Financial and Informational Integration Through Oracle Networks*

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First draft: August 2022. **This draft:** December 2023.

Abstract

Oracles are software components that enable data exchange between siloed blockchains and external environments, enhancing smart contract capabilities and platform interoperability. Using both hand-collected data from hundreds of DeFi protocols and market data for oracle networks, we find that oracle integration is positively associated with total value locked and platform/protocol valuation, triggered by positive network effects in adoption and usage. Our study reveals symbiotic gains from enhanced interoperability across protocols on a given chain and, depending on the mass of integrated protocols, among integrated chains. We also show that oracle integration improves risk-sharing and mitigates contagion; integrated protocols are more resilient than nonintegrated protocols during turbulent periods in crypto markets. We draw parallels between oracle integration and international economics, offering initial insights for regulators, entrepreneurs, and practitioners in the emerging space of decentralized finance.

JEL Classification: G15, G18, G29, K13, K24, K42, O16

Keywords: DeFi, blockchain, smart contracts, international economics, interoperability, risk-sharing

*We are grateful to members of Chainlink Labs for insightful discussions and feedback. We also thank Hami Amiraslani, Daniel Bens, Sean Foley (discussant), Niklas Haeusle, Cam Harvey, Peter Joos, Elsa Juliani, Charlie Kahn, Jongsub Lee (discussant), Gregor Matvos, Les Oxley (discussant), Shiwon Song, Lauren Sutioso, Baozhong Yang, Yilan Zheng, and seminar and conference participants at the 2023 New Zealand Finance Meeting, 6th Sydney Market Microstructure and Digital Finance Meeting, INSEAD School of Business, GSU-RFS Fintech Conference, Bank of Italy-P2P Financial Systems Conference, Bank of Canada Conference on "Networks in Modern Financial and Payment Systems," the 3rd Crypto and Blockchain Economics Research (CBER) Annual Conference, SCU Crypto Conference, 1st Virtual Symposium on Web3 Financing and Inclusivity, and the inaugural Wolfram ChainScience Conference (Boston) for extended discussions and helpful comments. The authors acknowledge generous support from the FinTech at Cornell Initiative and Ripple's University Blockchain Research Initiative (UBRI). The study was initiated in Cong's parallel capacity as the Senior Economic Advisor/Senior Economist and in Rabetti's role as an Economic Advisor at Chainlink Labs.

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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. This 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. Oracles are essential for triggering executions based on off-chain or cross-chain events, such as changes in market prices or weather conditions that are relevant to the terms and conditions specified in a contract.[2] Reliable oracles are deemed integral for expanding the types of digital agreements blockchains support by offering a universal gateway to off-chain sources of information and synchronizing multiple distributed ledgers to facilitate financial activities while maintaining privacy, autonomy, and security in the networks and the broader ecosystem.

We conduct the first comprehensive empirical analysis of how informational and financial integration through oracle networks affects the blockchain and DeFi ecosystems. In addition, we make a novel connection between studies on distributed networks and FinTech platforms with the international economics literature. Just as international integration involves exchanging capital, goods, information, assets, and services among different countries, oracle integration for blockchain and DeFi networks aims to provide seamless information flows for smart contracting, crypto assets,

[1] Web3, a.k.a. Web 3.0 or decentralized web, refers to the next generation of the 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.

and Web3 services across various digital ecosystems. As such, the implications of oracle integration for system outcomes, such as total value locked (TVL), token market capitalization, and user base 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, studies on blockchains and oracle integration may add insights and understanding to the extant literature in international economics and finance.

Instead of unitary centralized oracles (COs), which have a number of vulnerabilities, 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.[3] Our goal is to understand the oracle market and investigate the impact of oracle integration on the focal digital network and its interactions with other ecosystems, blockchain-based or off-chain. To this end, we collect data on hundreds of DeFi protocols and data on both COs and DONs, and document initial evidence that oracle integration has positive effects on adoption, usage, market valuation of tokens, and TVL. TVL, the total value of digital assets that are locked or staked in a particular decentralized finance (DeFi) platform or decentralized application (dApp), is arguably the most popular metric in the industry to gauge project success. Integrated networks also become more correlated with one another in terms of these measures and risk-sharing benefits appear to outweigh potential contagion effects or concerns about systemic risks in our sample.

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 the end of 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 TVL. Decentralized exchange, decentralized lending,

[3]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, suppose the centralized oracle on which a smart contract relies goes offline. In that case, the 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 financial losses to users and network instability given how blockchain transactions and smart contracts are automated, immutable, and irreversible.

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 do not 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. The determinants of DON integration we document provide stylized empirical facts for future studies on the heterogeneity in oracle network adoption.

We examine two key economic outcomes of DeFi protocols—TVL and market capitalization of tokens—to assess the effects of oracle integration. Assets whose dollar value counts towards TVL include cryptocurrencies such as Ether, Bitcoin, and various altcoins, which 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 US dollars of total tokens in circulation times their price. It serves as a proxy for the market valuation of DeFi protocols. 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 increase of 75%) and market capitalization (average increase of 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. We address endogeneity concerns using matched samples and synthetic control methods.

The potential impact of DON integration is not limited to these financial 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 this chain'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 by 36.21% after integration. We also examine symbiotic

[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, and they generate financial returns in the form of interest, staking rewards, or governance tokens, depending on the specific platform or program (e.g., Cong, He, and Tang, 2021; Augustin, Chen-Zhang, and Shin, 2022).

gains among integrated protocols to mitigate selection effects that could drive the observed correlations. 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 of Ethereum, the largest smart contracting platform and a blockchain with the largest number of integrated protocols, supports this conjecture. TVL correlations among DeFi protocols on the Ethereum blockchain are shown to be increasing in the mass of integrated protocols.

On the one hand, the increased correlation across blockchain networks may lead to systematic risk. On the other hand, as we know from the international economics literature, the connections allow risk-sharing. We therefore investigate whether DON integration and interoperability improve ecosystem resilience during crises. Specifically, we investigate whether two recent events that triggered meltdowns in crypto markets—the Terra-Luna crash and the collapse of the cryptocurrency exchange FTX—differentially affected market capitalization (and its subsequent rebound) for integrated versus non-integrated protocols. Although the entire DeFi market crashed during these two events — exhibiting a high level of contagion across the ecosystem — integrated DeFi protocols experienced faster recovery in their market capitalization compared to non-integrated protocols, suggesting that DON integration fosters market resilience among integrated protocols.

Next, we examine whether oracle integration and interoperability gains translate to network effects. Using on-chain variables to test user base and on-chain activity growth, such as the number of unique wallets and on-chain transfers within specific DeFi protocol industries and blockchain ecosystems, we find substantial network effects/economies 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 the DON launch is 56% and 76% higher, respectively, for integrated protocols than for non-integrated protocols. We conclude that DON integration fosters more rapid development of integrated protocols' on-chain activities and user adoption. Their strong network effects likely explain the aforementioned financial effects of DON integration.

These findings collectively suggest that integrating oracle networks benefits DeFi protocols through enhanced adoption and interoperability. These effects then translate into user base 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. Although causality is not our focus, we verify that the results also hold in a sample excluding DeFi protocols with post-live integration and in analyses with matched samples and synthetic controls.

Our study mainly contributes to two areas of research. First, the study advances the emerging literature on blockchain economics and DeFi. Harvey, Ramachandran, and Santoro (2021), John, Kogan, and Saleh (2022), Mik (2023), and Harvey and Rabetti (2023) offer general introductions to the topic. An emerging literature in computer science focuses on the technical aspects of oracle networks (e.g., Breidenbach, Cachin, Coventry, Juels, and Miller, 2021; Zhang, Maram, Malvai, Goldfeder, and Juels, 2020). Regarding the economics of oracle networks, Adams, Wan, and Zinsmeister (2022) study the difficulty, potential cost, and likelihood of oracle manipulations on Uniswap v3 under Ethereum PoS while Braun, Haeusle, and Karpischek (2022) uncover severe collusion vulnerabilities in decentralized autonomous organizations in general. Complementing these conceptual or theoretical discourses, we join Cong, Hui, Tucker, and Zhou (2023) (which discusses layer-2-based scaling using data from Chainlink) as the earliest empirical studies on oracle networks.

Our study also informs the current debate over crypto regulation (e.g. Cong, Li, Tang, and Yang, 2023; Amiram, Jørgensen, and Rabetti, 2022; Cong, Landsman, Maydew, and Rabetti, 2023; Rabetti, 2023; Cong, Grauer, Rabetti, and Updegrave, 2023), by highlighting that decentralized solutions can potentially replace certain aspects of regulatory oversight in DeFi markets, especially for ensuring reliability and verifiability of financial information. Our paper complements the work of Amiram, Lyandres, and Rabetti (2021), who argue that self-regulation and industry initiatives are potentially more effective than government regulation, helping to identify a constructive approach toward a regulatory framework for DeFi.

Second, our study is the first to relate digital networks to the literature on international economics and financial integration, effectively introducing the "international economics of digital economies." The literature on how international integration affects economic outcomes such as productivity, growth, and asset returns at the country level typically documents effects that are 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).[5] We treat digital platforms as cyber-countries and oracle integration bridging ecosystems as the equivalent of international financial integration (through, e.g., cross-border capital flows), to expand our understanding of the impacts of financial and informational integration into the digital domain.

In addition, there is evidence of threshold effects leading to nonlinearities in the relationships between these variables (Kose, Prasad, and Taylor, 2011). Financial integration influences 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 enhanced adoption and 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.

Finally, our study yields relevant insights for practitioners. In addition to serving as the breeding ground for prominent FinTech start-ups, the DeFi market has also become the largest alternative financing market worldwide, amassing several billions of dollars in funds raised, investments, and transaction volume. Blockchain-based Web3 infrastructures are also being introduced to supply chains, sustainability, and differential privacy. Just as the study of "tokenomics" has emerged as the backbone for the successful valuation of effective token system designs for blockchain-based ventures, our study informs entrepreneurs, investors, DeFi communities, and regulators regarding decisions related to platform interoperability, information aggregation, and smart contracting in this vibrant emerging space.[6]

The remainder of the paper 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

[5]For instance, foreign direct investment and portfolio equity flows are positively associated with higher output and productivity growth in recipient economies and better risk-sharing outcomes. Debt inflows (including bank loans and sovereign debt financed by foreign investors) yield few growth or risk-sharing benefits. The former flows also better convey the indirect benefits of financial globalization, such as technology transfers.

[6]Tokenomics, the economics of token valuation and system design, is introduced and developed in a series of articles (e.g. Cong, Li, and Wang, 2021; Li and Mann, 2021; Cong, Li, and Wang, 2022; Malinova and Park, 2018). It encompasses the monetary policy of token supply, incentives for network development and decentralized contribution, dynamic token valuation, governance and voting, etc.

DONs leads to market integration, with implications for adoption, usage, risks, and correlation in economic outcomes. Section 5 concludes and offers caveats for interpreting our findings.

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 purports to offer greater access, transparency, and user ownership through decentralized and trust-minimized public blockchains. The aim is to give users more control over their data and enable their participation in decentralized applications and peer-to-peer interactions without having to rely on conventional centralized platforms or intermediaries that may possess concentrated market power.

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

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

The data manipulation problem can be 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 validate real-world data accurately. Centralized or insecure blockchain oracles undermine the trust minimization property of blockchains, as they allow individual participants or institutions to control the data inputs fed into the blockchain, exposing the system to manipulations.

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 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 copies another or if they both use the same data provider, they behave like a CO. Many studies (e.g., Cong and He, 2019; Braun et al., 2022) discuss various collusion problems. Moreover, leading DON services such as Chainlink currently use a centralized DON administrator 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 currently involves deploying a network of oracle nodes on the blockchain that the focal DeFi resides, and setting up the protocols for the oracle network to get compensated for the services they provide. The integration potentially helps the DeFi to thrive by providing the architecture needed for efficient execution of the DeFi services while supporting a growing user base. Some of the main DON functions include data feeds, verifiable random number (VRF) generators, APIs to external data sources, and smart contract automation (e.g., keepers).

Smart contracts frequently 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.[7] In addition, DON enables smart contracts to access an external data source in a decentralized manner. Whether the contract requires sports results, the latest weather, or publicly available data, the DON contract library provides crucial tools for DeFi contracts.

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

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

2.2 Data Collection

We gathered data for the period encompassing early 2021 to August 2022 on a number of key variables, including TVL, market capitalization, staking activity, and fully diluted market capitalization. Information concerning DeFi protocols mainly comes from DefiLlama, which we complement with time series data on price and market capitalization from a combination of coingecko.com and coinmarketcap.com, code production (e.g., commits) from github.com, social media interactions from twitter.com, and on-chain (e.g., transactions and ownership) data from ETHplorer.com, EtherScan.com, and chains nodes such as Avalanche, Binance, Arbitrum, and others. This extensive dataset covers 1,575 DeFi protocols spanning across more than 25 distinct DeFi industries.

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

Finally, we acquired information on hundreds of oracle integrations from publicly available information on the Chainlink network, data aggregators such as Defillama, and DeFi protocol disclosures on various social media platforms.

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. Some oracles, such as CoinGecko price feeds, are centralized and provide specific services. Others, such as Chainlink, are administrators that manage the operation of third-party oracle networks.

[Figure 1 about here]

The DON market currently secures over $50 billion in TVL. 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 featuring 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 TVL ($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 or voting rights), such as *Bridge*, *Lending*, *Services*, and *Yield*. Together with *DEX*, these industries constitute the core of DeFi market functioning.[8]

[Table 2 about here]

DeFi protocols are often multichain, as indicated by the chains-per-protocol average being greater 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 average daily transactions of 35,730, 5,296, and 4,288, respectively. Clearly, the DeFi marketplace has now become diversified beyond its initial function of lending applications.

[Table 3 about here]

Table 3 reports the distribution of DeFi protocols grouped by industry.[9] 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*, feature much higher levels of integration, with more than half of such protocols being DON-integrated. On average, across 1,575 DeFi protocols in our database, only 17.33% utilize decentralized oracles.

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

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

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 DON integration.

3 Determinants and Effects of DON Integration

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

3.1 Days to Integration

DeFi protocols often adopt DON before their operations go live. (Table 4 shows that 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.

[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 follow with 11.45%, 6.07% and 0.62%, respectively, of the integration.

3.2 Determinants 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 are also significant 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. Lastly, 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 the ability of DON to provide 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, thereby 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 following integration. The panel on the right illustrates gains in TVL at the chain level economy after integration. Using TVL scaled by a chain's TVL at its integration date as a measure of these gains, we document rapid growth for 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 the demand for data from smart contract developers and for 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 weaknesses of such oracles discussed earlier. FDV and

Staking have positive effects on TVL at integration. However, 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.

3.4 Endogeneity Concerns

A potential concern in interpreting our results is that of endogenous selection—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 of the protocols in our sample to pin down the effects of DON integration by comparing outcomes for pairs of integrated and non-integrated protocols matched on other characteristics.

Specifically, we use Nearest Neighbour (NN) propensity score matching (PSM), a common method for estimating treatment responses from observational data. We use multivariate weighted k-nearest neighbours-based control group selection within industries and chains for clustering, pairing the elements of the treatment (i.e., protocols with DON integration) and control groups in the original vector space of the covariates (protocol characteristics, including staking, fully diluted market capitalization value, the number of listed blockchains, and the number of integrated oracles and within industries and blockchains). The dissimilarities of the protocols are calculated as the weighted distances of the subjects. The weights are calculated from a logistic regression model fitted on the status of treatment assignment.

[Table 7 about here]

Table 7 reports summary statistics for the matching exercise. Panel A displays the mean values for the characteristics of DeFi protocols with DON integration, others (including CO integration), and their mean differences. The last column, which reports the percentage improvement of the matching procedure, indicates that the propensity matching score successfully improved the distance between the two groups' characteristics by an overall 70.4%. Panel B reports the number of matched observations within analysis clusters for TVL, market capitalization (MCap), number of unique users, and on-chain transfers. As expected, matched control protocols decrease when conditioning to data availability on pricing and on-chain activities.

Panels C and D of Table 6 show that DON integration positively affects both TVL and market capitalization relative to peer protocols that lack DON integration (including CO-integrated protocols) using the propensity matching score procedure described above. These results further validate our previous assessment that DON integration significantly impacts TVL and market capitalization of DeFi protocols, particularly over longer time horizons.

For robustness, we also conduct a synthetic control analysis. For this exercise, we use the matched samples constructed based on the propensity matching score described earlier to mitigate concerns about imbalances in the panel data. The procedure allows both the treatment and control groups to be balanced pre-treatment and ensures that control units are not exposed to the treatment effects (e.g., Abadie and Gardeazabal, 2003; Campos, Coricelli, and Moretti, 2019; Ben-Michael, Feller, and Rothstein, 2021). Note that the exclusion criterion is likely achieved as we show in Table 6 that the gap in TVL between groups post-event (i.e., DON integration) is significant within matched samples. Therefore, we use the matched treated (DeFi protocols with DON integration) and control (DeFI protocols with CO integration or without third-party oracles) groups to estimate the TVL growth path for integrated protocols as if they did not adopt DON protocol (a synthetic control). The counterfactual outcome of the treatment group is, therefore, imputed in a linear combination of control protocols on the outcome variable (i.e., TVL).

[Figure 3 about here]

Figure 3 displays the empirical results, revealing a significant gap in TVL growth between integrated protocols and the synthetically matched control group (about 30% differential in TVL growth for a window beyond 60 days). This additional robustness test further mitigates concerns that our results on TVL growth post DON integration might reflect endogeneity related to protocol characteristics rather than the effects of integration.

3.5 Robustness Checks and Additional Tests

Appendix B provides several robustness checks and additional tests regarding the economic impact of DON integration at the DeFi protocol level. Although we use industry and blockchain fixed effects and control for the protocol's fully diluted valuation and the total value of staked assets at the time of launch, there may still be a concern with unobserved protocol characteristics or market conditions at the time of smart contract launch that may affect the probability of given protocol to integrate oracle networks. Therefore, we re-run all our specifications in Table 6, with time-fixed effects in Table B1. Time-fixed effects partially absorb the more immediate impact of DON integration in the early windows (day and week). However, the long-term effects (month and quarter) remain significantly positive, mitigating our concerns that unobserved characteristics and market conditions at launch drive our results.

DeFi protocols whose DON integration occurs exclusively before the protocol smart-contract launch, without post-launch oracle integrations, may have more accentuated economic effects. The reason is that this protocol's decision to integrate DON before launch likely incorporates the DeFi team's decision to provide an extensive array of services that are more reliable, accurate, and likely manipulation-free due to the incorporation of a third party (DON) as the data provider for hybrid smart contracts already at launch. It also suggests that the DeFi protocol has been launched completely bug-free and with full capabilities, potentially signaling high quality to markets and attracting a large demand. Table B2 empirical results on DeFi protocols without post-launch integration supports this assumption. The coefficients in this specification are more significant and almost twice as large as those reported in our main specification, suggesting that DON integration impact is more accentuated for completely finished protocols. In contrast, DeFi protocols with several Oracle integrations in the post-live phase suggest these protocols were launched in an incomplete form. That is, without exploring its full capabilities and with potential bugs or limitations. Table B3 collaborates with this intuition as DON integration has either no significant impact or a negative impact on the total value locked of this subset of DeFI protocols.

Another important aspect relates to the heterogeneity of DON services. As discussed in our earlier sections, DON integration also includes other services beyond access to external data in the form of price feeds. These services are Keepers, external entities (usually a data provider) that perform various tasks, such as data validation, submitting updates, triggering specific actions based on predefined conditions, and maintaining the integrity of the oracle network; VRF (Verifiable Random Function), a cryptographic method used to generate random numbers in a verifiable manner within a blockchain or decentralized network often used for gaming and NFT applications; and

Proof-of-reserve, a mechanism used to validate and provide evidence that a service or platform holds the assets it claims to have in reserve. Although these services are relevant to the well-functioning and credibility of DeFi protocols, they are deemed second-order to our purposes because price feeds provide access to external data and promote a new array of decentralized finance services in which some protocols would not even exist without such capabilities. For instance, DeFi protocols providing weather insurance cannot operate without DON integration. Therefore, we expect to have more accentuated effects of DON integration for protocols using price feeds service than other services. The results in Table B4 support this assumption.

Finally, besides the direct impacts on the integrating protocol, DON integration may have spillover effects on other protocols with highly interlinked financial ties. Consider the case of DeFi lending and decentralized exchanges (DEXs) protocols. On the one hand, Lending protocols are highly dependent on DON to access price feeds to keep track of the current value of collateralized assets. On the other hand, DEXs are not oracle-dependent as their prices derive directly from supply-demand interactions at the protocol's platform. Still, the latter likely benefits tremendously from lending protocols integrating DON as it attracts DeFi lending protocol's arbitrageurs—those that can liquidate undercollaterized positions in the lending markets and sell the collateralized assets at a premium in a DEX in the same blockchain environment. Therefore, we expect that DeFi integration at lending protocols will have spillover effects on DEX's economic activities. Table B5 examines this conjecture. The results support spillover effects from DeFi lending DON integration on local—in the same blockchain—decentralized exchanges. Moreover, indirect effects on longer windows are about three times larger than the direct effects documented in our main specification. This suggests that DON integration emerges as a vital piece to the well-functioning of all protocols within a blockchain environment.

4 The "International Economics" of Digital Networks

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 the global economy and financial markets, with the ability to reduce barriers to flows of information and enable the operation of smart contracts and financial transactions that transcend individual blockchains.

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 8 about here]

Panel A of Table 8 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.[10] 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 concerning Ethereum, Fantom, Harmony, Heco, and xDai, increased by 0.21, 0.57, 0.44, 0.31, and 1.13, respectively.

Figure 4 illustrates how the correlations increased post-integration, possibly reflecting positive symbiotic gains arising from increased interoperability between chains.[11] For instance, the correlation between the TVLs of Avalanche and Ethereum increased by 36.21% post-integration.

[Figure 4 about here]

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

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

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

Interoperability at DeFi protocol level. As protocols within a given chain implement DON integration, are there symbiotic gains among integrated protocols? Table 9 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 9 about here]

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

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

4.2 Integration and Risks

Growth, risk-sharing, and threshold effects. One strand of literature in international finance examines how a particular form of integration can affect 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 findings on the positive impacts of DON integration, which provides a more reliable and less noisy approach to integrating with off-chain markets or other blockchains (relative to CO integration or no integration), on variables such as TVL and user base growth echo the findings of 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) as well as 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 align with the findings of 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 markets and developing economies.[12] Analogously, do DON-integrated protocols show more resilience in crises? Anecdotes suggest that DONs could contribute to the price stability during a market crisis.[13] But large-sample empirical evidence is lacking.

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 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 volatility.

Figure 5 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 industry × blockchain level.

[Figure 5 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 lost value and became worthless. Our empirical analysis indicates that DeFi protocols with DON integration rebounded more quickly from this market downturn than those without DON integration.[14]

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

[13] When the Curve Hack took place, the price of the Curve dropped to the bottom on DEX, but since Binance kept its price at $0.6 and that Chainlink heavily weighs Binance in the price feed, the Curve price was thus kept at a certain level and was prevented from further deterioration or even liquidation. The market recovered afterwards. See https://cointelegraph.com/news/cex-price-feed-curve-price-collapse-100m-vulnerability.

[14] 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.

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 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.

4.3 Network Effects

DON integration and the interoperability that it enables may also create network effects that boost the user base and activity in the protocols and platforms involved. Note that network externality of user participation can be particularly strong on certain digital platforms (social media, exchanges, etc.) and adoption can be more frictionless and endogenous, relative to those at the country level (Cong et al., 2021; Cong and Xiao, 2021). Therefore, understanding potential network effects is especially important in our setting. Doing so helps us to examine the underlying economic channels for the effects of integration discussed earlier. Specifically, we estimate:

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

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

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 that these are cross-sectional regressions at the DeFi protocol level.

[Table 10 about here]

Table 10 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, following DON integration.[15]

Centralized oracles yield statistically negligible effects in nearly all cases, with weak positive effects on the user base only at the quarterly horizon. Furthermore, FDV is positively associated with the extent of on-chain activity across all time horizons. 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

[15] Similar outcomes are observed in a more stringent analysis with time-fixed effects (Appendix B, Table B6).

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 (see Table 7).

5 Conclusion

Oracles underpin the functioning of the DeFi ecosystem by allowing smart contracts and various protocols operating on decentralized blockchains to interact with other digital networks or off-chain real-world markets, through the inward and outward transmissions of information. Oracle networks, especially decentralized oracle networks (DONs), aim to ensure the reliability, accuracy, and timeliness of information provided to and from specific blockchains, and to protect investors and users by preventing the execution of smart contracts based on erroneous or manipulated data.

We provide the first comprehensive description of the oracles market and document benefits accruing to DeFi protocols that adopt DON integration, such as increased adoption, usage, valuation, and risk-sharing. 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. Despite concerns about systemic risks arising from integration, integrated protocols have in fact proven more resilient than non-integrated protocols during recent periods of turbulence in crypto markets. We relate our findings to international economics to offer insights for investors, entrepreneurs, DeFi communities, and policy-makers.

Our findings should be interpreted with caution for several reasons. First, the DeFi market is nascent and fast-evolving. Innovative protocols and upcoming crypto regulations may disrupt the current market structure. Moreover, more mature and stable markets with alternative channels for information and value exchange with other (conventional) markets are outside the scope of our analysis. 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 worthwhile to study how interactions among administrators affect the market for DeFi protocols.

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

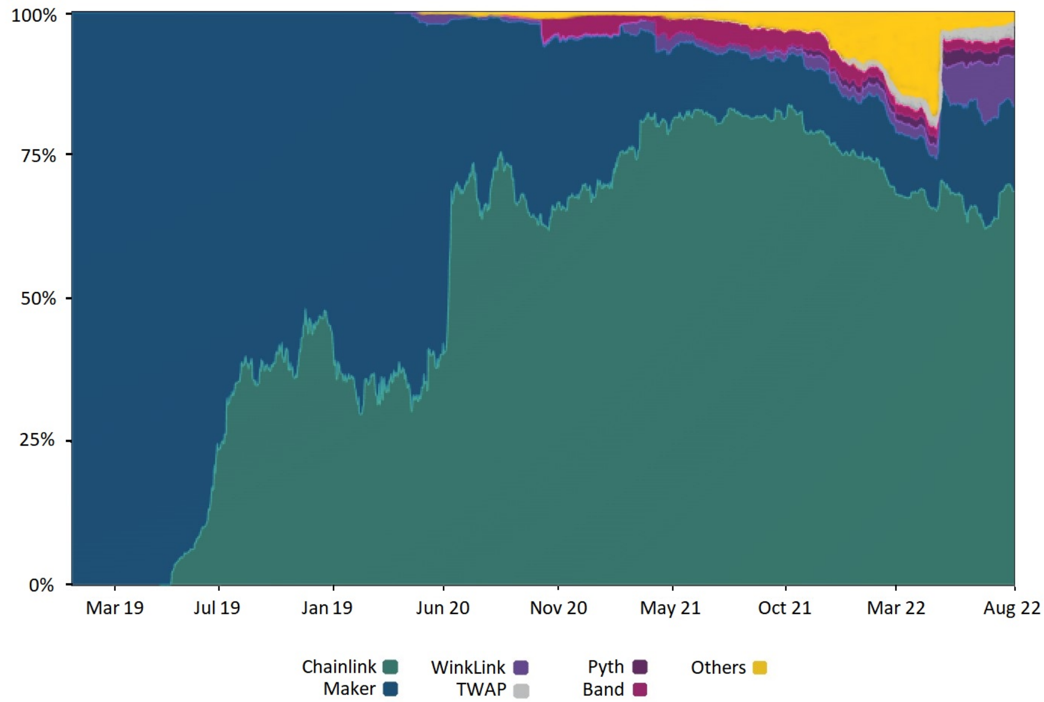

Figure 2. Decentralized oracle networks' evolution: This figure depicts the evolution of oracle networks deployed across blockchains and their respective TVL. The X-Axis captures the days from the first deployed oracle. The Y-Axis captures the number of deployed oracles in the left-hand-side figure,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

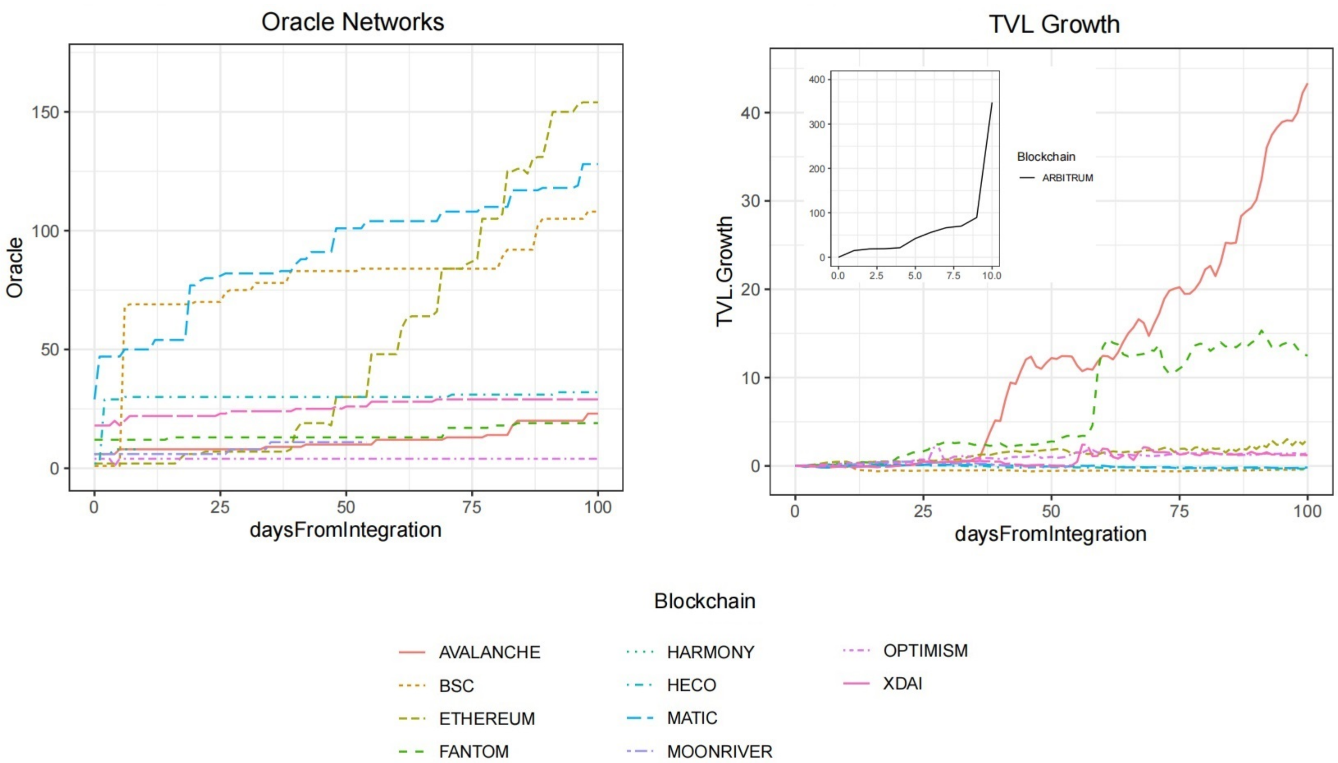

Figure 3. Synthetic control: This figure depicts the mean average evolution of TVL growth for integrated protocols (blue line) and a synthetic control group (red line). The synthetic control group post-live TVL is estimated based on the balanced sample in Table 7 and matched in outcomes. The X-Axis depicts the days to integration. The Y-Axis depicts the cumulative TVL Growth (measured in percentage).

Figure 4. TVL correlations (Avalanche): This figure depicts Spearman correlations for TVL among chains. The left-hand-side (right-hand-side) figure depicts correlations among chains before (after) Avalanche integration. Spearman correlations among chains are presented in the range −1 (dark red) to +1 (dark blue).

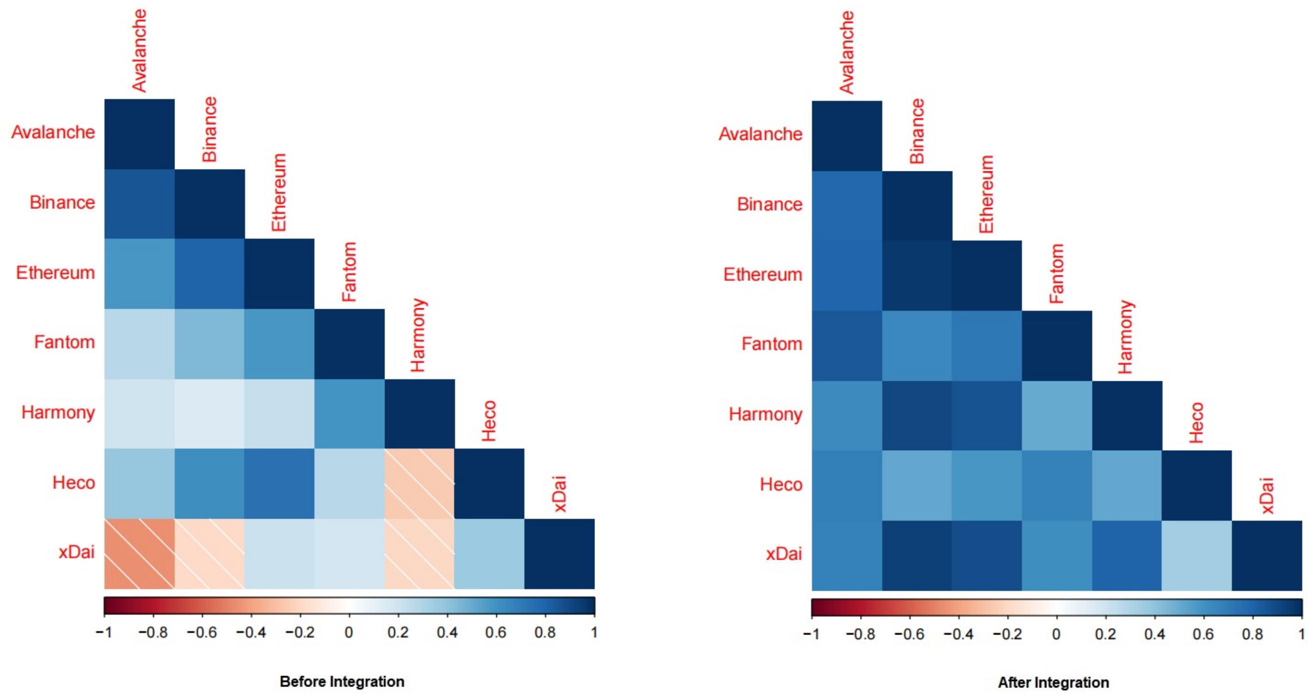

Figure 5. Resilience in Times of crisis: This figure depicts daily standardized market capitalization coefficients for DeFi protocols with DON integration (*Treat*, in orange) and without DON integration (*Control*, in light blue). Panel A depicts the daily coefficients around the Terra-Luna crash. Panel 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 industry × blockchain.

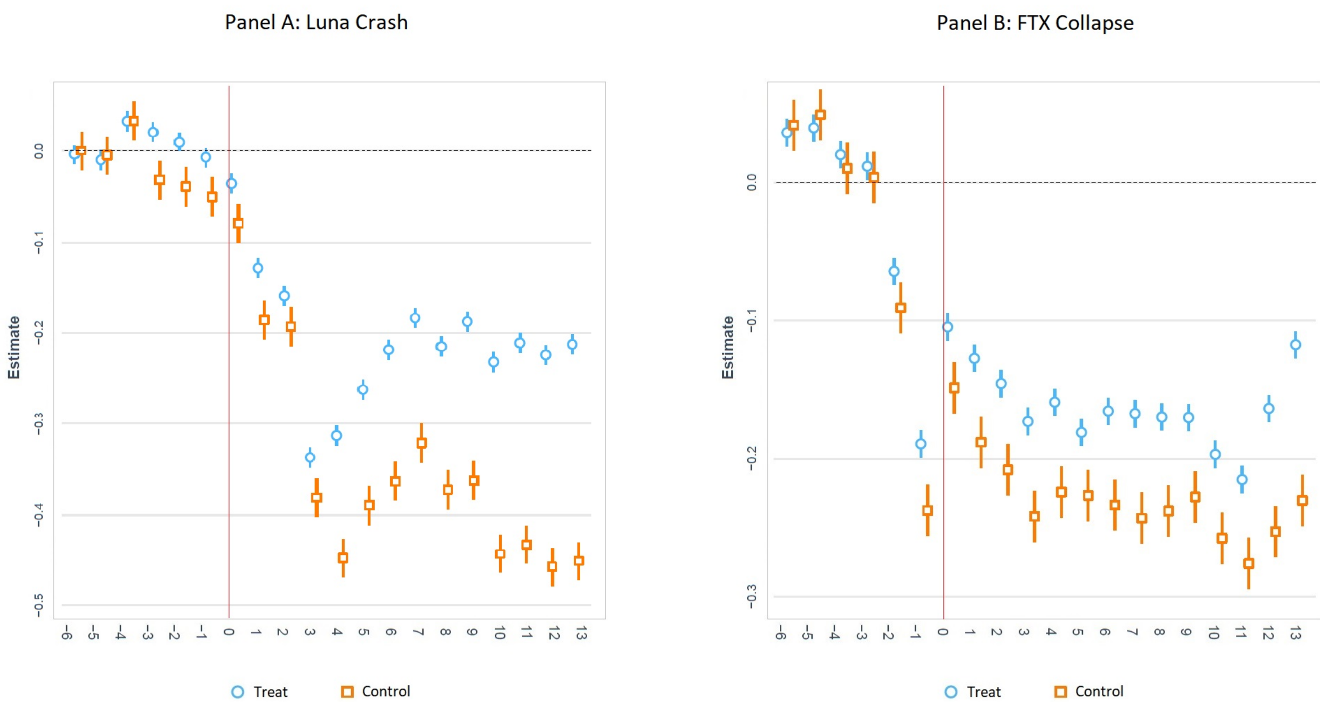

Table 1. The market of oracles: This table depicts the market share of oracles including the number of DeFi protocols and their TVL expressed in dollars.

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 industry × blockchain. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

	M1	M2	M3	M4
log(1 + FDV)	0.08 ***	0.07 ***	0.06 ***	0.05 ***
	(0.01)	(0.01)	(0.01)	(0.01)
log(1 + FDV)	0.01	0.03 ***	0.03 ***	0.04 ***
	(0.01)	(0.01)	(0.01)	(0.01)
Derivatives		1.09 **	0.94 *	0.78
		(0.53)	(0.55)	(0.57)
Lending		0.97 ***	0.84 **	0.75 **
		(0.36)	(0.37)	(0.38)
Options		1.42 ***	1.01 **	0.87 *
		(0.47)	(0.49)	(0.50)
Reserve Currency		-0.66	-0.76 *	-0.93 **
		(0.42)	(0.44)	(0.45)
Multi-Chain			0.76 **	0.58 *
			(0.30)	(0.31)
Industry	No	Yes	Yes	Yes
Blockchain	No	No	Yes	Yes
Time	No	No	No	Yes
Obs.	1,575	1,575	1,575	1,575
Pseudo r^2	0.11	0.19	0.24	0.27

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 Table 7. TVL (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 industry × 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)
Industry	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. PSM-NN: 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 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

Table 8. 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 9. Between protocols interoperability (Ethereum): This table reports Spearman correlations for the TVL of DeFi protocols. Panel A reports the correlations among DeFi protocols with oracle integration. Panel B reports the correlations among all DeFi protocols. *Mean* represents the mean differences for TVL correlations before and after protocols integrate. *Sd* represents the average differences in standard deviations for TVL correlations before and after protocols 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 10. 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 Table 7. 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 industry × 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.

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

Continue.

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

continuation.

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

continuation.

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

Appendix B: Complementary Tables

Table B1. Post-live performance responses to oracle adoption (Economic and financial activities): This table reports the summary statistics for equation 2 in Panel A, and equation 3 in Panel B. TVL (i.e., aggregate value in dollars of all assets currently being held in a DeFi protocol) is the dependent variable in Panel A. Market capitalization (i.e., aggregate value in dollars of total tokens in circulation times their price) is the dependent variable in Panel B. The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the industry × blockchain. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

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

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

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

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

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

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

TVL (DON Characteristics)				
	Day	**Week**	**Month**	**Quarter**
DON(Price Feed)	-4.50	25.37	68.72 **	73.56 *
	(12.36)	(22.54)	(30.90)	(40.89)
DON(Keeper)	49.17	-5.06	1.45	41.52
	(38.30)	(69.24)	(93.46)	(121.62)
DON(VRF)	7.22	-36.07	-40.82	-57.77
	(14.23)	(25.75)	(35.02)	(43.75)
DON(Proof-of-Reserve)	-30.51	-52.04	-62.78	-48.58
	(110.22)	(199.20)	(270.29)	(338.07)
log(1 + FDV)	1.55 ***	2.43 **	3.18 **	5.65 ***
	(0.54)	(0.98)	(1.34)	(1.78)
log(1 + Staking)	0.68	1.11	3.79 **	6.05 **
	(0.73)	(1.33)	(1.84)	(2.48)
log(1 + # Chains)	-2.07	-26.05	-43.90	-59.20
	(17.50)	(31.64)	(43.73)	(56.03)
log(1 + Oracles)	12.26	16.32	33.67	43.27
	(15.90)	(29.40)	(41.14)	(56.57)
Industry	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
Obs.	1,373	1,349	1,273	1,047
Adj.r^2	0.03	0.04	0.08	0.13

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

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

Table B6. Post-live performance responses to oracle adoption (On-chain activities): This table reports the summary statistics for Equation 4 in Panel A, and Equation 5 in Panel B. Panel A's dependent variable is the number of on-chain unique users (i.e., unique wallets with at least one token). Panel B's dependent variable is the number of on-chain transfers (i.e., the number of on-chain transactions). The variables of interest, *DON*, is an indicator variable that equals one for DeFi protocols with DON integration before the live date and zero otherwise. The remaining variables include *CO*, an indicator variable that equals one for DeFi protocols with CO integration before the live date and zero otherwise; *Chains*, the number of listed chains; *Oracles*, the number of listed oracles; *FDV*, the fully diluted market capitalization value; and, *Staking*, the total value of staked coins. All continuous variables are expressed in logarithms. Standard errors (reported in parentheses) are heteroskedasticity consistent and clustered at the industry × blockchain. All specifications have Industry, Blockchain, and Time fixed effects. * Significant at 10 percent; ** Significant at 5 percent; *** Significant at 1 percent.

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

Table B7. Blockchains: This table presents the top 200 blockchains ranked by total value locked as of November 2023. Total value locked represents the cumulative value in dollars of all assets either deposited or transacted through a smart contract. The notation (m) denotes million, while (b) signifies billion.

Name	Protocols	TVL	Name	Protocols	TVL	Name	Protocols	TVL	Name	Protocols	TVL
Ethereum	968	$30.04b	Manta	25	$28.08m	Filecoin	16	$3.9m	Shibarium	14	$983,694
Tron	26	$8.214b	Conflux	11	$25.44m	ICP	4	$3.89m	Grove	1	$940,716
BSC	669	$3.149b	Parallel	5	$24.18m	GodwokenV1	7	$3.81m	Hydra	3	$904,837
Arbitrum	498	$2.398b	Polygon zkEVM	49	$22.46m	Doge	3	$3.79m	MEER	1	$783,121
Solana	116	$943.54m	Heco	49	$22.27m	ThunderCore	8	$3.7m	Step	2	$757,300
Polygon	495	$919.47m	Stellar	2	$22.07m	Dogechain	42	$3.58m	Obyte	6	$729,305
Avalanche	349	$850.03m	Telos	26	$21.56m	Oasys	1	$3.52m	Bitgert	11	$728,560
Optimism	203	$840.05m	Secret	9	$19.42m	XDC	6	$3.46m	Comdex	5	$716,697
Cardano	30	$419.39m	Radix	6	$18.94m	opBNB	32	$3.39m	MAP Relay Chain	2	$681,701
Cronos	104	$361.79m	Scroll	45	$17.25m	XPLA	2	$3.36m	Rangers	1	$656,010
Base	196	$329.12m	HydraDX	1	$15.97m	Sei	6	$3.36m	Energi	1	$648,687
Bitcoin	9	$316.93m	IoTeX	22	$15.86m	NOS	1	$3.26m	Starcoin	3	$631,756
Gnosis	58	$257.61m	Pego	2	$15.78m	SXnetwork	1	$3.21m	MVC	1	$614,059
Kava	133	$248.9m	OKTChain	36	$15.62m	Heiko	5	$3.17m	RENEC	1	$603,227
Thorchain	2	$200.38m	FSC	1	$15.05m	Nolus	1	$2.99m	Kintsugi	1	$595,700
Sui	24	$190.6m	UX	2	$14.33m	Horizen EON	5	$2.98m	Aura Network	1	$577,324
MultiversX	19	$188.93m	Icon	5	$12.52m	Archway	3	$2.78m	Syscoin	4	$562,984
Fusion	2	$167.83m	TON	12	$12.17m	Milkomeda C1	20	$2.69m	Dash	1	$466,536
Osmosis	10	$161.96m	Flow	3	$12.08m	Everscale	2	$2.69m	Europa	2	$419,825
zkSync Era	92	$161.73m	DFK	2	$11.42m	Velas	12	$2.54m	Neon	3	$412,973
Mixin	10	$155.37m	Injective	8	$11.11m	Elastos	3	$2.42m	Crab	1	$408,719
PulseChain	32	$144.51m	Waves	9	$10.62m	FunctionX	3	$2.42m	EnergyWeb	1	$386,712
DefiChain	2	$127.91m	Bifrost Network	2	$10.53m	CosmosHub	3	$2.36m	Sora	2	$333,285
Klaytn	46	$127.62m	Ontology	3	$9.07m	Carbon	4	$2.36m	ENULS	3	$312,551
Ronin	4	$126.61m	Proton	3	$8.75m	Rollux	2	$2.22m	Boba_Bnb	2	$307,354
Mantle	46	$123.16m	Ergo	8	$8.32m	Crescent	2	$2.17m	Nova Network	2	$284,034
Rootstock	9	$121.75m	Oraichain	2	$7.85m	KCC	27	$2.08m	CSC	5	$269,456
Celo	44	$116.17m	Ultron	3	$7.78m	Alephium	2	$2.02m	EthereumPoW	18	$227,115
EOS	20	$101.8m	Vision	2	$7.25m	Elysium	1	$2.01m	Bitindi	2	$193,821
Kujira	14	$85.31m	Harmony	60	$6.93m	Arbitrum Nova	9	$1.96m	ALV	2	$185,807
Algorand	29	$84.23m	Karura	5	$6.7m	EOS EVM	7	$1.89m	Concordium	1	$183,334
Fantom	303	$77.24m	Meter	10	$6.56m	Equilibrium	1	$1.84m	Callisto	1	$181,144
Canto	20	$70.89m	Kardia	6	$6.2m	Oasis	19	$1.72m	Loop	2	$148,937
Aptos	32	$70.5m	Moonriver	54	$6.1m	Juno	9	$1.67m	TomoChain	4	$131,641
Near	21	$62.36m	Evmos	20	$6.06m	Bittorrent	14	$1.64m	Shiden	7	$128,096
Moonbeam	55	$47.86m	Terra Classic	30	$5.85m	Persistence	3	$1.58m	OntologyEVM	4	$111,058
Linea	51	$46.68m	smartBCH	23	$5.63m	Fuse	16	$1.57m	Kroma	1	$109,079
Hedera	8	$46.6m	Wanchain	8	$5.61m	Chihuahua	3	$1.53m	Findora	5	$108,726
WEMIX3.0	10	$41.8m	Beam	1	$5.58m	Theta	5	$1.5m	Tenet	2	$108,420
Neutron	4	$41.35m	ShimmerEVM	5	$5.22m	EthereumClassic	6	$1.42m	Godwoken	3	$104,349
Astar	36	$36.75m	Vite	4	$4.95m	Kadena	5	$1.41m	ZYX	1	$98,051
Tezos	17	$35.14m	Litecoin	3	$4.93m	Tombchain	1	$1.3m	Stargaze	2	$83,691
Aurora	57	$35.04m	Flare	3	$4.78m	Nahmii	1	$1.19m	Newton	1	$78,265
Stacks	5	$34.45m	Zilliqa	7	$4.62m	Libre	1	$1.16m	Ubiq	1	$63,130
NEO	6	$34.27m	Nuls	4	$4.59m	Bostrom	1	$1.15m	DSC	1	$57,544
Terra	13	$33.37m	Interlay	3	$4.39m	Migaloo	3	$1.14m	MultiVAC	3	$42,706
Starknet	17	$32.59m	Songbird	5	$4.29m	VeChain	2	$1.04m	Goerli	1	$35,693
Metis	45	$30.97m	CORE	18	$4.2m	Onus	5	$1.03m	Lachain	3	$31,389
Mayachain	1	$29.44m	Boba	27	$4m	Wax	3	$1m	LightLink	2	$29,273
Acala	7	$28.42m	Bitcoincash	2	$3.97m	Bifrost	3	$991,465	Milkomeda A1	3	$26,270