PUBLIC BLOCKCHAIN ECOSYSTEM AND DAPP ADOPTION

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ABSTRACT

As a cutting-edge technology, blockchain has aroused great interest from an increasing number of economists and management scholars. However, most of the prior studies are constrained in relevant topics of cryptocurrencies and payment systems, using theoretical analysis but lacking empirical support. Also, little is known about public blockchain platforms and their built-on decentralized applications (DApps). This study focuses on the growth of DApps, especially examining the driving forces of DApps' adoption. With the empirical test using the sample of DApps on six popular public blockchain platforms, this paper finds that prior transaction volumes have a positive impact on DApps' adoption. Moreover, under the inner blockchain tradeoff between decentralization and scalability, a choice between transaction security and speed for DApps' users, the research argues that higher transactions will boost users to choose DApps in more decentralized platforms.

BIOGRAPHICAL SKETCH

Qian Wang is a second-year master's student in applied economics and management (AEM) at Cornell University. He obtained a B.A. in economics from Beihang University before joining Cornell. His research focus on strategy, innovation, and entrepreneurship. Qian will start a Ph.D. in management at Cornell University in fall 2021.

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TABLE OF CONTENTS

I. Introduction

First popularized as the revolutionary, distributed ledger technology behind Bitcoin, blockchain has aroused numerous attentions from academia for its unique characteristics of transparency, autonomy, and immutability. Plenty of economists and management scholars have started discussing its significance and potential applications in economic relationships and business services. A great number of researchers concentrate on the cryptocurrency and finance sector, the initial application of blockchain technologies. They use both qualitative and quantitative ways to clarify some key features of cryptocurrencies (Harvey, 2014; Hsieh et al., 2018), dig in the underlying designs (e.g., Halaburda and Haeringer, 2019), the factors associated with cryptocurrencies' performance (Wang and Vergne, 2017; Cennamo et al., 2020), and cryptocurrencies' potential contributions to entrepreneurs and stakeholder coordination (Catalini and Gans, 2018). Except for digital currencies, many researchers have also started investigating other potential impacts and applications of the blockchain, including corporate governance (Yermack, 2017; Beck et al., 2018; Lumineau et al., 2020), banking (Raskin and Yermack, 2018), industrial organization and competition (Cong and He, 2019), insurance sector (Hans et al., 2017) and others potential areas (Felin and Lakhani, 2018). However, these papers mostly use theoretical analysis to investigate blockchain's possible effects but do not have empirical support. Moreover, they only use a generalized blockchain framework for their study but do not consider the diverse categories of blockchain technology based on consensus mechanism, scalability, distributed mechanism, and other technical sides. Therefore, which business domains the blockchain technologies can contribute to and how blockchain technologies can be applied to potential business services are still unresolved questions.

The release of many public blockchain platforms, such as Ethereum, provides us a hint for the above questions. Except for being used as decentralized databases, blockchains can be used as platforms. To be specific, public blockchain platforms offer a shared technological resource that third parties can use to develop digital services (Thomas et al., 2014). They make it easier to create smart contracts, self-enforcing code so that third-party developers can create a range of decentralized applications (DApps), running as programed. DApps are stored on and executed by a public blockchain platform. Therefore, unlike a regular application dependent on a centralized platform and controlled by a particular party, DApps have their backend codes running on a decentralized peer-to-peer network and can enable direct transactions between end-users and resources without a centrally trusted party. Based on the public blockchain platforms, developers do not need to spend much time creating their own blockchain before developing a DApp. Thus, they can focus more on their product's applied side, thinking about how to build up business service based on a given blockchain platform. More importantly, public blockchain platforms go beyond cryptocurrency and payment and essentially stimulates the burst of blockchain applications in various areas. For instance, up till now, there are around 3,000 DApps built on Ethereum with daily active users over 82,000, which cover a broad range of categories, such as games, social, decentralized finance, and gambling[1].

[1] Based on the statistics from www.stateofthedapps.com/stats.

Though more and more public blockchain platforms and DApps are emerging, their development is still early and has not been much popularized. For example, the number of active daily users of one of the most popular DApps is only around 6,000, far less than popular applications people usually use, such as Twitter and TikTok. Therefore, blockchain entrepreneurs and researchers still wonder whether a killer DApp, which millions of people use daily, is possible and how the potential killer DApp would be like. It would have profound implications on business innovation and the commercialization of blockchain technologies. To answer this broad question, it is necessary to address what drives the adoption for DApps.

This study focuses on the public blockchain ecosystem with an overview of public blockchain platforms and DApps. And more importantly, it sheds light on what drives the adoption for DApps. Starting from the discussion of decentralization in transactions, the essential characteristic of public blockchain platforms and DApps, this paper argues that the prior transaction volumes have a positive impact on DApps' adoption. Moreover, based on the tradeoff between degree of decentralization and scalability, this research points out that higher transactions will boost the adoption for DApps in more decentralized platforms. The hypotheses are empirically tested using the sample of DApps, lying in six popular public blockchain platforms.

The remainder of this paper is structured as follows. In the next section, I present the theoretical and empirical context of this study. Then I introduce the relevant theories and develop the research hypotheses. This is followed by a description of the methods employed, including the data, variable illustration, and analysis techniques.

Finally, I present the results and end with a discussion of the implications and limitations of the findings, and potential extensions of this study.

II. Context

Blockchain definition and characteristics

Though there is no one standard definition of blockchain, the most parsimonious and commonly used explanation of blockchain is a "distributed ledger of transactions" (Halaburda, 2018). To be specific, blockchain is a distributed ledger technology in the form of a distributed transactional database, secured by cryptography and governed by a consensus mechanism (Beck et al., 2017). It is originally put forward by pseudonymous Satoshi Nakamoto in the white paper "Bitcoin: A Peer-to-Peer Electronic Cash System" in 2008.[2] Therefore, Bitcoin is generally considered the first and widely used application of blockchain. Besides Bitcoin, blockchain can also power other cryptocurrencies and other potential applications, giving it several unique characteristics.

While people usually refer to blockchain's general form, especially the original blockchain underlying Bitcoin, it has several categories within the general framework based on different characteristics. More specifically, they differ regarding their mechanisms to enforce consensus, the power of included programming languages, their capabilities to define who is allowed to participate in a network, and the type of cryptocurrency they include (Beck and Müller-Bloch, 2017; Yli-Huumo et al., 2016). Correspondingly, they also have various performance properties such as throughput, scalability, latency, energy consumption (Bano et al., 2019). There are predominantly two types of blockchains: public and private blockchain (Ferdous et al., 2020). The public blockchain is also known as the permissionless blockchain, allowing anyone to

[2] https://bitcoin.org/bitcoin.pdf

participate in the blockchain to create and validate blocks and modify the chain state by storing and updating data through transactions among participating entities. Under this circumstance, the blockchain state, its transactions, and the data stored are transparent and accessible to everyone. Yet, this raises privacy concerns when the privacy of such data needs to be preserved. Private blockchain, which is also known as the permissioned blockchain, has a restrictive notion compared to its public counterpart. Only authorized and trusted entities can participate in the activities within the blockchain. It may ensure the privacy of chain data, which might be desirable in some particular cases. The original blockchain setting underlying Bitcoin and many others is permissionless.

There are a couple of manifestations of blockchain technology. In essence, it provides a decentralized, immutable record of transactions that uses preprogrammed algorithms and protocols to automatically execute and validate transactions without relying on a centralized third party. More specifically, its main characteristics are listed as follows: (1) Decentralization. The database is fully decentralized and runs on computers provided by volunteers worldwide, meaning there is no central database to hack and no single entity that controls it. (2) Immutability. Each set of records in the database is referred to as a "block," and anything that is recorded in the database is preserved there forever. (3) Security. Because of the database's immutability, once a record has been entered, it is almost impossible to manipulate or alter that record (Tapscott and Tapscott, 2017). Besides, blockchain is not "just a record" for monetary transactions. Still, it can also contain the so-called smart contracts, which are programs stored on the blockchain that run as implemented without any risk of downtime, censorship, or fraud (Buterin, 2014). Thus, it allows even parties who do not fully trust each other to conduct mutual transactions without relying on trusted intermediaries. These perceived benefits of the blockchain may explain why an increasing number of banks are currently developing a vision of what blockchain technology means for their business (Glaser, 2017). It may become an even more valuable enabler of economic and social transactions, for instance, as a more general digital asset ownership record (Lindman et al., 2017). Though it brings benefits in places, there are also new types of costs (Murray et al., 2019). For instance, recording transactions on a decentralized ledger takes more time than on a centralized ledger because of the consensus mechanisms that need to be employed. Moreover, the need to store the copies of the ledger in multiple locations may significantly add to storage and computational costs. To date, it has not been clearly demonstrated in which circumstances the benefits of employing a distributed ledger outweigh the cost of delays and duplicated storage (Pereira et al., 2019).

Blockchain technology has been received a lot of public attention, as advocates argue that it constitutes the foundation for truly trust-free economic transactions (Glaser, 2017) and the potential to disrupt various intermediary services (Tapscott and Tapscott, 2016). While it acquires fame as the underlying technology of Bitcoin (Beck and Müller-Bloch, 2017), it is currently expanding to other areas of application (Wörner et al., 2016). Industries such as finance, healthcare, education, government, and real estate are discovering blockchain technology's potential possibilities. For example, governments may be prone to corruption, but blockchain can play a role in the voting process to create a verifiable track record of citizens' votes, making it less likely to tamper with ballots. In the healthcare industry, blockchain technology may be used to update patient records in near real-time and eliminate human error, enabling accurate information that is both up-to-date and secure (Siyal et al., 2019). In the supply chain area, blockchain may be used to create an audit trail of every stop an item makes through the supply chain; thus, relevant efficiency and transparency can be greatly increased. However, most of them are still constrained in the exchange area and are not easily accessible to customers. The widespread applications of blockchain technology are still unclear (Risius, 2017).

Blockchain research in economics and management

While blockchain is a relatively recent phenomenon, it has sparked many increasing streams of research in economics and management (Halaburda and Haeringer, 2019). The main research areas on blockchain by economists and management scholars can be classified into the following three categories: (1) cryptocurrency and the blockchain in the finance sector. (2) real-world implications given the blockchain's characteristics. (3) blockchain's general implications on organizational governance and trust formation.

Since Bitcoin and other cryptocurrencies are the first batches of application of blockchain technologies, the examination of blockchain's applications has started from cryptocurrencies and the finance sector. Plenty of studies have focused on the cryptocurrency market, investigating potential explanations of cryptocurrencies' market values and prices (e.g., Wang and Vergne, 2017; Cennamo et al., 2020). Except for fundamental functions like payment and exchange, many researchers have examined more managerial implications of cryptocurrency, especially the initial coin offerings (ICOs). To be specific, entrepreneurs can use ICOs to fund venture start-up costs and facilitate coordination among stakeholders (Catalini and Gans, 2018). Also, the fast development of cryptocurrencies and blockchain technology may affect the current financial system, bringing new challenges and opportunities (Hsieh et al., 2018) and push the current banking system, especially the central banks, to react to the emerging digital currencies (Raskin and Yermack, 2018). They may change the way financial institutions, regulators, and individuals interact in a financial system and may provide a peer-to-peer and decentralized payment system competing against traditional financial institutions (Egelund-Muller et al., 2017). Moreover, smart contracts powered by blockchain technology could contribute to financial contracts and trading efficiency (Tinn, 2017; Bakos and Halaburda, 2019).

Besides the financial sector, blockchain technologies may challenge and boost other industries' development based on its unique characteristics on transaction verification (Felin and Lakhani, 2018), such as human resources and procurement, sales and marketing, and legal affairs (Tapscott and Tapscott, 2017). They may also contribute to operations and supply chain management and others (Cole et al., 2019). Nevertheless, in general, application-oriented contributions to blockchain research appears to be scarce and focused on a limited number of topics, such as payment system (Risius and Spohrer, 2017). How blockchain technology can make real contributions to different business sectors is still unclear.

Except for specific industries, blockchain may contribute to economic coordination and organizational governance in some more general discussions

(Davidson et al., 2018). Blockchain may transform the organization's governance and coordination by eliminating transaction costs, improving consensus effectiveness, and others (Tapscott and Tapscott, 2017; Murray et al., 2019; Cong and He, 2019). Specifically, it could offer a new way to enforce agreements and achieve cooperation, distinct from traditional governance forms, including contractual and relational governance (Lumineau et al., 2020). Also, it may affect the balance of power among managers, institutional investors, small shareholders, and other parties involved in corporate governance (Yermack, 2017) through decision rights, incentives, and others (Beck et al., 2018). The distributed trust founded by blockchain technology can potentially transform organizations' boundaries and extend the theory of trust formation between organizations (Seidel, 2018). For instance, smart contracts powered by blockchain technology provide a potential deduction-related trust that reinforces classical trust cues (Obermeier and Henkel, 2020).

Based on the above review, although blockchain is considered to be potentially disruptive in various areas by researchers, there is a lack of specific understanding of where and how blockchain technology can be really applicable and where it has mentionable practical effects (Risius and Spohrer, 2017). To be precise, there are several limitations and theoretical gaps in current blockchain research. First, most of the prior studies only analyze the general form of blockchain technology. Still, they have not paid much attention to distinct features of different blockchains (Walsh et al., 2016), such as consensus mechanisms, level of permission, and various application consequences, such as scalability, security, and privacy. And different blockchain technologies may have different implications on business services. Second, there is a mentionable amount of conceptual research, particularly on prototypes and analytical investigations into cryptocurrencies. However, the amount of blockchain-related quantitative research beyond cryptocurrencies is relatively scarce. Third, since public blockchain platform, such as Ethereum, is a relatively new phenomenon, existing research has not examined much about blockchain technology as a platform base.

While several recent studies have started moving on to the platform perspective and evaluated the differences between centralization and decentralization on platform governance (Pereira et al., 2019; Vergne, 2020; Chen et al., 2020), most of them still constrain in introductory and theoretical analysis of characteristics of blockchain platforms. The emerging blockchain platform and DApp economy still lack thorough examination. This study provides an overview of public blockchain platforms and DApps and explores the driving forces of DApps' adoption. It can be a good starting point to dig into the public blockchain ecosystem, the inter-relationship between blockchain platforms and their built-on DApps, and how their relationship affects DApps' adoption and growth. The quantitative analysis based on DApp level data can also be a reference for future empirical research on blockchain.

Public blockchain platforms and DApps

Except for replacing centralized databases, public blockchain can be used as platforms since they can offer a shared technological resource that third parties can use to develop digital applications and services (Thomas et al., 2014). Public blockchain platforms are open for anyone to build up decentralized applications (DApps), and it may offer a potential solution for blockchain commercialization and business innovation. Developers can directly use the so-called smart contracts: a set of rules that live on-chain for all to see and run precisely according to those rules, to create a wide range of DApps covering various categories, such as games, digital collectibles, online-voting systems, decentralized financial products, and many others. Rather than using a centralized server or database, DApps rely on their underlying blockchain platforms to the backend for program logic and storage.

Prior empirical studies in economics and management have covered various digital platforms such as video game platform (e.g., Boudreau, 2012; Cennamo 2018; Rietveld and Eggers, 2018), smartphone mobile platform (e.g., Kapoor and Agarwal, 2017), social platform (e.g., Li and Agarwal 2017), etc. These are centralized platforms based on for-profit companies that develop and maintain centralized access to the corresponding technological ecosystem, bringing people and businesses together to facilitate transactions (Vergne, 2021). The critical difference between public blockchain platforms and prior digital platforms, such as Amazon and Facebook, is decentralization. Public blockchain platforms are based on decentralized governance and data infrastructure, allowing marketplace agents to transact directly with each other without a trusted intermediary (Catalini and Gans, 2018; Nakamoto, 2008; Davidson et al., 2018). Such disintermediation can reduce transaction costs (Halaburda, 2018) and failures inherent to centralized platforms, such as lack of transparency, corruption, censorship, and excessive market power (Atzori, 2015; Catalini and Gans, 2018).

More specifically, the comparisons between decentralized platforms and centralized platforms in various dimensions are shown in the following table (Table 1).

First, the decision-making in a centralized platform is typically controlled by the platform owner. Some centralized platforms, such as Android, indeed establish open-source movements, embracing various opinions to amend the code or others. Nevertheless, most community members cannot directly participate in the decision implementation (Vergne, 2021). In contrast, the choice for public blockchain platforms is more democratic: some blockchain platforms encourage the whole community to maintain relevant protocols and decide about the platforms' directions (Böhme et al., 2015). Second, centralized platforms often directly regulate access and membership, requiring users and complementors' authentication (Boudreau and Hagiu, 2009). For public blockchain platforms, they are vertically open at the complementor and user level (Eisenmann et al., 2009), but there are both permissioned and permissionless blockchains at the infrastructure technology level. Third, public blockchain platforms also differ from centralized platforms regarding transaction verification processes, which obey a pre-agreed consensus mechanism. While in centralized platforms, the platform owner is the entity validating transactions and deciding which transactions are valid or not. In blockchain platforms, an independent pool of validators verifies the transactions, such as miners in the Bitcoin blockchain. It applies a verification system to ensure consensus among users about the ledger's actual state, fueled by cryptocurrency-incentive to involve validators in a disintermediated verification process (Davidson et al., 2018). Fourth, while in centralized platforms, the platform sponsor owns and controls the access to data. In blockchain-based platforms, the ledger of transactions, which stores all transactions' history, is stored in many locations simultaneously in a distributed fashion (Nakamoto, 2008).

Table 1. Basic comparisons between centralized and public blockchain platforms

Dimensions	Centralized Platforms	Public Blockchain Platforms
Decision making	Platform owner	Platform owner or Platform community
Entry rules	Permissioned	Permissionless or Permissioned
Transaction verifications	Centralized	Decentralized
Data ownership	Proprietary	Distributed
Examples	Amazon, Facebook	Ethereum, EOSIO, Neo

Compared to the normal Applications (Apps), DApps have their backend codes running on a decentralized peer-to-peer network while normal Apps' backend codes are running on centralized servers[3]. Although there is no strict definition of DApps from whitepapers or previously academic papers, there are some noticeable standard features of DApps. First, open source. Ideally, it should be governed by autonomy, and any changes must be decided by the consensus of its users. Its codebase should be available for scrutiny. Also, anyone can deploy a copy of the frontend and connect it to the public blockchain network. Second, decentralization. Records of the application's operation are supposed to be stored on a public blockchain platform to avoid centralization pitfalls. DApps can enable direct transactions between end-users and resources without an intermediary or centrally trusted party since they will always run as programmed. Almost no one, including the DApp developers or platform developers, can alter that record once stored on the underlying blockchain. In other words, transactions published to the blockchain are signed with a private key, and only the account owner can take actions within DApp. Third, incentivized. Validators of the blockchain are usually incentivized by rewarding them with cryptographic tokens.

[3] https://ethereum.org/en/developers/docs/dapps/

Similarly, DApp users are incentivized by sharing contents, finishing collecting projects with tokens in many DApps. There are also a couple of non-technical differences between DApps and normal Apps. First, although some DApps can be accessed via mobile platforms, such as App Store and Google Play, most of the DApps can only be accessed through a web page. Thus, there is no particular App-store to get into or download the DApps. Second, almost no DApp are set by multi-platforms, which means most of them are tied to a specific platform. The multi-home of DApps is still under exploration. Third, normal App developers often offer two versions of the same app, a free version and a paid version in major apps stores (Ghose and Han, 2014). Nevertheless, this does not apply to the DApps for now.

Public blockchain platforms offer swift implementations of automated transaction management with comparatively little coding effort for DApp developers. In this area, the blockchain application layer that provides intermediary services is of primary interest. And the focus lies on the design of smart contracts and the development of DApps that run on them (Glaser, 2017). In other words, DApp developers do not need to invent their blockchain technologies but can focus on the application and commercialization side: how to make their products or service valuable and acceptable for customers. It may stimulate blockchain's business innovation and figure out some widespread applications (Killer DApps) of blockchain technology. However, the community size of the public blockchain platforms and DApps is relatively tiny, and blockchain applications are far less than popularized. A significant question concerning the popularity of blockchain applications is what drives the adoption of DApp, and it is still unclear. This study tries to shed light on this question starting from a critical difference between DApps and normal Apps – decentralization and figure out how the degree of decentralization matters for DApp's adoption.

III. Theory and Hypotheses

Decentralization and transactions

Prior studies on App's adoption have examined various factors, such as past rank (Carare, 2012; Garg and Telang, 2013), in-app purchase and advertisement option (Ghose and Han, 2014), structural positioning in the app network (Kim et al., 2013). However, since DApp is built on a blockchain platform rather than centralized platforms, some unique factors linked with blockchain may affect DApp's adoption, which could affect people's choice of decentralized platforms and DApps.

What makes a blockchain a very special kind of ledger is decentralization (Gencer et al., 2018). Broadly speaking, decentralization refers to the degree of diversification in ownership, influence, and value in the blockchain. To be specific, decentralization means the broad dispersion of the ability to exchange data and information within communication systems (Vergne 2021). In particular, blockchain can enable the decentralization of transaction validation (Catalini and Gans, 2018). Blockchain can provide an open, distributed ledger of transactions where information is stored in a network of decentralized nodes. All actors are automatically connected to the technical infrastructure. Therefore, instead of being managed by a single centralized party, such as a bank or platform owner, blockchain allows transactions to be stored in multiple copies on various independent computers within a decentralized network. Correspondingly, no single entity can control the ledger. Any of the computers on the network can make a change to the ledger, but only by following rules dictated by a "consensus protocol," a mathematical algorithm that requires a majority of the other computers on the network to agree with the change.

Running on the public blockchain platforms, DApps rely on their underlying blockchain platforms to the backend for program logic and storage and user transactions. Therefore, an essential feature of DApp is to provide relatively safe and transparent transactions based on the decentralization characteristic of blockchain technology. Correspondingly, the transaction condition is a key factor which attracts DApp users and correspondingly a significant element potential DApp users paying attention to (Pereira et al., 2019). However, transparency and safety of transactions are varied among DApps given differences in underlying platforms and DApps' types and nature (Wu, 2019). Thus, users can refer to the prior transaction volumes of DApps, a direct and easily accessible index, to value their corresponding transaction conditions to some extent. If there are more transactions happening on a DApp, the reliability and safety of transactions on this DApp may perform better, which could encourage users' adoption.

Moreover, several studies have examined the role of network effects on product adoption (e.g., Afuah, 2013; Boudreau, 2012; Foerderer et al., 2018; Cennamo et al., 2020). Here prior transaction volumes can be an indicator of transaction activeness and opportunities, measuring the activeness that users engage in each DApp. As more users getting active on a DApp, additional users who want to get transactions on DApps will be more likely to join in. Accordingly, this study hypothesizes that users will be more likely to choose the DApp where more transactions are happening.

HYPOTHESIS 1 (H1). *Transaction volumes of a DApp have positive impact on its adoption.*

The tradeoff between decentralization and scalability

Ideally, strong decentralization enables the possibility of not trusting any particular blockchain providers or authorities while ensuring the whole system's trustworthiness and security. However, this advantage is not free. Decentralization, which has backed the fast growth of many blockchains, comes at the cost of scalability (Abadi and Brunnermeier, 2018). The tradeoff between decentralization and scalability brings growing pains for public blockchain platforms like Ethereum. Nowadays, most blockchain networks are slow compared to traditional centralized technologies like AWS or the Visa network, making it costly to use. For instance, Ethereum can process transactions in the range of 15 transactions per second[4], and some blockchains are even slower. On the other hand, blockchain networks' unique properties, such as transparency and immutability, cannot be realized in the same way with centralized approaches given the inner technological bottleneck. As more and more developers and users continue to experiment with novel uses of these properties in DApps, popular platforms are facing scalability and transaction limits. Under this circumstance, blockchain scalability is widely seen as a limiting factor in further blockchain adoption among DApp developers and end-users. This may be the one reason explaining why blockchain has not been commonly used in people's daily lives.

Consensus mechanism as a key component of decentralized degree

A crucial component of any blockchain system that affects its decentralization degree is the underlying consensus mechanism (Bano et al., 2019). A consensus

[4] https://coincheckup.com/coins/ethereum/analysis#facts-and-figures

mechanism (algorithm/protocol) is a way of reaching a consensus between trustless entities. In blockchain technology, it is used to specify how to get multiple nodes to agree on a value and to reach a consensus about if a block is valid or not. The performance of blockchain networks relies on the performance of the adopted consensus mechanisms, and it has a significant impact on the perceived usability of blockchain applications (Ferdous et al., 2020). The Proof of Work (PoW) and Delegated Proof of Stake (DPoS) are the two most popular consensus mechanisms used by currently public blockchain platforms. Also, they can be a good reflection of the tradeoff between decentralization and scalability.

PoW is the first consensus mechanism in blockchain, which underlies Bitcoin and Ethereum. Based on the PoW consensus mechanism, all nodes attempt to find the solution to a hash puzzle, and the node that wins adds the following block to the blockchain (Bano et al., 2019). The miner that solves the mathematical problem first adds the block to the blockchain, and the network rewards the miner for doing so (Xie et al., 2019). Proof-of-work is a relatively inefficient consensus mechanism, not only in terms of electricity (the process to solve a crypto-puzzle is very computationally intensive) and in terms of speed (the verification process is very time-consuming). And maintaining the entire history of transactions consumes more memory than, for example, keeping balances. This can be problematic for use-cases that require high throughput[5].

Some public blockchain platforms use the delegated consensus mechanism to deal with scalability problems (Perez et al., 2020). For instance, DPoS is proposed to

[5] https://cointelegraph.com/news/vitalik-buterin-talks-scalability-ethereum-blockchain-is-almost-full

improve the bottlenecks of PoW. In the Proof of Stake (PoS) setting, when building a block, a participant needs to deposit stake into a contract to win the block-building chance, which is proportional to the amount of stake (King and Nadal, 2012), which is generally in the form of tokens. In other words, a participant can enter new transactions according to the number of tokens they already have (Seibold and Samman, 2016). Thus, the decentralization degree of a PoS blockchain depends on the distribution of stake. Owning more tokens refers to higher block creation power. It helps eliminate the need for a large amount of expensive mining, run on a tiny fraction of the power, solve the scalability problem to some extent. Still, it may arouse the sacrifice of decentralization degree, especially in the DPoS setting. DPoS does not require every participant to build blocks directly (Larimer, 2014). Instead, participants can delegate a validator. This can reduce the number of validators in consensus, and at the same time, it makes one participant harder to directly build a block, which incurs a negative impact on the trust model. As the DPoS consensus mechanism reduces the number of validators to build blocks, the centralization degree would increase because only a handful of delegates who hold the majority of the decision-making power and power are corruptible. Take EOSIO as an example; there are twenty-one block-producing nodes in the EOSIO network[6], far fewer than the PoW consensus mechanism, such as Ethereum. It is not totally centralized but is much more centralized than many PoW blockchain networks. The system assigns votes based on stake of cryptocurrency holdings for each node. This means that the top 10 (or even top 100) token holders can impose their dictations on the EOSIO ecosystem without

[6] https://github.com/EOSIO/Documentation/blob/master/TechnicalWhitePaper.md

any opposition[7]. On the other hand, by becoming more centralized, EOSIO achieves higher transaction throughput than either Ethereum or Bitcoin. Public blockchain platforms using the DPoS consensus mechanism lies in the middle between strict decentralized platforms and centralized platforms.

Decentralization degree in platforms and DApps' adoption

While decentralization is the key characteristic of blockchain technologies, decentralization degrees among different blockchains are varied. In the public blockchain setting, PoW blockchain platforms have a higher decentralization degree but relatively lower scalability (Perez et al., 2020). Blockchain platforms with a delegated consensus mechanism have higher scalability but sacrifice their decentralization degree. Since DApp follows the mechanism of its underlying blockchain platform, DApp users also need to pay attention to the tradeoff. From the DApp users' side, the tradeoff between decentralization and scalability is a choice between transaction security and transaction speed. And the degree of decentralization of a DApp's underlying platform is a platform-level factor that affects the above tradeoff. Therefore, a significant question what degree of decentralization do the DApp users require. It may depend on the users' preferences between security and speed. If users care more about the security of their transactions, they will be more likely to choose DApps in platforms with a higher degree of decentralization when they have a higher demand for transactions within DApps. If users care more about the

[7] https://www.investopedia.com/news/top-100-holders-eos-own-75-or-11b-worth/

speed of their transactions, they will have a opposite choice. Then, the two hypotheses of this study is drew as following.

HYPOTHESIS 2A (H2A). *Higher transactions can boost users to choose DApps in more decentralized platforms if users care more about the transaction security*.

HYPOTHESIS 2B (H2B). *Higher transactions can boost users to choose DApps in more centralized platforms if users care more about the transaction speed.*

IV. Data and Measure

Data Resources

The primary data resource of this study is the State of the DApps (www.stateofthedapps.com), a not-for-profit curated directory of DApps. There are several advantages of this data resource. First, with the goal of connecting DApp creators and users, the State of the DApps is well-known for its autonomy and objectivity. Second, it is widely accepted and used by blockchain communities, even Vitalik Buterin, the co-founder of Ethereum. Third, while it initially focuses on DApp information for only Ethereum blockchain, it has been included data from other mainstream platforms such as EOS, Neo, and Hive, which provide great coverage of the most popular public blockchain platforms. I use the web-scraper technique to collect DApp data from the State of the DApps every week starting from June 8th, 2020, and build up a dataset covering 38 weeks (2020 June to 2021 February). To be specific, the dataset includes various DApp categories such as Games, Gambling, High Risk, Social, and bountiful DApp information such as status, development activities, active users, transactions. Also, I track some developer-side information such as GitHub star, GitHub forks, Reddit members of each DApp from their GitHub repositories and Reddit websites to measure their attention from developers and users.

The Platform data of this study mainly comes from Crunchbase (www.crunchbase.com). Crunchbase is a leading platform providing business information about private and public companies. It covers various information, including platform introduction, funding, mergers and acquisitions, team members, and active technologies. I also get some supplemental information platform technical characteristics such as consensus mechanism directly from the blockchain platforms' official websites or original whitepapers.

Measure

This study's dependent variable is Daily Active Users (DAU), which is the unique number of daily active users of each DApp. It is the most relevant measure for an application's adoption in prior research (e.g., Kummer and Schulte, 2019). To reduce the skew in this variable, a natural logarithmic transformation is applied.

One key independent variable in this study is Daily Transactions, which is the number of daily transactions on each DApp. A logarithmic transformation is again applied to it, dealing with the left-skewed distribution and allowing the coefficient to be interpreted as elasticity. Another key independent variable in this study is Delegated. It is a dummy variable with the value equals 1 if the DApp's underlying platform uses a delegated consensus mechanism and with the value equals 0 if the DApp's underlying platform uses a non-delegated consensus mechanism. I also built up an interaction term between Delegated and Daily Transaction Numbers to figure out how decentralization degree affects the relationship between DApp's demands and transactions.

Also, I control several variables which may affect the DApp's adoption. To be specific, Development Activities is the number of development activities of the DApp within 30 days, which can be a measure of update of application (e.g., Boudreau, 2012; Tiwana, 2015; Foerderer et al., 2018). Rating is the users' rating on the State of the DApps, which can measure applications' quality to some extent (Yin et al., 2014).

GitHub Stars is the number of "Star" on DApp's Github repositories[8]. People use "Star" to indicate that they like a project or have an interest in following what is going on with the repository later. It can be a good measurement of people's interests and attention on DApp's technological structure and update. IOS is a dummy variable, indicating with the corresponding DApp being available on Apple App Store or not, which can measure whether the DApp can be accessed through multiple ways[9]. Twitter is a dummy variable, indicating whether the DApp has a Twitter account or not, which can be a measurement of whether the DApp uses social media for advertising its content and service or not[10]. The correlation among these main variables in this study is shown in the below table (Table 2).

In total, the original dataset contains information on over 3,000 DApps, which lie in the six most popular public blockchain platforms. The data covers 38 weekly periods from June 2020 to July 2021. It is an unbalanced panel dataset since there are new DApp launching and being collected by the State of DApps. To avoid some potential bias, I drop the DApps with no active users and transactions at first.

Table 2. Correlations

	Mean	S.D.	1	2	3	4	5	6	7	8
1. log (Users)	2.6038	2.1848	1							
2. log (Transactions)	3.4626	2.7602	0.9413	1						
3. log (Development)	3.0167	2.3461	0.3528	0.2774	1					
4. Rating	0.1997	0.1240	0.1669	0.188	-0.0731	1				
5. log (GitHub Star)	2.8688	2.1588	0.333	0.2352	0.6263	-0.2509	1			
6. IOS	0.0352	0.1842	0.1232	0.1178	0.0686	0.0402	0.0134	1		
7.Twitter	0.3927	0.4883	0.0173	0.0023	0.0469	0.0176	0.0322	0.029	1	
8. Delegated	0.1758	0.3807	0.0833	0.1980	-0.1546	0.0418	-0.2384	0.1913	-0.0748	1

[8] Two similar variables are GitHub forks and Reddit members. I do not include them in the regression model since they have high multicollinearity with the GitHub star.

[9] A similar variable is whether the DApp is available on Google Play or not. I do not include it in the regression model since it has very high multicollinearity with the IOS.

[10] A Similar variable is whether the DApp has a Facebook account or not. I do not include it in the regression model since it has very high multicollinearity with Twitter.

Public blockchain platform overview

My database covers the six popular public blockchain platforms. Table 3 presents a summary of information and characteristics of these popular blockchain platforms. The current public blockchain ecosystem is like a binary market, the leader Ethereum and other followers. Ethereum[11] is the earliest public blockchain platform with the whitepaper published in 2013 and the network alive in 2015. It is also the leading platform powering the cryptocurrency Ether (ETH) and thousands of DApps covering various categories such as decentralized finance, exchanges, and games. However, Ethereum faces the scalability problem since it uses the PoW consensus mechanism. Developed by the private company block.one, EOSIO[12] (also named EOS) is usually called "Ethereum Killer" because it claims to eliminate transaction fees and launches a different consensus mechanism, Delegated Proof of Stake (DPoS), to highly increases the transaction speeds. EOS's goal is to be decentralized enough to keep the most exciting blockchain properties intact but centralized enough to achieve significantly higher performance than competing blockchain networks. Its whitepaper was published in 2017, and the network is alive since 2018. Like EOSIO, many other public blockchain platforms use the DPoS consensus mechanism, pursuing minimal transaction fees and high transaction speeds. And there are very tight relationships among these DPoS platforms. For example, Steem[13] was acquired by TRON[14] in 2020.

[11] https://ethereum.org/
[12] https://eos.io/
[13] https://steem.com/
[14] https://tron.network/

The establishment of Hive[15] was a response to the TRON takeover from the Steem community who worried about the centralized control by TRON. It was created by implementing a hard fork of the Steem code. After Hive's launch in 2020, some prominent DApps in Steem, such as Splinterland, migrated to Hive.

Table 3 Public Blockchain Platforms

	Whitepaper released	Mainnet Launched	Consensus Mechanism	Licence	Company Type	Headquarter Country
Ethereum	2013	2015	PoW	LGPL-3.0	Non-Profit	Switzerland
EOS	2017	2018	DPoS	MIT	For Profit	Cayman Island
NEO	2015	2016	dBFT[16]	MIT	Non-Profit	China
TRON	2017	2018	DPoS	LGPL-3.0	For Profit	Singapore
STEEM	2016	2016	DPoS	MIT	For Profit	US
HIVE	2020	2020	DPoS	MIT	Non-Profit	Canada

Table 4 presents an overview of DApp distribution among platforms and categories (based on cross-section data at 02/22/2021). As one of the earliest public blockchain platforms, Ethereum powers many DApps and covers multiple DApp categories. Among the following platforms, EOS and TRON are well-rounded platforms covering all different kinds of categories. However, the number of DApps built on their platforms still lags behind Ethereum a lot. Neo[17] has plenty of DApps on games, while it does not have any DApps on Gambling and High-risk. Steem and Hive have lots of famous DApps on social and games, while they do not have many DApps in other categories. For instance, Steemit, a social DApp that lies in Steem, is

[15] https://hive.io/

[16] Neo uses delegated Delegated Byzantine Fault Tolerance (dBFT 2.0) consensus mechanism rather than DPoS. However, since it is also a delegated consensus mechanism and share similar decentralized degree with DPoS, I do not differentiate in the following regression analysis.

[17] https://neo.org/

renowned for returning value to the users by rewarding them for sharing content and make users the platform stakeholders.

Table 4. DApps by Category in Main Blockchain Platforms[18]

	DEFI	EXCHANGES	GAMBLING	GAMES	HIGH-RISK	OTHERS	SOCIAL	Total
EOS	22	58	122	59	8	27	38	334
ETHEREUM	503	441	416	533	305	466	396	3,060
HIVE	3	3	1	8	0	1	32	48
NEO	3	3	0	13	0	0	3	22
STEEM	4	6	9	7	0	2	51	79
TRON	21	6	17	9	8	4	2	67
Total	556	517	565	629	321	500	522	3,610

Note: DEFI means Decentralized Finance. Other category includes energy, health, and property services.

[18] It is based on a cross sectional data at 02/22/2021.

V. Methods and Regression Results

Methods

This study uses quantitative analysis, and the specific regression model is shown in the below equation. The dependent and independent variables have been discussed in the above measurement part. θ_i is the platform control and category control. ε_{it} is the unobservable error term.

$$\begin{aligned}\log(\text{Users})_{it} = {} & \beta_1 + \beta_2 \log(\text{Transactions})_{i,t-1} \\ & + \beta_3 Delegated_i + \beta_4 \log(Transactions)_{i,t-1} * Delegated_i \\ & + \beta_5 \log(Development\ Activities)_{i,t-1} + \beta_6 Rating_{i,t-1} \\ & + \beta_7 \log(GitHub\ Stars)_{i,t-1} + \beta_8 IOS_{i,t-1} + \beta_9 Twitter_{i,t-1} + \theta_i + \varepsilon_{i,t-1}\end{aligned}$$

I start the basic analysis from the Ordinary Least Square (OLS) model. Then I use the fixed effects model to remove the potential time-invariant omitted variable bias within-group. Moreover, all the explanatory variables were lagged by one week in the analyses to deal with causality to some extent.

Results

Table 5 provides empirical support for Hypothesis 1. Model (1) is the pooled OLS regression without any constraint. Model (2) is the pooled OLS regression constrained on live DApps. Model (3) is the pooled OLS regression on live DApps, adding platform and category controlled. Similarly, model (4) to model (5) shares the same constraints using the fixed-effects model. Based on the regression results, the coefficient of transactions is positive and significant at the 99% significance level, coinciding with Hypothesis 1 that higher transaction volumes of DApps can boost their demands. To be specific, a 1% increase in daily transaction volume can arouse around 0.33% (in Model 6) increase in daily active users. For the controlled variables, the number of GitHub stars on DApps' GitHub repositories has a positive effect on DApps' adoption. This may indicate that the GitHub star is an essential reference to DApps' quality and popularity for users. Also, the rating number on the State of DApps and the number of development activities within 30 days have a significantly positive effect on DApps' adoption under the OLS model. The coefficients are positive but not significant at even the 95% significance level under the fixed-effects model. The difference between the two models may originate from the fact that the update of rating and development activities is not very frequent, thus there are not many variations.

Table 6 provides empirical support for Hypothesis 2. Model (1) is the pooled OLS regression without any constraint. Model (2) is the pooled OLS regression constrained on live DApps. Model (3) is the pooled OLS regression on live DApps, adding platform and category controlled. Similarly, model (4) to model (5) shares the same constraints using the fixed-effects model. The interaction term is negative and significant at the 99% significance level based on the regression results. This can support Hypothesis 2A because a 1% increase in daily transaction volumes will arouse around 0.351% increase in daily users for DApp in the non-delegated consensus mechanism. In comparison, a 1% increase in daily transaction volumes will only arouse approximately 0.1656% (0.3510%-0.1854%) increase in daily users for DApp in the delegated consensus mechanism. The empirical results show that at this point, DApp users may care more about transaction security and prefer to choose DApps in more decentralized platforms when they have higher transaction demand. This may originate from the following reason. Compared to normal Apps, DApps have not obtained much popularity, and the corresponding community size is minimal. They choose to use DApps since they care more about the transactions' reliability and safety, especially in some high-risk categories, such as gambling and finance. Otherwise, they can choose normal Apps which have much better transaction speed and larger community size.

Table 5. Regression Results (without decentralization interaction)

	(1)	(2)	(3)	(4)	(5)
log (Transactions)	0.7415***	0.7249***	0.7224***	0.3303***	0.3303***
	(0.011)	(0.011)	(0.012)	(0.016)	(0.016)
log (Development)	0.0559***	0.0485***	0.0514***	0.0173	0.0174
	(0.010)	(0.010)	(0.010)	(0.020)	(0.020)
Rating	0.4639***	0.5793***	0.4677***	0.0641	0.0649
	(0.135)	(0.136)	(0.142)	(0.233)	(0.237)
log (GitHub Star)	0.1161***	0.1346***	0.1028***	0.1490***	0.1489***
	(0.014)	(0.014)	(0.015)	(0.040)	(0.040)
IOS	0.0786	0.1070*	0.1165*		
	(0.063)	(0.064)	(0.068)		
Twitter	0.0993*	0.0977*	0.0825	0.0536	0.0557
	(0.055)	(0.055)	(0.055)	(0.037)	(0.038)
Constant	-0.6228***	-0.6496***	-0.8356***	1.2263***	1.2193***
	(0.078)	(0.081)	(0.181)	(0.214)	(0.219)
Live DApps	No	Yes	Yes	No	Yes
Platform, category controlled	No	No	Yes		
N	2545	2464	2464	2545	2464
R^2	0.8203	0.8077	0.8213	0.7860	0.7752

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Regression Results (with decentralization interaction)

	(1)	(2)	(3)	(4)	(5)
log (Transactions)	0.7802***	0.7789***	0.7691***	0.3509***	0.3510***
	(0.010)	(0.010)	(0.011)	(0.017)	(0.017)
Delegate	0.2982**	0.3979***	0.6673***		
	(0.138)	(0.129)	(0.159)		
Interaction	-0.1062***	-0.1619***	-0.2157***	-0.1855***	-0.1854***
	(0.023)	(0.021)	(0.024)	(0.050)	(0.051)
log (Development)	0.0576***	0.0480***	0.0557***	0.0165	0.0165
	(0.010)	(0.010)	(0.010)	(0.019)	(0.020)
Rating	0.3305**	0.4184***	0.4553***	0.0643	0.0651
	(0.138)	(0.141)	(0.142)	(0.232)	(0.236)
log (GitHub Star)	0.0856***	0.0931***	0.0782***	0.1485***	0.1484***
	(0.013)	(0.013)	(0.015)	(0.039)	(0.040)
IOS	0.1487**	0.2445***	0.1135*		
	(0.067)	(0.068)	(0.059)		
Twitter	0.0963*	0.0863	0.1055**	0.0513	0.0534
	(0.054)	(0.054)	(0.054)	(0.037)	(0.038)
Constant	-0.5758***	-0.5775***	-0.5551***	1.2726***	1.2503***
	(0.078)	(0.081)	(0.086)	(0.214)	(0.219)
Live DApps	No	Yes	Yes	No	Yes
Platform, category controlled	No	No	Yes		
N	2545	2464	2464	2545	2464
R^2	0.8273	0.8213	0.8323	0.6567	0.6857

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

VI. Conclusion and Discussion

Conclusion and Contributions

Although blockchain has sparked broad research interests in economists and management scholars, most of the prior blockchain research in economics and management mainly constrains in the cryptocurrency and finance sector and use broadly theoretical analysis without any empirical support. Little is known about public blockchain platforms and DApps. To fill up this gap, this study provides an empirical analysis of blockchain platforms and their built-on DApps. To be specific, this research focuses on the driving forces of DApps' adoption. With the empirical test over six popular public blockchain platforms and their built on DApps, this paper finds that transaction volumes positively impact DApps' adoption. More importantly, under the tradeoff between decentralization and scalability, it further points out that higher transactions will boost users to choose DApps in more decentralized platforms.

This study may contribute to the current literature and studies in the following perspectives. First, it goes beyond blockchain technologies' implications on cryptocurrency and the finance sector and examines the public blockchain from the platform perspective. Second, it provides a descriptive analysis of the public blockchain platforms and DApps, including their similarities and differences with centralized platforms and Apps. Also, it sheds light on how transactions can be an essential driving force of DApps' adoption and explain how the underlying platforms' degree of decentralization, the unique feature of blockchain, affects the above relationship. Third, it provides quantitative analysis using the sample of DApps in six public blockchain platforms, which provides a potential direction for future quantitatively empirical analysis in blockchain technology.

Limitations and Extensions

Some of the limitations of this study can suggest directions for future research. First, this paper only considers the public blockchain platform, while the private blockchain platforms are also worth investigating. Many technology giants and banks have invested a lot in their private blockchain applications and service, stimulating potential business innovation in blockchain technologies. And it would also be interesting to compare some top applications in public blockchain platforms and private blockchain platforms separately. Second, this study uses the consensus mechanism as the measurement of decentralization degree. Although the consensus mechanism can be an essential technical measurement in the platform level, other dimensions of decentralization degree should also be considered for a much more fine-grained measurement. For example, mining power, community participation, and network structure can also affect the public blockchain platform's decentralization degree (Gencer et al., 2018). With a better measurement of the degree of decentralization, it could help to clarify the concern that other characteristics of Ethereum drive the differences in adoption. Third, this research does not differentiate different types of DApps in the theoretical analysis while these supply factors are also important for explaining the product adoption (Stoneman and Ireland, 1983). Different DApps may have different approaches to storing transactions on their underlying blockchain platforms. More specifically, some DApps record every transaction that occurs within their DApps. But some DApps use their underlying blockchain platforms to record asset transactions, and other activities within their DApps are managed through a centralized database. This kind of character may affect user's choices. Also, addressing more information from the developer side, especially the heterogeneities of publishers or developers' background of DApps, can help better understand the motivations or goals of their DApps and thus sperate different kinds of DApps. For instance, it would be helpful to figure out whether developers originate from non-profit organizations or for-profit organizations and whether the developers are sponsored or supported by the platforms. Fourth, the generalization of this study's conclusions can be challenged since the scale of transactions in the current public blockchain ecosystem is relatively small. If the transaction volumes are large enough in the future, the scalability problem might cause PoW platforms to suffer. Or otherwise, DApps can only provide service requiring low transaction volumes in the future. Also, a critical concern here is that Ethereum DApps can be an outlier. I rerun the regression with Ethereum DApps and non-Ethereum DApps separately, and find that Hypothesis 1 can still be validated but the magnitude of coefficients indeed vary.

There are a couple of potential extensions for future studies with the development of a more fine-grained database and further understanding of blockchain in economics and management. First, though this study uses a fixed-effect model to test the hypotheses empirically, potential endogenous problems may still exist. For instance, there might exist reverse causality between the number of active users and the number of transactions. Since the pubic blockchain ecosystem is still nascent stage, no obvious external shocks can be used to build up a more robust identification method yet.

However, since the public blockchain platforms have been paid much more attention, some potential external shocks, such as a disruptive new entrant, big technical transition of a given platform, can play a significant role in future studies' empirical settings. For instance, Ethereum has started implementing the Ethereum 2.0 update, which includes a transition to Proof of Stake (PoS) and an increase in transaction throughput to make Ethereum more scalable and sustainable. Second, to better understand both the inside and outside of DApps, it would be helpful to conduct multiple interviews with blockchain platform developers, DApp developers, DApp website technical staff, DApp users, and computer scientists in various ways. I have tried to reach out to some DApp developers, DApp website technical staff, and computer scientists via email and Twitter message and obtained plenty of great suggestions and opinions. But the scale of interviewees is still minimal, and the sampling is not very standardized. Third, future researchers can figure out ways to track more detailed platform-level and DApp-level data as the market grows rapidly. For instance, some transaction-related variables, such as the number of smart contracts on each platform, can be directly from the blockchain explorer of each platform, providing the most thorough information of transactions on each platform. Also, additional DApp-level information, such as the revenue of each DApp, can be helped to identify killer DApp (Li et al., 2016; Yin et al., 2014).

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