages of DeFi.

Moreover, our study yields insights that are relevant for practitioners. The DeFi market has become the breeding ground for several start-ups and also the largest alternative financing market worldwide, amassing several billions of dollars in funds raised, investments, and transaction volume. Tokenomics — the economic and incentive systems that underlie the issuance, distribution, and use of cryptocurrencies — or digital tokens has emerged as the backbone for the success of blockchain-based ventures.[5] As DeFi applications thrive, the results in this paper are relevant for entrepreneurs, investors, and consumers in this vibrant emerging market.

The remainder of this study is structured as follows. Section 2 provides the institutional background, describes the data, and summarizes stylized patterns. Section 3 analyzes the impact of DON integration by DeFi protocols. Section 4 documents how the interoperability enabled by DONs leads to market integration and examines whether adoption and interoperability effects translate to network gains. Section 5 concludes and offers caveats for interpreting our results.

2 Institutional Background and Data

2.1 Oracles and the DON Approach

Web3 and blockchain oracles. Web2 primarily comprises user data and real-world information stored in centralized servers, making these databases vulnerable to data loss and manipulation. In contrast, Web3 offers greater access, transparency, and user ownership through decentralized and trust-minimized public blockchains. Web3 aims to address some of the limitations and issues of Web2 by leveraging decentralized blockchain technology. In Web3, users have more control over their data and can participate in decentralized applications that do not rely on centralized servers.

However, the blockchain oracle problem remains a significant challenge for smart contracts. While oracles can provide access to off-chain data and computation, there are concerns about the quality and reliability of that data. Smart contracts cannot verify the accuracy of external data sources, which could result in errors or even malicious manipulation of the contract's outcome. Ensuring data quality and preventing data manipulation will be critical for successfully adopting Web3 and smart contract technology.

[5]Tokenomics encompasses the design of a token's supply and demand dynamics, its distribution mechanisms, and its use cases within a particular ecosystem or network. Tokenomics also includes the governance and decision-making mechanisms used to manage the token's ecosystem, such as voting systems or stakeholder participation models.

Information reporting, manipulation, and a DON solution. While decentralized blockchain technology remains trustless, ensuring the accuracy and reliability of information received by protocols operating on blockchains is crucial for maintaining system integrity. The issue of data manipulation in smart contracts arises when unreliable or centralized oracles are used as a gateway to off-chain data sources, which could lead to inaccurate or tampered information being fed into the contract. This creates a problem as 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 broken down 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 accurately validate real-world data. 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 attacks. The centralization of the oracle layer also increases the risk of a single point of failure.

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, DONs require multiple nodes to reach a consensus, reducing the risk of data manipulation. To illustrate how DONs 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 similar security techniques as 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 reputation system takes into account data quality, historical reliability, and average response time.

Note that current DONs are not panaceas. Some DONs may appear decentralized, but if, for instance, one oracle simply copies another or if they both use the same data provider, they could behave like a CO. Many studies (e.g., Cong and He, 2019; Braun et al., 2022) discuss various collusion problems. Moreover, Chainlink and the like use a centralized DON administrator at the moment, and are not fully decentralized, though they are working toward more decentralized systems where multiple DON administrators can participate and compete. In that sense, the DONs we refer to in this study can be considered hybrid setups where DONs retain some centralized elements but are more decentralized than COs.

DON services and use cases. DON integration potentially helps DeFi protocols to thrive by providing the architecture they need for efficient execution of their services and 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).

Often, smart contracts need to act upon the prices of assets in real-time. This is especially true in DeFi. For example, Synthetix uses data feeds to determine prices on its derivatives platform. 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.[6] Additionally, 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 cryptographic proof of how those values were 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 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 trust-minimized and decentralized manner. The network aims to provide a protocol for incentivizing execution and governance of execution within the Keeper ecosystem. Relying on Keepers can help DeFi protocols reach market faster and save gas fees (transaction fees) by offloading expensive on-chain automation logic to DON's decentralized Keepers Network.

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

2.2 Data

We obtain data from several sources. First, we procure DeFi protocol characteristics from the most comprehensive DeFi data aggregator, DefiLlama.com. The data includes TVL, staking, industry classification, and price information for more than 1,500 protocols and 100 chains. We complement our dataset 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. Finally, we hand-collect data on oracle integration using independent assessments by a team of research assistants.

2.3 Patterns and Trends

Market for Oracles and DONs. The market for oracles has grown tremendously in recent years with rapidly rising demand due to the evolution of the DeFi marketplace. While some oracles such as Congecko price feeds are centralized and provide specific services, others such as Chainlink are administrators that manage operations of third-party oracle networks.

[Figure 1 about here]

The DON market currently secures over $50 billion in total value locked. Chainlink has become the most prominent DON administrator, with about two-thirds of the current market share (Figure 1). As of May 2023, 30 oracles (those with a total value secured of at least 1 million dollars) are in operation.

[Table 1 about here]

Table 1 breaks down the number of DeFi protocols and their respective TVL per oracle. Chainlink leads in the number of integrated protocols (51.88%) and TVL in these protocols (68.79%). Among the top five DONs, TWAP, Pyth, Internal, and Band, follow with 51, 22, 22, and 19 integrated protocols, respectively. These five DONs account for 372 DeFi protocols that feature DON integration.

The DeFi landscape and relevance for DONs. Table 2 reports the characteristics of DeFi protocols grouped by industries. DeFi protocols in the Decentralized Exchanges (DEXs) category have the largest total value locked ($57.75 billion) and market capitalization ($28.34) among all categories. DEXs are also the largest group of DeFi protocols, accounting for about a third of the market (438 protocols). Other industries such as *Lending* ($45 billion), *Liquid Staking* ($19 billion), and *Bridge* ($24 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, voting rights, or passive income), such as *Bridge*, *Lending*, *Services*, and *Yield*. Together with *DEX*, these industries are at the core of DeFi market functioning.[7]

[Table 2 about here]

DeFi protocols are often multichain, as indicated by the chains-per-protocol average being larger than one. *Bridge* protocols run across the largest number of chains on average (6.43). This is not surprising, as the main function of bridge protocols is to link chains through chain-agnostic smart contract solutions. Auditing is also essential for DeFi in ensuring that a smart contract is bug-free and works as designed (Rabetti (2023)). It is a supply-driven action that often occurs before a DeFi protocol goes live, before a token is launched, or before a staking program is initiated. However, the practice is still new in this market, as shown by an average number of audits below two across all protocols.

The average number of daily users — a proxy for protocol adoption — is highly skewed, taking large values for *Chain* (261), *NFT Marketplace* (158), and *Gaming* (128), but small values for *Liquid Staking* (25), *Privacy* (21) and *Farm* (19). Alternatively, the number of daily transfers — a proxy for liquidity — indicates that the most liquid protocols are *NFT Marketplace*, *Staking*, and *Algo-Stables* with 35,730, 5,296, and 4,288 daily average number of transactions. Clearly, the DeFi marketplace has now become diversified beyond lending applications — its initial implementation.

[Table 3 about here]

[7] See Appendix A for the description of each DeFi category.

Table 3 reports the distribution of DeFi protocols grouped by industry.[8] Although *DEX* and *Yield* are the largest industries with 438 and 315 protocols, respectively, the percentage of DON integrated protocols within these two industries is only 7.76% and 9.21%, 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*, *Prediction Market*, and decentralized *Lending*, have more than half of their protocols being oracle-integrated. On average, across 1,575 DeFi protocols in our database, only 17.33% utilize the services of decentralized oracles.

These statistics have 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 together account for 47.81% 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 resilience for integrated protocols, then the overall DeFi market is currently operating at sub-optimal levels of integration. To examine this proposition, we now turn to an empirical investigation of the presumed benefits of DON integration.

3 DON Integration and DeFi Adoption

3.1 Days to Integration

DeFi protocols often adopt DON before their operations go live (Table 4). About 53% percent of protocols that undertook DON integration did so before going 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 for such early adopters is minus 195 (minus 151) days. The mean (median) average days to integration for late adopters, those that undertake DON integration after going live, is 146 (102) days. Among all integrated protocols, the mean (median) average days to integration relative to the go-live date is 35 (7) days before the protocol goes live, with a standard deviation of 233 days.

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

[Table 4 about here]

The considerable variation in days to integration suggests that while DON integration is crucial for some services to go live (e.g., price feeds for DeFi lending), an increasing spectrum of DON 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. VRF (Keepers and Proof of Reserve) follows with 11.45% (6.07% and 0.62%, respectively) of the integration.

3.2 Determinants of DON Integration

We begin by assessing the determinants of DON integration. In this baseline analysis, we examine the relationship between measures of the degree of success of DeFi protocols and DON integration. The results could hint at selection effects—that more successful protocols undertake DON integration. We also formally test for differences across DeFi industries in the extent of DON integration. This baseline analysis serves as a guide for a more careful examination of the determinants and implications of DON integration.

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

$$DON_i = \alpha + \beta FDV + \gamma Staking + \Theta + \Lambda + \epsilon, \tag{1}$$

where the dependent variable DON in equation 1 is an indicator variable that takes the value of one for a DeFi protocol with DON integration and zero otherwise. FDV is the fully diluted market capitalization value (e.g., includes no issued coins) one week before integration and reported in dollars; $Staking$ is the total value of staked coins one week before integration and reported in dollars; Θ represents industry fixed effects; Λ represents blockchain fixed effects; and ϵ is the error term. The subscript i indicates cross-sectional regressions at the DeFi protocol level.

[Table 5 about here]

Table 5 reports the main determinants of DON integration. Both proxies for DeFi protocol success (FDV and Staking) are increasing in the likelihood of DON integration. This correlation implies that successful DeFi protocols are more likely to undertake DON integration. Industry fixed effects also play an essential role in determining the likelihood of DON integration, as indicated by an increase in the R^2 from 0.11 to 0.19 in the regression with industry fixed effects (M2).

Additionally, Derivatives, Lending, and Options are substantially more likely to have DON integration than other industries, consistent with price feeds being crucial for these protocols. Finally, blockchain fixed effects also play an essential role, as indicated by an improvement in the R^2 to 0.24 in the most restrictive regression (M3). DeFi protocols listed on multiple chains are the most likely to use DON services, consistent with DON providing additional interoperability benefits.

3.3 Effects on Adoption and Growth

Effects at the chain 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, the provisioning of verifiable random number generators may also create value by boosting the development of on-chain gaming applications. Moreover, DON also allows the automation of some development tasks, minimizing costs and enhancing user experiences.

Avalanche's successful integration of price feeds illustrates how DON integration can facilitate ecosystem growth. Before the deployment of DON, the Avalanche ecosystem was greatly limited in creating automated market makers (e.g., decentralized exchanges) and yield aggregators (e.g., decentralized lending). By contrast, after deployment, various money markets and other oracle-integrated applications were enabled, boosting liquidity and paving the way for rapid growth. Avalanche's TVL grew by a multiple of 88 in the first few months after DON integration.

[Figure 2 about here]

Figure 2 illustrates the evolution and effects 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 from integration. The panel on the right illustrates gains in TVL at the chain level economy after integration. Using TVL scaled by a chain's initial TVL at its integration date as a measure of these gains, we document rapid growth for 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.

Effects at the DeFi-protocol level. We turn next to examining the effects of DON integration when a DeFi protocol goes live. DON integration benefits vary across protocols and chains, depending on several factors such as demand for data from smart contract developers, applications from users, and the relative competitiveness of the newly supported blockchain compared to other networks. As a blockchain-agnostic protocol, DON can expand support to any network and serve the demand for data, off-chain computation, and cross-chain interoperability. When such oracle services are made available, developers can create new advanced protocols, fostering growth in an entire blockchain ecosystem and attracting more market activity.

For all of these reasons, 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:

$$TVL_i = \alpha + \beta DON + \gamma CO + \eta FDV + \iota Staking + \delta Chains + \zeta Oracles + \Theta + \Lambda + \epsilon, \quad (2)$$

and,

$$MCap_i = \alpha + \beta DON + \gamma CO + \eta FDV + \iota Staking + \delta Chains + \zeta Oracles + \Theta + \Lambda + \epsilon, \quad (3)$$

where the dependent variables in equations 2 and 3 represent the growth in TVL and market capitalization, respectively, over horizons of a day, week, month, or quarter. The dependent variables in both equations are as follows: *DON*, an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise; *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *FDV*, the fully diluted market capitalization value one week before the live date and reported in dollars; *Staking*, the total value of staked coins one week before the live date and reported in dollars; *Chains*, the number (in logs) of listed chains for a given DeFi protocol; *Oracles*, the number (in logs) of oracles providing services to a given DeFi protocol; Θ represents industry fixed effects; Λ represents blockchain fixed effects; and ϵ is the error term. The subscript i indicates cross-sectional regressions at the DeFi protocol level.

The results, reported in Table 6, show that DON integration has positive effects on protocols' TVL and market capitalization. Panel A documents that DeFi protocols with integration in place have an average supplementary TVL growth of 35.12%, 74.85%, and 92.21% in the first week, month, and quarter, respectively, after going live. Panel B indicates that DON integration has similar but smaller effects on market capitalization, with 25.50%, 42.63%, and 75.57% average supplementary market capitalization growth, respectively, over the same time horizons.

[Table 6 about here]

The effects of integration via COs on TVL and market capitalization are generally not statistically significant, possibly reflecting the various weaknesses of such oracles discsussed earlier. FDV and Staking have positive effects on TVL at integration. But these effects are restricted to more extended periods for market capitalization responses. Other features, such as the number of listed chains and the number of oracles, do not influence the performance of DeFi protocols. These results hold within DeFi categories (e.g., DEXs, Yield, and Insurance), blockchains (e.g., Ethereum), and in a sample excluding protocols with post-live integration.

Endogeneity concerns. A potential concern in interpreting our results is that of endogeneity—protocols that undertake DON integration could systematically have characteristics that lead to better outcomes. To address this concern, we undertake a matched-sample analysis that uses the observed characteristics of all 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. The propensity score matching procedure that we employ and the resulting samples are described in Appendix B. Panels C and D of Table 6 present results showing that DON integration has positive effects on both TVL and market capitalization relative to peer protocols that lack DON integration (including CO-integrated protocols). These results further validate our previous assessment that DON integration has significant positive impacts on TVL and market capitalization of DeFi protocols, particularly over longer time horizons.

Finally, we also conduct a synthetic control analysis as an added check on our results. For this exercise, we use the matched sample constructed using the procedure described in Appendix B but restrict it to DeFi protocols with post-live integration in order to estimate the TVL growth path relative to the synthetic controls. The results, shown in Appendix C, reveal a significant gap (about 30% for a window beyond 60 days) in TVL growth between integrated protocols and the synthetic group. This additional robustness test further mitigates concerns that our results might simply reflect endogeneity related to protocol characteristics rather than the effects of DON integration.

4 Interoperability, Integration, and "International" Finance

4.1 Interoperability Effects: Network Symbiosis

Chain level interoperability. One interesting question is whether blockchains experience symbiotic gains from DON integration. As an illustration of the possible gains, 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.[9] 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.[10] For instance, the correlation between the TVLs of Avalanche and Ethereum's increased by 36.21% post-integration.

Adoption of DON integration 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

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

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

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 DONs 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]

As indicated by the positive differences in mean correlations among integrated protocols (Panel A), interoperability increases as the mass of integrated protocols expands within a given chain. The post-integrations 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 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. Correlations may also be affected by chain-specific effects, such as overall growth in the number of users due to market conditions.

4.2 Network Effects

In addition to adoption and interoperability effects, DON integration may also have network effects that result in enhancements to a protocol's user base and its amount of activity. To test this proposition, we estimate the following regressions:

$$USER_i = \alpha + \beta DON + \gamma CO + \eta FDV + \iota Staking + \delta Chains + \zeta Oracles + \Theta + \Lambda + \epsilon, \quad (4)$$

and,

$$TRANSFER_i = \alpha + \beta DON + \gamma CO + \eta FDV + \iota Staking + \delta Chains + \zeta Oracles + \Theta + \Lambda + \epsilon, \quad (5)$$

where the dependent variables *USER* and *TRANSFER* refer to the percentage growth in the total number of on-chain users and transfers, respectively, over horizons of a day, week, month, or quarter after integration. The independent variables in both regressions are as follows: *DON* is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise; CO is an indicator variable that equals one for DeFi protocols with centralized oracle integration before the live date and zero otherwise; FDV is the fully diluted market capitalization value one week before the live date and reported in dollars; $Staking$ is the total value of staked coins one week before the live date and reported in dollars; $Chains$ is the number of listed chains for a given DeFi protocol (in logs); $Oracles$ is the number of oracles providing services to a given DeFi protocol (in logs); Θ represents industry fixed effects; Λ represents blockchain fixed effects; and ϵ is the error term. The subscript i indicates these are cross-sectional regressions at the DeFi protocol level.

Table 9 reports estimates of integration effects on the post-live on-chain activity of DeFi protocols. The results suggest that DON integration before a protocol goes live is associated with increased user adoption and on-chain activity. Compared to non-integrated protocols, Panel A documents average increases in the number of users for integrated protocols of 36.40%, 50.83%, 55.71%, and 67.97% over the first day, week, month, and quarter, respectively, after DON integration. Panel B documents similar but slightly larger effects for on-chain transfers. Compared to non-integrated protocols, on-chain transfers for integrated protocols increase on average by

69.20%, 76.14%, and 82.22% in the first week, month, and quarter, respectively.

[Table 9 about here]

Centralized oracles yield statistically negligible effects in nearly all cases, with weak positive effects on the userbase only at the quarterly horizon. Furthermore, FDV is positively associated with the extent of on-chain activity across all windows. However, Staking, the number of listed chains, and the number of integrated oracles do not affect on-chain activity. These results hold within DeFi categories (e.g., DEXs, Yield, and Insurance), blockchains (e.g., Ethereum), and in a sample excluding protocols with post-live integration.

Finally, in Panels C and D, we present summary statistics that capture the effects of DON integration compared to a set of protocols that are matched on other characteristics but are not DON integrated (including CO-integrated protocols). The coefficients in this more restricted analysis are smaller and weaker in statistical significance at short horizons. Nonetheless, the results broadly validate our earlier assessment that DON integration positively influences on-chain activity, particularly at horizons beyond one week after integration.[11]

4.3 Integration and Risks

Growth, risk-sharing, and threshold dffects. Our analysis is closely connected to the literature examining how financial integration affects macroeconomic outcomes such as growth, volatility, and business cycle correlations. Blockchains are analogous to individual countries with their own financial systems, while DON integration is the equivalent of integration into global financial markets, reducing barriers to flows of information as well as enabling the operation of smart contracts and financial transactions that transcend individual blockchains.

One strand of literature in international finance examines how the particular form of integration affects macroeconomic outcomes. For instance, foreign direct investment (FDI) and portfolio inflows are associated with higher growth and better risk-sharing outcomes for emerging market economies, while debt inflows have detrimental effects (see, for instance, Bekaert et al. (2005) and Henry (2007)). Our results on the positive impacts of DON integration, which is a more reliable and less noisy approach to integrating with off-chain markets or other blockchains, compared to

[11] See Appendix B for the matching procedure and descriptions of the matched samples.

CO integration or no integration on variables such as TVL and user base growth echo the findings in this literature.

A related strand of literature examines threshold effects—how certain country characteristics, such as levels of human capital and financial development, influence whether or not a country benefits from financial integration. One interesting finding in the international finance literature is that the level of integration itself is an important threshold—countries that are more integrated into global financial markets have better growth and risk-sharing outcomes than those that are less integrated, conditioning on other determinants of growth and volatility (Kose et al. (2011)). Our findings in this paper suggest that threshold effects are important in the DeFi environment as well, with the benefits of interoperability increasing nonlinearly. In particular, as discussed earlier, DON integration enhances interoperability among integrated protocols and this effect gets stronger as the mass of integrated protocols on the Ethereum blockchain has grown.

It has been documented that cross-border financial linkages increase business cycle correlations (as measured by cross-country correlations of GDP growth, e.g., see Kose et al., 2003) and also the cross-country correlation of asset returns (Bekaert et al., 2016), while also improving risk-sharing (as reflected in lower volatility and higher cross-country correlations of consumption growth, see Kose, Prasad, and Terrones, 2009). Our results on how the degree of interoperability, reflected in the mass of integrated protocols within a given chain as well as chain-level interoperability, increase TVL correlations between protocols and blockchain ecosystems while reducing the volatility of those correlations is in line with the findings in the international finance literature.

Risk-sharing or contagion? resilience in times of crisis. The literature on globalization includes evidence that countries that are 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 is seen to have these benefits for emerging market and developing economies.[12] Analogously, do DON-integrated protocols show more resilience in the face of crises?

Two recent events that shook the cryptocurrency market allow us to examine this proposition. The first is the unraveling of the TerraLuna algorithmic stablecoin in May 2022. The second is

[12]See Calvo, Izquierdo, and Mej'a (2004), Frankel and Cavallo (2004), Cavallo (2007), and Edwards (2008).

the collapse of the FTX exchange, then the second largest cryptocurrency exchange, in November 2022. Both events led to substantial and broad-based declines in cryptocurrency valuations, accompanied by spikes in price volatilty.

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]

Panel A presents daily coefficients surrounding the Terra-Luna crash. 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 became valueless. Our empirical analysis indicates that DeFi protocols with DON integration rebounded more quickly from this market downturn than those without DON integration.[13]

Panel B outlines the daily coefficients around the FTX Collapse event. On November 2, 2022, CoinDesk reported on a leaked document suggesting that Alameda Research, the hedge fund run by FTX founder Sam Bankman-Fried, held an unusually large number of FTT tokens, the native token on the FTX blockchain. Following this revelation, Binance declared its intention to sell its FTT tokens on November 6. This announcement precipitated a sharp decline in FTT's price and prompted a surge in withdrawal requests from FTX, reflecting traders' fear of another crypto company collapse. FTX, grappling with estimated withdrawal requests amounting to $6 billion over three days, faced a liquidity crunch. It signaled a shortfall of funds to meet the withdrawal demands and subsequently filed for bankruptcy on November 11. Our empirical findings suggest that DeFi

[13] 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.

protocols with DON integration demonstrated quicker market recovery than those without DON integration in the wake of the FTX collapse as well.

Taken together, our examination of these two pivotal events in the cryptocurrency landscape suggests that, in times of crisis, DeFi protocols with DON integration exhibit greater resilience than those without DON integration.

5 Conclusion

Oracles underpin the functioning of the DeFi ecosystem by allowing smart contracts and various protocols operating on decentralized blockchains to interact with off-chain environments, both real-world markets and other blockchains, through the reliable inward and outward transmission of information. DONs aim to preserve many of the benefits of decentralization while ensuring the reliability, accuracy, and timeliness of information provided to and from specific blockchains. Additionally, DON also enhances investor protection by preventing the execution of smart contract rules based on erroneous or manipulated data.

We document several benefits that accrue to DeFi protocols that adopt DON integration. These benefits come from positive effects on protocol liquidity, token allocation, user adoption, and on-chain activity. The 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. By enabling smart contract applications to gain access to off-native blockchain data systems, DON accelerates DeFi protocols' value creation by enhancing interoperability between ecosystems. Perhaps more importantly, integrated protocols are more resilient during times of crisis than non-integrated protocols.

However, our findings should be interpreted with caution for several reasons. First, the DeFi market is still young, and innovative protocols and services could disrupt the market in the future. Additionally, our results may be less compelling in the context of more mature and stable markets with alternative channels for communicating with conventional markets. Moreover, upcoming crypto regulation may reshape the DeFi landscape in ways that affect the magnitudes of the benefits of DON integration that we have documented. Finally, we focus our analysis on the largest DON administrators in the market. DONs themselves are evolving and could change in terms of form, functionality, and industrial organization. As the space of DON administrators expands, it will be interesting to study how interactions among administrators affect the market for DeFi protocols.

References

Adams, A., X. Wan, and N. Zinsmeister (2022). Uniswap v3 twap oracles in proof of stake. Working paper. Available at http://dx.doi.org/10.2139/ssrn.4384409.

Ali, A., Y. S, S. T, and T. R (2023). Decentralised escrow protocol that facilitates secure transactions between trustless parties. Available at http://dx.doi.org/10.2139/ssrn.4365306. In *Proceedings of the International Conference on Innovative Computing & Communication (ICICC) 2022*.

Amiram, D., B. N. Jørgensen, and D. Rabetti (2022). Coins for bombs: The predictability of on-chain transfers for terrorist attacks. *Journal of Accounting Research 60*(2), 427–466.

Amiram, D., E. Lyandres, and D. Rabetti (2021). Cooking the order books: Information manipulation and competition among crypto exchanges. Avaliable at http://dx.doi.org/10.2139/ssrn.3745617.

Bekaert, G., C. R. Harvey, A. Kiguel, and X. Wang (2016). Globalization and asset returns. *Annual Review of Financial Economics 8*, 221–88.

Bekaert, G., C. R. Harvey, and C. Lundblad (2005). Does financial liberalization spur growth? *Journal of Financial Economics 77*(1), 3–55.

Braun, A., N. Hä usle, and S. Karpischek (2022). Collusion-proof decentralized autonomous organizations. Working paper. Available at http://dx.doi.org/10.2139/ssrn.3760531.

Calvo, G., A. Izquierdo, and L. F. Mej'a (2004, June). On the empirics of sudden stops: The relevance of balance-sheet effects. In *Federal Reserve Bank of San Francisco Proceedings*.

Cavallo, E. A. (2007). Output volatility and openness to trade: A reassessment. RES Working Paper 4518, Inter-American Development Bank, Research Department.

Coeurdacier, N., H. Rey, and P. Winant (2020). Financial integration and growth in a risky world. *Journal of Monetary Economics 112*, 1–21.

Cong, L., C. R. Harvey, D. Rabetti, and Z.-Y. Wu (2022). An anatomy of crypto-enabled cybercrimes. Working paper. Available at http://dx.doi.org/10.2139/ssrn.4188661.

Cong, L., W. R. Landsman, E. L. Maydew, and D. Rabetti (2023). Tax-loss harvesting with cryptocurrencies. Forthcoming. Available at https://doi.org/10.1016/j.jacceco.2023.101607. *Journal of Accounting and Economics*.

Cong, L. W., K. Grauer, D. Rabetti, and H. Updegrave (2023). Blockchain forensics and crypto-related cybercrimes. Book chapters. Available at http://dx.doi.org/10.2139/ssrn.4358561.

Cong, L. W. and Z. He (2019). Blockchain disruption and smart contracts. *The Review of Financial Studies 32*(5), 1754–1797.

Cong, L. W., X. Li, K. Tang, and Y. Yang (2023). Crypto wash trading. Working paper. Avaliable at https://dx.doi.org/10.2139/ssrn.3530220.

Edwards, S. (2008). Financial openness, currency crises and output losses. In S. Edwards and M. G. P. Garcia (Eds.), *Financial markets volatility and performance in emerging markets*, National Bureau of Economic Research Conference Report. University of Chicago Press.

Foley, S., J. R. Karlsen, and T. J. Putnins (2019). Sex, drugs, and bitcoin: How much illegal activity is financed through cryptocurrencies? *The Review of Financial Studies 32*(5), 1798–1853.

Frankel, J. and E. A. Cavallo (2004). Does openness to trade make countries more vulnerable to sudden stops or less? Using gravity to establish causality. Avaliable at https://www.nber.org/papers/w10957. NBER Working Paper 10957, National Bureau of Economic Research.

Griffin, J. M. and A. Shams (2020). Is Bitcoin really un-tethered? *Journal of Finance 74*(4), 1913–1964.

Harvey, C., A. Ramachandran, and J. Santoro (2021). DeFi and the Future of Finance. Book. Publisher: Wiley. Available at: books.google.com.

Henry, P., B. (2007). Capital account liberalization: Theory, evidence, and speculation. *Journal of Economic Literature 45*(4), 887–935.

John, K., L. Kogan, and F. Saleh (2022). Smart contracts and decentralized finance. Working paper. Available at http://dx.doi.org/10.2139/ssrn.4222528.

Kose, A., E. Prasad, K. Rogoff, and S. Wei (2009). Financial globalization: A reappraisal. *IMF Economic Review 56*, 8–62.

Kose, A., E. Prasad, and A. Taylor (2011). Thresholds in the process of international financial integration. *Journal of International Money and Finance 30*(1), 147–179.

Kose, A., E. Prasad, and M. Terrones (2003). How does globalization affect the synchronization of business cycles? *American Economic Review 93*(2), 57–62.

Kose, A., E. Prasad, and M. Terrones (2009). Does openness to international financial flows raise productivity growth? *Journal of International Money and Finance 28*(4), 554–580.

Lyandres, E., B. Palazzo, and D. Rabetti (2022). Initial coin offering (ICO) success and post-ICO performance. *Management Science 68*(12), 8515–9218.

Michels, J. (2012). Do unverifiable disclosures matter? Evidence from peer-to-peer lending. *The Accounting Review 87*(4), 1385–1413.

Mik, E. (2023). *Smart Contracts and the 'Oracle Problem' in the Context of InsurTech*. Springer. Forthcoming.

Rabetti, D. (2023). Auditing decentralized finance (DeFi) protocols. Working paper. Available at https://ssrn.com/abstract=4458298.

Sokolov, K. (2021). Ransomware activity and blockchain congestion. *Journal of Financial Economics 141*(2), 771–782.

Uhlig, H. (2022). A luna-tic stablecoin crash. Becker Friedman Institute for Economics Working Paper. Available at http://dx.doi.org/10.2139/ssrn.4163038.

Figure 1. The market of oracles: This figure depicts the evolution of the market share in the oracle markets, where market share is calculated as the total value locked for integrated protocols. The Y-Axis captures the percentage portion of the market for Chainlink, Maker, WinLink, TWAP, Pyth, Band and Others.

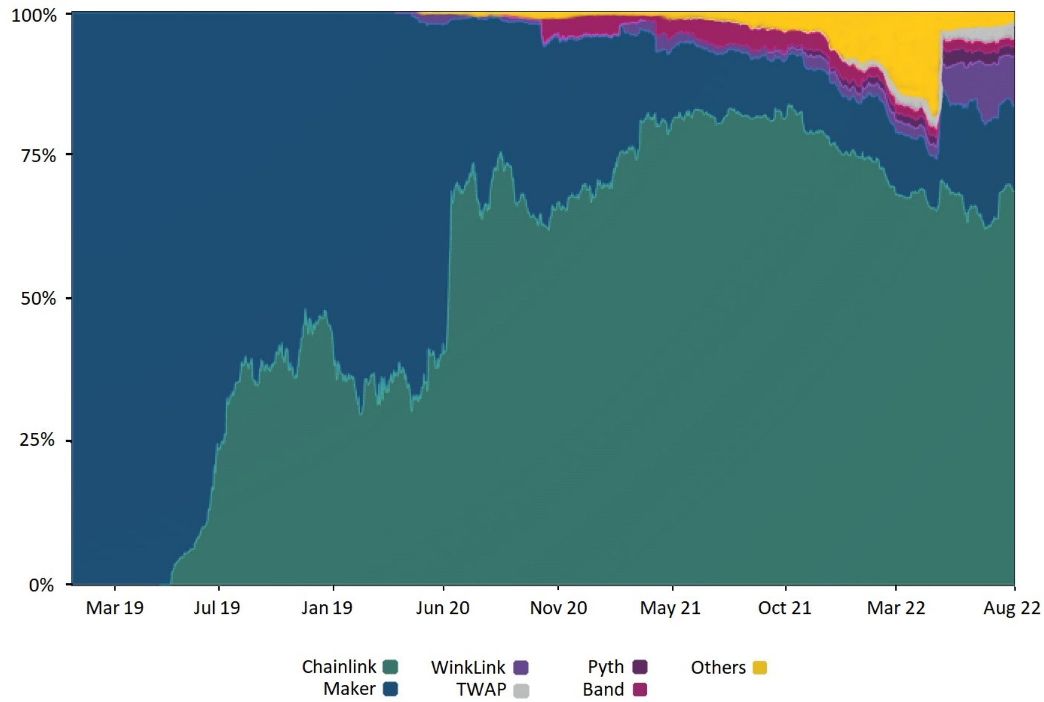

Figure 2. Decentralized oracle networks' evolution: This figure depicts the evolution of oracle networks deployed across blockchains and their respective total value locked. The X-Axis captures the days from the first deployed oracle. The Y-Axis captures the number of deployed oracles in the left-hand-side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

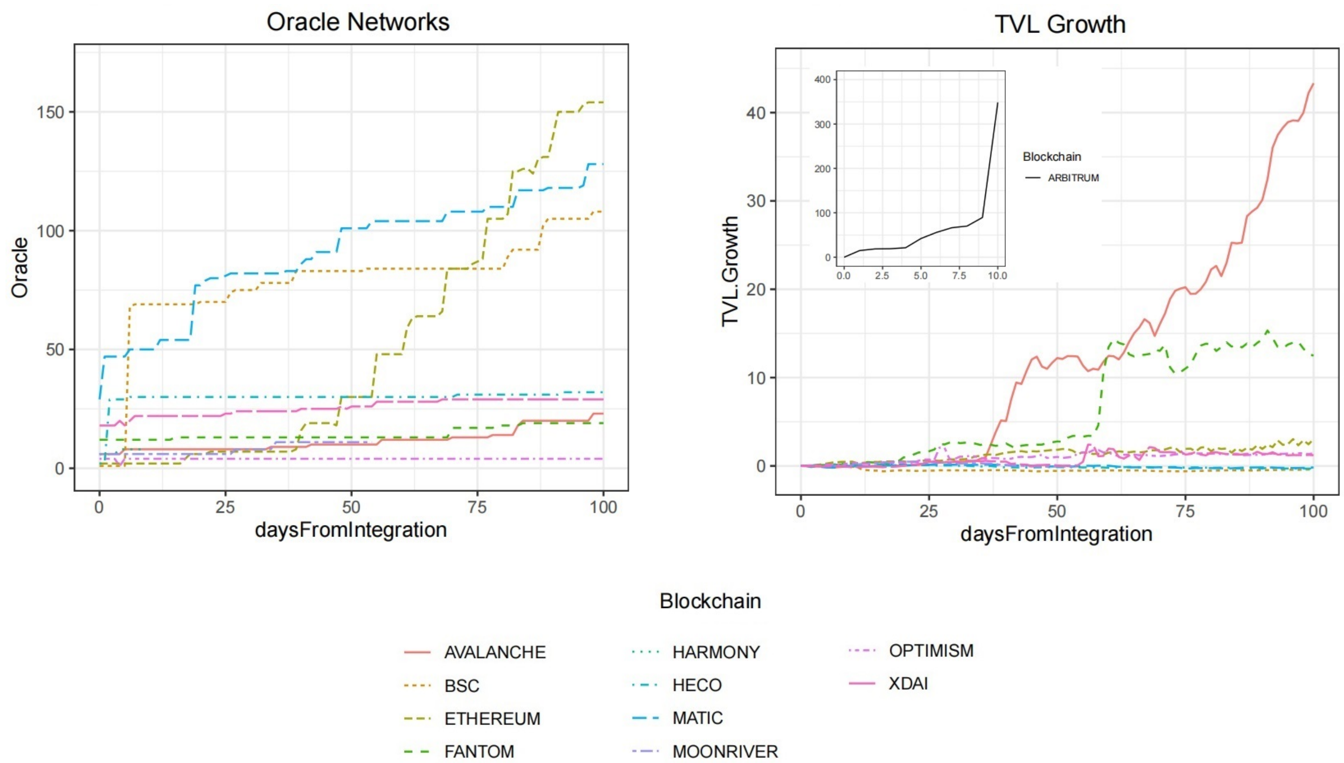

Figure 3. TVL correlations (Avalanche): This figure depicts Spearman correlations for total value locked among chains. The left-hand-side (right-hand-side) figure depicts correlations among chains before (after) Avalanche integration. Spearman correlations among chains are presented in the range −1 (dark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

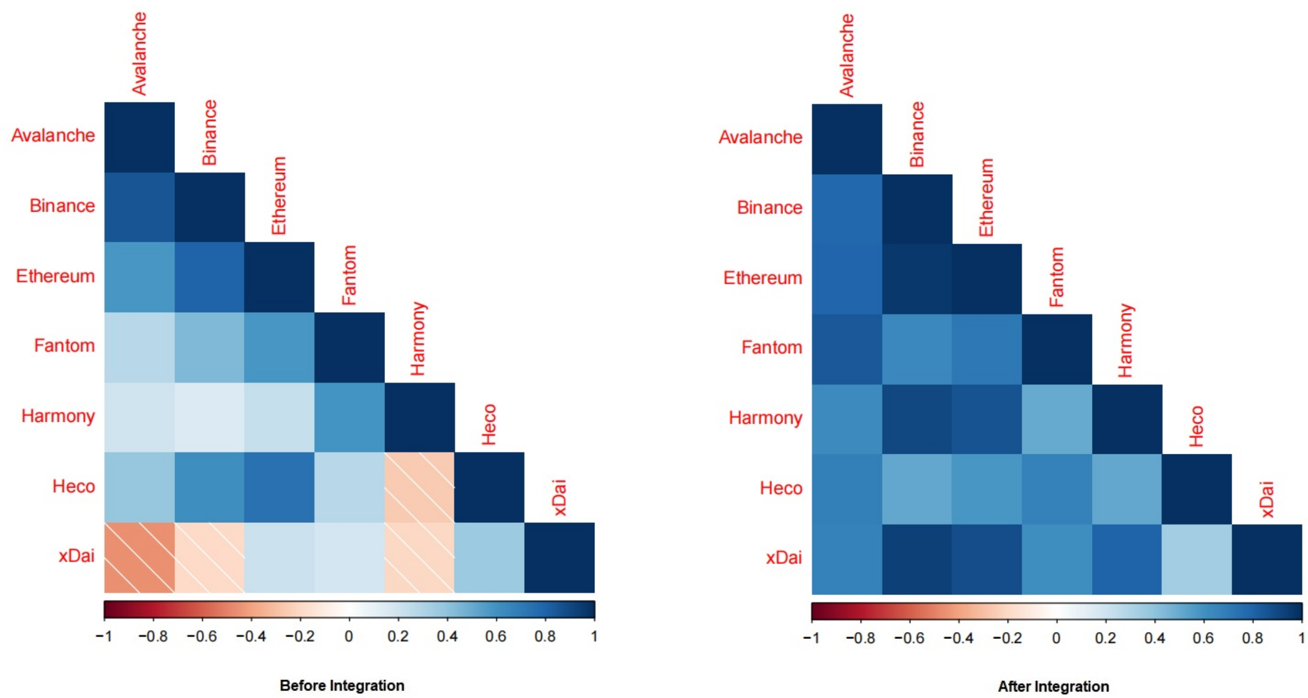

Figure 4. Resilience in Times of crisis: This figure depicts daily standardized market capitalization coefficients for DeFi protocols with DON integration (*Treat*, in orange) and without DON integration (*Control*, in light blue). Panel A depicts the daily coefficients around the Terra-Luna crash. Panel B depicts the daily coefficients 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.

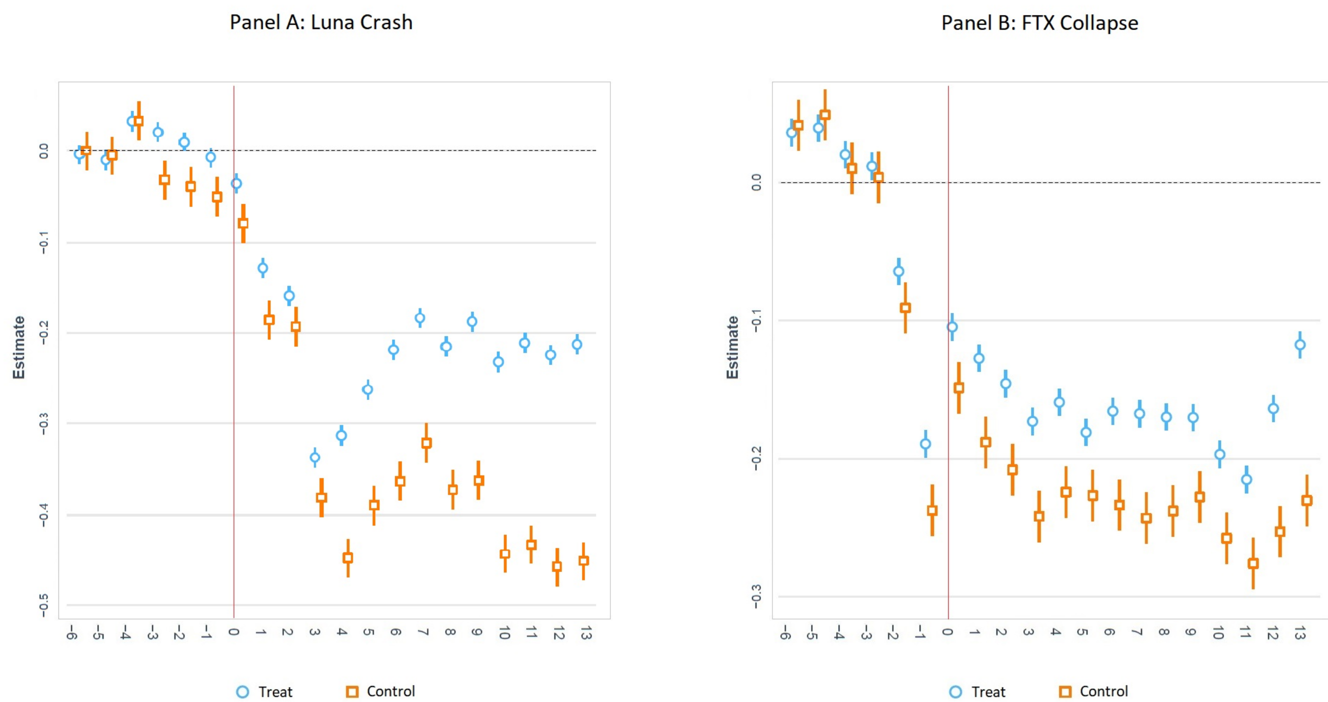

Table 1. The market of oracles: This table depicts the market share of oracles including the number of DeFi protocols and their total value locked (TVL) expressed in dollars.

Oracle	Protocols	Protocols (%)	TVL	TVL (%)
Chainlink	193	51.88%	$37.89b	68.79%
Maker	2	0.54%	$8.18b	14.85%
WINkLink	2	0.54%	$4.78b	8.68%
TWAP	51	13.71%	$1.44b	2.61%
Pyth	22	5.91%	$901.48m	1.64%
Band	19	5.11%	$731.5m	1.33%
DIA	17	4.57%	$318.55m	0.58%
Internal	22	5.91%	$169.48m	0.31%
Flux	4	1.08%	$157.3m	0.29%
UMA	6	1.61%	$118.67m	0.22%
Nest	4	1.08%	$114.02m	0.21%
NFTOracle	1	0.27%	$90.05m	0.16%
ReserveOracle	1	0.27%	$90.05m	0.16%
Coinmarketcap	1	0.27%	$39.65m	0.07%
Ubinetic	2	0.54%	$21.68m	0.04%
Switchboard	5	1.34%	$11.83m	0.02%
Coingecko	6	1.61%	$10.92m	0.02%
Harbinger	1	0.27%	$6.18m	0.01%
Witnet	3	0.81%	$2.8m	0.01%
Crypto.org API	1	0.27%	$1.89m	0.00%
Money On Chain	1	0.27%	$1.56m	0.00%
Umbrella Network	1	0.27%	$1.47m	0.00%
Oraclize.it	1	0.27%	$1.21m	0.00%
Delphioracle	1	0.27%	$1.21m	0.00%
LiquidApps	1	0.27%	$1.21m	0.00%
Bluzelle	1	0.27%	$1.16m	0.00%
Terrand	1	0.27%	$3.26k	0.00%
ExOracle	1	0.27%	$26.14	0.00%
Zapper.fi	1	0.27%	$0	0.00%
Total	372	100.00%	$55.08b	100.00%

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 billion of dollars. See Appendix A for the description of each industry.

Category	Protocols	TVL ($b)	Mcap ($b)	Chains	Audits	Users[live]	Transfers[live]
Algo-Stables	80	5.29	2.74	1.19	0.85	92.96	4,287.70
Bridge	21	24.46	11.63	6.43	1.29	89.78	1,808.33
CDP	35	16.46	2.33	1.57	1.56	72.31	718.44
Chain	9	10.19	8.85	1.00	0.89	260.83	1,687.00
Cross Chain	14	1.99	0.27	5.79	1.43	49.68	755.33
Derivatives	25	3.15	2.28	1.40	1.83	60.33	372.67
DEX	438	57.75	28.34	1.48	1.19	68.80	2,044.48
Farm	34	0.04	0.01	1.26	0.88	19.00	30.00
Gaming	17	0.02	2.93	1.53	0.94	128.42	2,298.67
Indexes	27	0.60	0.16	1.63	1.33	45.01	211.21
Insurance	19	1.20	0.66	1.47	1.56	69.00	281.75
Launchpad	21	0.05	0.42	1.19	1.20	95.83	402.71
Lending	143	44.88	6.83	1.69	1.61	72.74	831.42
Liquid Staking	26	19.11	2.09	1.46	1.23	24.80	115.33
NFT Lending	3	0.00	0.04	2.00	2.00	123.93	1,210.00
NFT Marketplace	7	0.04	0.37	1.57	0.57	158.05	35,730.00
Options	34	0.92	0.33	2.00	1.53	58.59	482.67
Oracle	3	0.00	0.18	1.33	1.33	52.33	125.00
Payments	8	0.84	1.13	2.00	1.25	49.00	179.00
Prediction Market	10	0.01	0.00	1.00	0.60	43.50	108.50
Privacy	7	0.58	0.23	1.29	1.43	21.00	53.00
Reserve Currency	116	0.96	0.65	1.08	0.25	134.67	1,125.89
Services	49	4.45	1.16	1.59	0.72	93.21	1,728.52
Staking	44	0.62	0.62	1.23	0.93	79.32	5,295.94
Synthetics	22	0.56	0.64	1.45	1.50	59.50	209.22
Yield	315	19.22	3.01	1.43	1.31	53.56	358.04
Yield Aggregator	48	4.28	1.00	2.44	1.31	78.35	1,172.67
Grand Total	1,575	217.67	78.91	1.58	1.17	73.54	1,614.36

Table 3. Distribution of DON integrated protocols: This table depicts the distribution of DON integrated DeFi protocols per category. See Appendix A for the description of each industry.

Category	Protocols	Integrated	Non-Integrated	Integrated (%)
DEX	438	34	404	7.76%
Yield	315	29	286	9.21%
Lending	143	77	66	53.85%
Reserve Currency	115	4	111	3.48%
Algo-Stables	80	18	62	22.50%
Services	49	4	45	8.16%
Yield Aggregator	48	13	35	27.08%
Staking	44	5	39	11.36%
CDP	35	15	20	42.86%
Farm	34	0	34	0.00%
Options	34	17	17	50.00%
Indexes	27	5	22	18.52%
Liquid Staking	26	3	23	11.54%
Derivatives	25	16	9	64.00%
Synthetics	22	9	13	40.91%
Bridge	21	1	20	4.76%
Launchpad	21	2	19	9.52%
Insurance	19	5	14	26.32%
Gaming	17	2	15	11.76%
Cross Chain	14	3	11	21.43%
Prediction Market	10	6	4	60.00%
Chain	9	0	9	0.00%
Payments	8	1	7	12.50%
NFT Marketplace	7	0	7	0.00%
Privacy	7	1	6	14.29%
Oracle	3	0	3	0.00%
NFT Lending	2	1	1	50.00%
Others	2	2	0	100.00%
Grand Total	1,575	273	1,302	17.33%

Table 4. Days to oracle integration: This table depicts the summary statistics for days to integration. The variable is calculated as the difference in days between the oracle integration date and DeFi protocol going-live (deploying the main smart-contract) date.

Integration	**Protocols**	**Min.**	**Median**	**Mean**	**Max.**	**Sd**
All	395	-899	-7	-35	776	233
Before Live	208	-899	-151	-195	-1	178
After Live	184	3	102	146	776	135

Table 5. Determinants of DON integration: This table depicts the determinants of DON integration including *FDV*, the fully diluted market capitalization value; *Staking*, the total value of staked coins; and indicators for DeFi protocol industries *Derivatives*, *Lending*, *Options*, *Reserve Currency*, and whether a protocol is listed in multiple chains (*Multi-Chain*). 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**
log(1 + FDV)	0.08 ***	0.07 ***	0.06 ***
	(0.01)	(0.01)	(0.01)
log(1 + Staking)	0.01	0.03 ***	0.03 ***
	(0.01)	(0.01)	(0.01)
Derivatives		1.09 **	0.94 *
		(0.53)	(0.55)
Lending		0.97 ***	0.84 **
		(0.36)	(0.37)
Options		1.42 ***	1.01 **
		(0.47)	(0.49)
Reserve Currency		-0.66	-0.76 *
		(0.42)	(0.44)
Multi-Chain			0.76 **
			(0.30)
Category	No	Yes	Yes
Blockchain	No	No	Yes
Obs.	1,575	1,575	1,575
Pseudo r^2	0.11	0.19	0.24

Table 6. Post-live performance responses to oracle adoption: This table reports the summary statistics for equation 2 in Panels A and C, and equation 3 in Panels B and D. Panels C and D report the results for matched samples according to Appendix B. Total value locked (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable in Panels A and C. Market capitalization (i.e., aggregate value in dollars of total tokens in circulation times their price) is the dependent variable in Panels B and D. 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; *Staking*, the total value of staked coins; and indicators for DeFi protocol industries *Derivatives*, *Lending*, *Options*, *Reserve Currency*, and whether a protocol is listed in multiple chains (*Multi-Chain*). 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: Total Value Locked				**Panel B: Market Capitalization**			
	Day	**Week**	**Month**	**Quarter**	**Day**	**Week**	**Month**	**Quarter**
DON	10.84	35.12 *	74.85 ***	92.21 **	2.65	25.50 *	42.63 **	75.57 ***
	(11.53)	(20.96)	(28.64)	(38.18)	(9.14)	(15.10)	(21.37)	(28.49)
CO	5.52	-16.84	-46.10	-40.51	-6.96	34.47	34.34	81.35 *
	(19.35)	(35.24)	(50.54)	(67.86)	(16.42)	(26.81)	(38.55)	(49.35)
log(1 + FDV)	1.43 ***	2.34 **	3.08 **	5.53 ***	0.34	-0.22	1.44	3.15 **
	(0.54)	(0.98)	(1.34)	(1.78)	(0.46)	(0.76)	(1.08)	(1.46)
log(1 + Staking)	0.67	1.09	3.63 **	5.89 **	0.83	-0.02	1.07	4.87 ***
	(0.73)	(1.32)	(1.83)	(2.47)	(0.57)	(0.93)	(1.34)	(1.83)
log(1 + # Chains)	-0.92	-26.77	-42.80	-56.74	-3.76	2.55	-13.84	23.47
	(17.40)	(31.44)	(43.37)	(55.54)	(14.78)	(24.13)	(34.25)	(42.50)
log(1 + # Oracles)	5.57	13.85	29.90	29.88	-11.43	-8.09	15.56	60.25
	(15.98)	(29.55)	(41.31)	(57.09)	(13.55)	(22.61)	(32.66)	(45.31)
Category	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	1,373	1,349	1,273	1,047	745	739	710	579
Adj.r^2	0.08	0.08	0.12	0.16	0.18	0.19	0.19	0.27

	Panel C: Total Value Locked (PSM)				**Panel D: Market Capitalization (PSM)**			
	Day	**Week**	**Month**	**Quarter**	**Day**	**Week**	**Month**	**Quarter**
DON	18.40	38.41	76.90 **	93.05 **	6.83	15.74	28.61	72.71 **
	(14.53)	(27.16)	(34.37)	(37.56)	(10.49)	(16.32)	(20.99)	(29.10)
Matched	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	482	482	482	482	346	346	346	346
Adj.r^2	0.07	0.08	0.10	0.11	0.07	0.07	0.11	0.19

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

Before / After	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 total value locked 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 integrate. *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

Table 9. Post-live network responses to oracle integration: This table reports the summary statistics for equation 4 in Panels A and C, and equation 5 in Panels B and D. Panels C and D report the results for matched samples according to Appendix B. The number of on-chain unique users (i.e., unique wallets with at least one token) is the dependent variable in Panels A and C. The number of on-chain transfers (i.e., number of on-chain transactions) is the dependent variable in Panels B and D. 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; *Staking*, the total value of staked coins; and indicators for DeFi protocol industries *Derivatives*, *Lending*, *Options*, *Reserve Currency*, and whether a protocol is listed in multiple chains (*Multi-Chain*). 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: On-Chain Unique Users				**Panel B: On-chain Transfers**			
	Day	**Week**	**Month**	**Quarter**	**Day**	**Week**	**Month**	**Quarter**
DON	36.40 *	50.83 **	55.71 ***	67.97 ***	43.41	69.20 **	76.14 ***	82.22 ***
	(22.00)	(21.22)	(19.96)	(20.70)	(31.70)	(29.02)	(28.30)	(29.35)
CO	57.11	49.97	52.11	60.68 *	44.44	57.24	49.25	72.95
	(35.61)	(32.32)	(33.50)	(33.58)	(51.32)	(45.81)	(47.51)	(45.93)
log(1 + FDV)	4.98 ***	5.11 ***	5.57 ***	5.05 ***	7.96 ***	6.36 ***	7.68 ***	6.49 ***
	(1.16)	(1.05)	(1.09)	(1.14)	(1.67)	(1.49)	(1.54)	(1.57)
log(1 + Staking)	0.71	0.61	-0.01	0.07	1.02	-0.06	-0.32	0.79
	(1.30)	(1.18)	(1.23)	(1.29)	(1.88)	(1.67)	(1.75)	(1.76)
log(1 + # Chains)	6.22	2.82	-10.92	14.54	21.40	28.90	-4.28	29.07
	(28.84)	(26.17)	(27.13)	(27.68)	(41.56)	(37.10)	(38.48)	(37.86)
log(1 + # Oracles)	0.51	-11.94	-35.08	9.48	-8.13	9.97	-45.15	-4.96
	(30.46)	(27.64)	(28.66)	(30.45)	(43.89)	(39.18)	(40.64)	(41.65)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	312	312	312	312	312	312	312	312
Adj.r^2	0.21	0.23	0.23	0.24	0.22	0.22	0.24	0.24

	Panel C: On-Chain Unique Users (PSM)				**Panel D: On-Chain Transfers (PSM)**			
	Day	**Week**	**Month**	**Quarter**	**Day**	**Week**	**Month**	**Quarter**
DON	0.29	0.41 **	0.47 **	0.46 **	0.33	0.61 **	0.57 **	0.59 **
	(0.21)	(0.19)	(0.20)	(0.20)	(0.31)	(0.26)	(0.28)	(0.27)
Matched	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	208	208	208	208	208	208	208	208
Adj.r^2	0.12	0.13	0.15	0.16	0.12	0.12	0.18	0.18

Appendix A: DeFi Industries

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

Category	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 by utilizing algorithms and smart contract protocols. Unlike traditional fiat-backed stablecoins that rely on centralized reserves, DeFi Algo Stables aim 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 act as bridges, connecting separate blockchain ecosystems and allowing 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, also known as Collateralized Debt Position protocols, are an integral part of the DeFi ecosystem. These protocols enable users to create and manage CDPs, which are 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, which provides security and mitigates 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 facilitate 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 creation of derivative products using blockchain technology. These protocols allow users to gain exposure to various financial instruments, such as futures, options, swaps, and synthetic assets, without the need for intermediaries or centralized exchanges. With DeFi Derivatives protocols, users can engage in decentralized derivatives trading, hedging strategies, and speculative investments. These platforms typically utilize smart contracts to create and settle derivative contracts, ensuring transparency, security, and automation of the trading process.
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 the need for intermediaries like traditional centralized exchanges. DEX protocols operate through smart contracts deployed on blockchain networks, which facilitate the matching and execution of trades in a transparent and decentralized manner. Many DEX protocols employ automated market-making algorithms and liquidity pools to ensure continuous liquidity and efficient trading.
Farm	Farm protocols are a type of 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 are utilized by decentralized exchanges or lending platforms to facilitate trading and lending activities. By providing liquidity to these pools, users can earn rewards in the form of 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.

Category	Description
Indexes	Indexes protocols are DeFi platforms that offer curated and diversified indexes of tokens within the DeFi ecosystem. These protocols enable users to gain exposure to a basket of DeFi assets and track the overall performance of the sector. 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 provide users with a diversified investment option that represents the broader DeFi market rather than investing in individual assets.
Insurance	Insurance protocols are a crucial component 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 features such as token vesting schedules, governance rights, or tiered investment structures.
Lending	Lending protocols enable users to lend and borrow digital assets in a peer-to-peer manner 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 the need for credit checks or cumbersome loan approval processes. In case of 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 utilization rate of the lending pool, or the creditworthiness of borrowers.
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 staking contract for a specific period, which restricts their liquidity and utility during that time. 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 in the form of additional staked tokens or other assets, which can be claimed periodically based on the staking protocol's parameters.
NFT Lending	NFT Lending are protocols that focus 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.

Category	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 showcase and trade their unique digital assets, such as artwork, collectibles, virtual real estate, or in-game items, directly 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 segment within DeFi that focus on options trading. These protocols enable users to trade options contracts in a decentralized and transparent manner, without the need for 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, as well as 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 provide external data to blockchain-based applications and smart contracts. These protocols act as bridges, facilitating the connection 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 focus on facilitating seamless and secure peer-to-peer transactions using cryptocurrencies or digital assets. These protocols offer features such as wallet integration, address management, and transaction tracking, allowing users to manage their digital assets and initiate payments directly from their wallets. They often support multiple cryptocurrencies, providing users with flexibility and choice in their payment options. Furthermore, Payments 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 engage in forecasting 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 provide users with increased 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 that are 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 supply of the stablecoin 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.

Category	Description
Services	Service protocols are DeFi platforms that offer a range of services and functionalities to users 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 provide a way for 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, typically in the form of cryptocurrencies, in a staking contract. 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 can vary depending on the specific staking protocol and the network being staked. Some protocols also offer additional features such as delegation, where users can delegate their stake to a trusted validator to earn rewards without the need for running their own infrastructure.
Synthetics	Synthetics allow users to replicate the value and performance of real-world assets, such as stocks, commodities, or fiat currencies, using blockchain-based tokens. 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 ratio determined by the protocol. The collateral acts as a guarantee to maintain 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 collateral for loans or participation in yield farming.
Uncollateralized Lending	Uncollateralized Lending protocols are a specialized subset within the DeFi ecosystem that allow users to borrow funds without the need for providing 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 features such as 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 activities such as 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 are platforms that aim to optimize and maximize yield generation for users 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. The Yield Aggregator protocol then allocates these assets across different strategies, such as liquidity provision, yield farming, lending, or staking, to maximize returns.

Appendix B: Matching

Matching: This table reports the summary statistics of the matching procedure. We employ propensity matching scores (PSM) based on the nearest neighborhood. 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 total value locked (TVL), market capitalization (MCap), number of unique users, and on-chain transfers.

Panel A: Matching Procedure

	DON	Others	Mean Diff	Perc. Improv.
Staking (Million)	14.67	13.03	1.64	60.28%
FDV (Million)	219.88	195.74	24.14	99.89%
# Chains	2.27	2.03	0.24	69.87%
# Oracles	0.57	0.51	0.06	40.27%
Overall Distance	0.43	0.39	0.04	70.47%

Panel B: Observations per Cluster

	TVL	MCap	Users	Transfers
Matched	241.00	173.00	104.00	104.00

Appendix C: Synthetic Control

Synthetic control: This figure depicts the mean average evolution of total value locked growth for integrated protocols (blue line) and a synthetic control group (red line). The synthetic control group post-live total value locked is estimated based on the balanced sample in Appendix B and matched in outcomes. The X-Axis depicts the days to integration. The Y-Axis depicts the cumulative TVL Growth (measured in percentage).