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Blockchain-based platforms: decentralized infrastructures and its boundary conditions

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ABSTRACT

Blockchain technology has been receiving much public attention recently, promising to disintermediate transactions through a decentralized governance and a distributed data-infrastructure. However, the majority of the previous studies have focused on the technical aspects, and overlooked blockchain investigation from a managerial perspective. In this paper, based on platform-ecosystem, transaction cost economics, and open-source literature, we contrast and compare blockchain-based platforms and centralized platforms; in other words, decentralized versus centralized governance of the platform. We base our conceptual analysis on three dimensions—transaction cost, cost of technology, and community involvement—, exploring the conditions under which blockchain-based platforms are more advantageous than centralized platforms. We, first, compare gains from lower opportunism and uncertainty thanks to protocols and smart contracts in blockchain technology versus costs of higher coordination and complexity of (re)writing those contracts. Second, we compare gains from immutability and transparency in blockchain-based platforms versus the technological cost of verification and distributed ledger infrastructure. Finally, we compare intrinsic and extrinsic motivations of community around centralized and blockchain-based platforms to participate and different mechanism involved, i.e. pricing mechanism in the former and crypto-incentives in the latter.

Keywords: blockchain technology; platform ecosystems; decentralized governance; transaction cost economics; smart contracts

1. Introduction

Despite the hype around blockchain technology, the main attempts to understand such technology has been mainly restricted to the technical aspects of the blockchain protocols and foundations, or the finance of crypto-currencies such as Bitcoin (Risius and Spohrer, 2017). Nonetheless, implications of the blockchain technology reach far beyond the financial system (e.g., De Filippi, 2017; Li *et al*., 2017). Consensus protocols, smart contracts, cryptography, and distributed ledgers allow for secure, immutable, transparent, and often cheaper transactions, which can be applied to a variety of contexts (Tschorsch and Scheuermann 2016; Halaburda, 2018). As a consequence, various digital platforms and start-ups have started adopting blockchain technology for micropayments, storage system, intellectual property, financial and physical assets, supply chain and logistics, social networks, media and open science amongst others applications (Li *et al*., 2017; Davidson, De Filippi, and Potts, 2018).

A broader understanding of blockchain and its peculiar attributes, from organisation and management perspective, is less explored (Constantinides, Henfridsson, and Parker, 2018; Risius and Spohrer, 2017). Filling this void, we build on platform governance, transaction cost economics, and open source communities literatures to investigate the costs and benefits of adopting blockchain technology as a decentralized platform infrastructure, exploring the boundary conditions and the trade-offs involved. Blockchain technology enables the property rights transfer and exchanges built upon decentralized governance and distributed data infrastructure (Catalini and Gans, 2017), in opposition to centralized platforms that present centralized governance and data infrastructure (e.g. Adner and Kapoor, 2010; Jacobides, Cennamo, and Gawer, 2018; Tiwana, Konsynski, and Bush, 2010). Thereby, we contrast and compare the centralized versus decentralized governance mechanisms, as in (conventional) centralized platforms and blockchain-based platforms, respectively to understand under which conditions are blockchain-based platforms more advantageous compared to centralized platforms.

Decentralization of governance and data-infrastructure in blockchain-based platforms (Halaburda, 2018) can to a certain extent mitigate centralized platforms inherent problems, such as a higher bargaining power for the platform sponsor, lock-in effects, censorship, data leakage, expropriation, and privacy risks (Catalini and Gans, 2017). Thereby, we discuss conceptually, how the promising properties of blockchain may, in turn, cause other challenges such as coordination and complexity problems, and high cost of verifying and storing transactions in absence of a third party. We categorize the benefits and costs arising at different levels pertaining to transaction costs, technology costs, and community involvement. Based on these three parameters, we propose a framework to circumscribe the boundary conditions for adopting blockchain-based platforms vis-à-vis centralized platforms. We, first, contrast the lower transaction cost associated to reduced opportunism and uncertainty with the higher coordination and complexity costs of changing rules for the blockchain platform when contracts need to be amended (i.e., in situations when uncertainty is higher). Second, we show that while blockchain technology provide benefits resulting from immutability and transparency (i.e. temper-resistance, and fraud prevention, cost of auditability) it can be too costly at both verification and storage levels. Lastly, we also show how blockchain-based platforms leverage on intrinsic and extrinsic (crypto-incentives and reputation effects) benefits to attract participants, in opposition to centralised platforms that mainly leverage extrinsic benefits.

Our paper contributes to the emerging, yet nascent, body of literature about the potential and limitation of blockchain technology (see Risius and Spohrer (2017) for a recent review of the previous studies). In particular, we provide an early answer to the question "how does blockchain technology address misaligned incentive structures and trust currently faced by digital platforms?" (Constantinides et al., 2018; p. 11). This paper explores the costs and benefits of blockchain-based platforms, drawing the boundary conditions of its applicability. The adoption of blockchain technology is not only a question of technology cost (see Catalini and Gans, 2017), which is rapidly decreasing, but is also a question of governance costs. This paper aims at exploring the tipping point of the trade-off between the cost and benefits of technology and governance modes to answer the question: "under which conditions shall transactions be conducted in blockchain-based platforms in contrast to centralized platforms?"

Before we explore when blockchain-based platforms are more advantageous than centralized platforms, we briefly explore the differences between centralized and blockchain-based platforms across governance and data-infrastructure dimensions.

2. Theoretical foundations

2.1. Centralized Platform governance

Platform ecosystems are increasingly dominating the business landscape. The so-called FAANG companies (Facebook, Amazon, Apple, Netflix, and Google), the "motors of S&P 500"[1], are only few infamous examples of platform ecosystem, which is a prevalent model, especially in digital industries, from smartphones, videogame consoles, media-based and video-on-demand portals, to Internet of Things (IoT) platforms and wearable devices. In these ecosystems, usually, a central firm sponsors the core components and interface upon which third-party firms (i.e. complementors) develop and offer their complementary products (i.e. complements) to the end-users (e.g., Adner and Kapoor, 2010; Jacobides *et al.*, 2018; Tiwana *et al.* 2010). The platform sponsor (e.g., Apple), at the core of the ecosystem (e.g., iOS App Store), facilitates the interaction between the complementors (e.g., app developers) and users

[1] See here: https://www.economist.com/business/2018/08/04/the-tech-giants-are-still-in-rude-health

(e.g., mobile users), for instance by reducing the search cost; it also provides complementors with a common set of technology, boundary resources (e.g., APIs and SDKs), and marketing capabilities (e.g. featured apps and top charts) (Ghazawneh and Henfridsson, 2013). Complementors, benefiting from participation and co-specialization in the ecosystems, build their product offering, hence creating value for the ecosystem and platform users (Ozalp Cennamo, and Gawer, 2018). There is also an indirect network effect between the users and complementors; users are better off by a high rate of complementors' participation (thus, complements variety), and vice versa (e.g., Parker and Van Alstyne, 2005).

Accordingly, a sustained rate of co-specialised innovation and product offerings by complementors intertwined with growth in platform adoption by users are pivotal for the platform success and survival. The platform sponsor, therefore, should apply appropriate governance mechanisms to motivate third-party firms to join the ecosystem and make investment, orchestrate the innovation process, regulate the access and interaction among users and complementors (Boudreau and Hagiu, 2009), enhance the network effect and attract users— in a nutshell, to manage the value co-creation and value capture processes within the platform ecosystem (Ceccagnoli, Forman, Huang, Wu, 2012).

The primary mechanism, which has been studied in a vast body of literature (e.g., Rochet and Tirole, 2003; Weyl, 2010), is the pricing structure. The decision about fixed membership fee and/or per-transaction fee and, cross-subsidisation pricing strategy are among the essential pricing structure decisions to manage the platform ecosystem (Rochet and Tirole, 2006).

An array of non-pricing instruments also exists for platform governance, such as exclusivity contracts with certain complementors (e.g., Cennamo and Santalo, 2013), platform sponsor decision to develop in-house complements, i.e. entry to the complementors market (e.g., Gawer and Henderson, 2007), the quality assurance and certification for the complementors and their products, or designing the entry rules. The last one, perhaps the most-studied topic in non-pricing governance mechanism, pertains to the platform openness (e.g., Boudreau, 2010; Eisenmann, Parker, and Van Alstyne, 2009; Parker and Van Alstyne, 2017) and the extent to which the platform applies exclusion/restriction policies for complementors to affiliate with the ecosystem. This openness can occur (vertically) at the complementors' level, at users level, or (horizontally) at the hardware and technology interface level. It can also be even deeper at sponsorship and governance level (Eisenmann *et al.,* 2009). For instance, Apple is less open than Google concerning the complementors' entry to the app store. Also, while Android is an open platform to various hardware developers (such as Samsung, HTC, etc.), iOS has remained closed to only Apple's iPhone. On the other hand, open software such as Linux are almost open platforms even to at the governance and design rule level. This is directly related to the concept of proprietary versus shared platform. The former is when the core functionality of the platform is under the control of a single sponsor (as in the case of Apple), while in the latter the platform sponsorship is shared collectively (e.g., Linux open software or Visa owned by an association of several banks). Later, we discuss more both the regulatory role of the platform and the right degree of openness in the "boundary conditions" section.

2.2.Blockchain-based platform

The blockchain technology encompasses the protocol that defines the main rules that will govern the platform functioning and the data infrastructure, and smart-contracts, which are self-executing contracts that enables automated transactions (Buterin, 2015; Davidson, De Filippi, and Potts, 2016a). In this section, we will compare Blockchain-based platforms' governance and data infrastructure with centralized platforms.

Blockchain-based platforms, either proprietary or non-proprietary, tend to present a decentralized decision-making in which the community around the platform not only suggests changes to the code and rules of the platform (by committing to codes usually in GitHub) but also decides which of these changes will be implemented through forums, discussion groups, or voting systems. For example, Satoshi Nakamoto launched the Bitcoin protocols (which also encompasses the blockchain technology itself) to the community, and nowadays the community around Bitcoin maintain the protocol, and decide about the directions of the technology through soft and hard forks of the code (Böhme *et al.*, 2015). Some proprietary centralized platforms have also initiated open source movements, as is the case of Android; however, while community members can make suggestions to amend the code, they are not able to decide which suggestions are actually implemented. The decisions about the future direction of the platform, which coincide with its technology components and interface, are centralized in the proprietary in centralized platforms in a censored open source fashion.

The entry rules determine who is allowed to participate in the platform, being related with the degree of the platform openness in opposition to censoring. Centralized platforms often directly regulate the access and membership, requiring users and complementors' authentication (Boudreau and Hagiu, 2009). Despite recent variations, blockchain original conception relies on freely open membership, also known as permissionless blockchain. In this sense, blockchain-based platforms are both horizontally open (at infrastructure technology and interface level) and vertically open (at complementors and users level) (Eisenmann *et al.*, 2009).

Blockchain-based platforms also differ from centralized platforms regarding verification processes, which obey to 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-based platforms, an independent pool of validators verify the transactions (known as miners in the Bitcoin blockchain). These validators need to follow a consensus mechanism based on peer-to-peer cryptographic verification process to be able to validate blocks of transactions, creating a secure, immutable, transparent, time-stamped public ledger (Davidson *et al.*, 2018). Validators follow a verification mechanism that allows to reach consensus about which transactions are true and eligible to be added to a block of transactions, which itself linked to the previous block, forming a continuous chain back to the original first block of all (Davidson *et al.*, 2018). Blockchain, thus, enables a trustless verification system that does not require a third party to verify transactions. Instead, it applies a verification system to ensure consensus among users about the true state of the ledger, fuelled by crypto-incentive to involve validators in a disintermediated verification process (Davidson *et al.*, 2018).

Decentralization of decision-making and verification processes require high levels of participation of the community around these platforms either by producing, consuming, voting, coding or verifying transactions. Crypto-incentives fuels such participation, encompassing crypto-tokens and cryptocurrencies. Crypto-incentives are blockchain fungible and tradable assets able to be exchanged inside the platform to buy complements or converted into other crypto-currencies or fiat currencies (such as USD or EUR) outside the focal platform. Blockchain community members can acquire crypto-tokens or cryptocurrencies through Initial Coin Offers (ICO), crypto exchanges, or instead, earn them by performing some activities inside the platform. The crypto-incentives fuels participation and verification of transactions, securing the maintenance of the platform (Davidson *et al.*, 2018). The crypto-incentives in blockchain-based platforms, equivalent to pricing structures and non-pricing instruments in centralized platforms, function as a coordinating mechanism which is essential to attract users, complementors, developers, and validators; hence, boosting the network effects.

Apart being a new paradigm for governance (i.e. at protocol or application stack), blockchain technology at the infrastructure level (mainly ownership and accessibility) is also fundamentally different when compared to centralized platforms. While in centralized platforms, the platform sponsor owns and control the access to data, in blockchain-based platforms, the ledger of transactions, which stores the history of all transactions, is stored in many locations simultaneously in a distributed fashion (Nakamoto, 2008). As the distributed ledger is replicated across the network nodes, if there is any attempt of a node to falsify a transaction (double spend), the moment that this node ledger is checked against all the other nodes' copies, the falsification is spotted and automatically corrected. This redundancy of information, along with the verification mechanism described earlier, ensures security, immutability, and transparency of transactions (Atzori, 2015; Risius and Spohrer, 2017).

Blockchain-based platforms are based on decentralized governance and data infrastructure, which allows marketplace agents to transact directly with each other without the need for a trusted intermediary (Catalini and Gans, 2017; Nakamoto, 2008; Davidson *et al.*, 2018). Blockchain-based platform, thus, represent an extreme case of "openness" with decentralized governance and a distributed data infrastructure able to disintermediate transaction. Such disintermediation can reduce transaction costs (Halaburda, 2018) and failures inherent to centralized platforms, such as lack of transparency, corruption, coercion, censorship, and excessive market power (Atzori, 2015; Catalini and Gans, 2017). Table 1 summarizes the above mentioned characteristics of centralized versus blockchain-based platforms.

Table 1. Main characteristics of blockchain-based platform versus centralized platform

Platform dimensions		Centralized platforms	Blockchain-based platforms
Governance	Decision-making	Centralized (platform owner take decisions)	Decentralized (community democratically take decisions about the future of the platform)
	Entry rules	Always Permissioned	Permissionless
	Verification of transactions	Centralized	Decentralized
	Incentives	Pricing mechanisms	Crypto-incentives
Data infrastructure	Ownership	Proprietary	Distributed
	Accessibility	Private access	Public access
Examples		Facebook, Amazon, Apple, Netflix, and Google	Steemit, Bitcoin, Ethereum

3. The boundary conditions: blockchain-based platforms vis-à-vis centralized platforms

Scholars defend that blockchain has the potential to improve productive efficiency of some economic operations, moving them closer to a peer-to-peer ideal (Davidson *et al*., 2018). The answer to the question why some transactions occur in blockchain-based platforms rather than in centralized platforms is because blockchain-based platforms can reduce transaction and technology costs, and foster community involvement, in comparison to centralized platforms. Yet, these advantages can be offset by some shortcomings such as higher coordination, complexity, verifications and storage costs, and lower intrinsic benefits in the medium-term. Building on these costs and benefits, we propose three main boundary conditions under which adopting blockchain-based platforms is more beneficial than centralized platform. We discuss each of these conditions as follows.

3.1. Transaction costs and smart contracts

Transaction cost economics (TCE) focuses on “transactions and the costs that attend completing transactions by one institutional mode rather than another” (Williamson, 1975: 1–2). In particular, it focuses on the relative efficiency of organizing through markets, hybrid forms, or hierarchies, with the main unit of analysis being a transaction (Williamson, 1985). This theory predicts that organizations choose the most efficient (TCE economizing) way of organizing depending on the nature of transactions. Guided by two assumptions of uncertainty and opportunism, three factors regarding the nature of transactions determine the choice of organization in TCE: asset specificity, uncertainty, and frequency. Asset specificity relates to the nature of investments in the transaction–if some assets that are required for the particular transaction cannot be used elsewhere without loss of (significant) productive value, then the asset specificity and the bilateral dependency between parties is high, which makes contracting through markets hazardous. Uncertainty relates to the ex-ante haggling and ex-post bargaining, and affects transactions only when there is some nontrivial level of asset specificity (David and Han, 2004). In those conditions with some asset specificity, as uncertainty rises, market becomes a less economic way of organizing compared to firms. Frequency is the last dimension, and it relates to the need of monitoring the transactions – as frequency increases, more resources required for monitoring the transactions in a market, and therefore hierarchical firm represents a better alternative when transaction frequency is high.

Uncertainty and opportunism relate these factors in different ways. Asset specificity is generally the stronger element in determining organization choices, and it is closely connected to opportunism. Although not everyone will be opportunistic, there is always the risk of opportunism – or as Williamson (1975) puts it forward "self-interest seeking with guile". On the other hand, uncertainty is more related to the bounded rationality – the fact that humans have "limited information, attention, and processing ability" (Simon, 1945), which gives rise to contractual incompleteness.

Blockchain, as a technology is quite relevant to approach from a TCE perspective as the technology itself has the purpose to disintermediate transactions, reducing transaction costs associated to opportunism and uncertainty. Blockchain-based technology encompass the protocol and self-executable smart contracts, which trigger transactions automatically under certain conditions (Iansiti and Lakhani, 2017). The fact that the protocol and the smart contracts are defined *ex-ante* and that smart-contracts are automatically triggered reduces opportunism in transactions (Davidson *et al*., 2018), especially relating to *ex-post* hold-up costs across parties in a transaction. Smart contracts also reduces transactions' uncertainty regarding information problems (Davidson *et al*., 2018) as the contract automation guarantees that under certain conditions the output will be the same and irreversible (see Williamson (1973), for sources of transactions uncertainty). In this sense, the degree of uncertainty about the execution conditions and output of a certain transaction decreases, reducing the transaction costs. Additionally, the cost of writing the protocol and smart-contracts is spread by the amount of transactions that on the limit can present an infinite frequency due its automated nature (Davidson *et al*., 2016a). Finally, as the blockchain technology suppresses the need for an intermediary— the traditional platform owner — contributes also to mitigating the hold-up risk caused by intermediary agent itself that could intervene in the transaction in order to realize individual gains through lack of candor or honesty (Davidson *et al*., 2016a; Williamson, 1973).[2]

The blockchain, however, generally require complete contracts as they get executed under certain conditions without intermediaries (therefore require full extent of contingencies), as opposed to companies that exist as a nexus of incomplete contracts (Wright and De Filippi, 2015; Davidson *et al*., 2016a; Hart and Moore, 1990). Nevertheless, some blockchain-based platforms are able to offer services usually performed by traditional firms. One example is Bitcoin that up to a certain extent replaces banks, and another is Steemit, which is a public blockchain-based platform for content generation, equivalent to Facebook. Blockchain-based platforms are able to substitute centralized platforms for the transactions that can be rendered

[2] However, it is important to note that ex-ante and ex-post bargaining and renegotiation costs may not be eliminated with blockchain (Davidson et al., 2016a)

as complete contracts, lowering the transactions cost for such activities through irreversible, transparent, and automated codes of contracts (Davidson *et al.*, 2018). Therefore, it is reasonable to admit that we do not need banks to perform certain types of transactions anymore, because such transactions are easy to parameterize and perform through Blockchain protocols; however, if you look for advice on specific financial assets and a customised treatment, which is a difficult transaction to parameterize, one might recur to traditional banks.

In sum, blockchain-based platforms, which rely on smart contracts and publicly available distributed ledgers, can replace centralized platforms when contracts are (quasi-) complete by reducing transaction costs related to opportunism and uncertainty.

There is, however, an additional set of costs that blockchain incur relating to coordination (Arrunada and Garicano, 2018) and complexity. Blockchain transactions are irreversible, being highly inflexible and restrictive in their nature. When consumers have a contract with a bank that takes care of their money, they incur the risk of misuse of their money and data, but they also expect a customised attendance based on their needs and some degree of irreversibility in case there is a mistake in a transaction or if the money get stolen. In blockchain, as the protocol and smart contracts are restricted to a certain amount of operational conditions that tend to be more standard than customised, it is unlikely that the contract predicts all contingencies, as unintentional mistake. Ultimately, as the full code, including protocol and smart contracts, is open source, new conditions could be inserted into machine-readable contracts that can indeed be altered in the future. Davidson *et al.* (2016b, 2018) defend that the complexity cost of improving or changing contracts would scale linearly, and transaction costs lowered. However, this view ignores that coordination costs increase in a growing open community as everyone can suggest changes in the code and have voting rights. Such level of coordination include key issues in blockchain-based platforms that lead communities to split-up through “hard forks” lead by minorities and inertia caused by the expectation of split up or not getting the required number of votes for the change (Arrunada and Garicano, 2018). This is the point when communities engage on extensive and intractable discussions. Community split-ups and inertia lead to inefficient outcomes, which we highlight as an increased coordination cost (Arrunada and Garicano, 2018).

Contractual changes in blockchain-based platforms increase complexity and coordination costs not only at the community level but also at a technological level. Davidson *et al.*'s (2018) argument that open databases allows for reduced costs of writing contracts is simply not feasible. Increasing complexity, by adding contingencies to the protocol or smart-contract, may cause big issues at the code level, as code bugs often lead to security breaches. For example, such problems led Decentralized Autonomous Organization (DAO) to be hacked, what eventually required a "hard fork" on the system, overriding the irreversibility principal and causing internal turmoil (Arrunada and Garicano, 2018). Such increasing code complexity can force transactions to have lower number of conditions. This then suggests that the addition of conditions to protocol and smart contracts exponentially increases costs due to increase of security and uncertainty costs, which we call complexity costs.

In sum, blockchain-based platforms can handle (quasi-)complete contracts with lower opportunism and uncertainty costs, therefore providing a transactions cost advantage. Yet, blockchain-based platforms get costlier when coordination and complexity is an issue (e.g., platforms with a massive number of members), mainly when high incompleteness requires too many conditions to enact transactions.

P1: When gains from reduced opportunity and uncertainty costs outweighs the losses from increased cost of coordination and complexity, the blockchain-based platforms are more advantageous than centralized platforms.

3.2. Cost of Technology and verification mechanism

Not only can blockchain reduce the transaction cost, but it may also lessen the initial building and ongoing activity costs directly related to the technology. Efficiency also comes from deleting layers of activity that are no longer needed because trusted third party is not required anymore (Davidson *et al.*, 2018). A central intermediary platform for securing the transaction, generating trust, and maintaining the data can open up the risk of data breach, privacy risks, and censorship risk (Catalini and Gans, 2017). Blockchain, by alleviating these risks and vulnerabilities, can be productivity enhancing. Yet, like other new technologies, blockchain, while beneficial in some dimensions and materializing previously non-existent opportunities, may suffer from drawbacks and inefficiencies on some other dimensions.

We classify the cost (dis)advantages of blockchain technology in two categories; first, at the protocol and application level. For example, blockchain enhances efficiency of international money transfer via omitting the cost of intermediation, process, and verification (Catalini and Gans, 2017). Each transaction (be it financial as in Bitcoin or other types of transaction such as property transfers) to be added to the chain of existing blocks needs to go through a verification process and consensus mechanism (such as the proof-of-work). The proof-of-work involves solving a randomized mathematical puzzle which is complicated to solve but easy to verify by other nodes of the peer-to-peer network. The validators of the blockchain (also called operators or miners) compete with each other to solve this puzzle which generates a number, called a hash, to encrypt and *seal* the blocks of the recent transactions. Upon verification of the hash value by other nodes, the new block will be attached to the blockchain. Each block contains the hash value of its own as well as that of the previous block; hence, the blocks are linked securely to each other.

Manipulating a single piece of information in the blockchain not only requires to generate a new hash for the given block; it also needs to alter all the consequent blocks′ hashes, so that no one can detect the break in the chain, a task which is nearly impossible in practice (e.g., Böhme, Christin, Edelman, and Moore, 2015). This protocol makes the information stored on the blockchain tamper-proof and immutable without any need to a central intermediary or a trustable third-party. This disintermediation, therefore, cuts the fee that would have been charged by the intermediary for conducting the transactions and operating costs of such platforms, and mitigates the risk of double-spending, data manipulation, and cost of auditing, amongst others, all of which has been called as cost of verification by Catalini and Gans (2017). They argue that blockchain technology makes a *costless verification* possible.

However, the real picture is not as promised above. The consensus and verification mechanism, which guaranties the immutability and transparency of the stored transactions, hence generating trust via protocol and codes without a need to a trustable party, inherits some restrictions. For instance, conducting transaction via Bitcoin network is still slower and less efficient than Visa or PayPal (Davidson *et al.*, 2018). In fact, the potential throughput in the Bitcoin is up to seven transactions per second, compared to two thousand transactions per second in Visa (Yli-Huum, Ko, Choi, Park, and Smolander, 2016). Moreover, the proof-of-work is indeed an energy consuming and capital-intensive task. It can cost "approximately $178 million per year at average US residential electricity prices" (Böhme *et al.*, 2015: 218). In fact, to keep the immutability of the blockchain the effort (time, energy, computing power, etc.) required for proof-of-work should remain difficult and costly enough, despite any feasible increase of computing power of the validators. Thus, the technological cost of verification and immutability of the blockchain are intertwined.

The second category of technology cost of blockchain-based platforms is related to the infrastructure (i.e. the bottom stack upon which protocols, tokens, and applications are built).

In the case of centralized-platforms, a single entity sponsors and owns the infrastructure stack or core of the platform while keeping the components to the complementors to develop. Conversely, in the blockchain-based platforms, as a distributed leger, the records of all transactions are stored on all the nodes of the network (i.e. users of the platform). In other words, the core of the platform is not owned by a single sponsor but shared and distributed across the users. As a copy of every piece of information is available on each node, the data hack and failure become even more difficult (on top of difficulties due to verification and consensus mechanism) and easily detectable. The double storage of data also provides the nodes of the network with transparency. On one hand, the more nodes have trace of the data; the data becomes more tamper-proof. On the other hand, scaling up the network means participation of more users with an access to the transaction data and ability to (dis)validate transactions. The blockchain protocol as a "trust machine"[3] does not rely on the trustworthiness of the users; however, the possibility of misconduct and fraudulent attempt cannot be excluded. Scaling up, for example being a entirely public platform without any entry rules, can increase the likelihood of misconduct, which creates diminishing returns to trustworthiness or deterioration of "peripheral trust" (Evans *et al*., 2016). These two opposite forces foreground a scalability trade-off for the platform—it is more difficult to fool many; yet, the probability of cheating increases with being open to many.

Additionally, distributed ledger brings cost savings by replacing the central servers and infrastructures with a peer-to-peer network. Yet, duplicating all records and updates of the data can makes the reconciliation and integrity of the ledgers slower and more costly, which deteriorate exponentially as the size of the network increase, which puts additional restriction to the scalability of blockchain-based platforms.

[3] See here: https://www.economist.com/leaders/2015/10/31/the-trust-machine

Finally, the cost advantage of blockchain technology is accentuated if the assets in transfer are purely digital, an ideal example of which is the Bitcoin. However, when the transactions represent some offline or physical entities (such as the usage of blockchain in supply chain or real estate sector) both the verification and storage become more costly, i.e. less technological cost advantage at both protocol/application and infrastructure stacks. There should be a reliable link between the digital record and the corresponding event in the physical world, which necessities the existence of some trustable parties (which are called oracles), without which the blocks may be a secure and immutable record of merely some *fake* assets/incidents (Catalini and Gans, 2017). Keeping a strong link between the two and solving this gateway problem (Halaburda, 2018) increases the cost of verification (i.e. multiple parties and agreed rules to verify the data entry and authenticity of the link) and/or the cost of infrastructure and storage (i.e. hardware devices such as GPS, RFID, or internet of things to substantiate and store the online record of the offline world).

Proposition 2. When the gains from immutability and transparency of transaction outweighs the losses from increased technology cost of verification and storage, the blockchain-based platforms are more advantageous than centralized platforms.

3.3. Community involvement and crypto-incentives

We have not yet discussed the role of the collective of individuals that build and sustain blockchain-based platforms. Similarly to other online communities, specifically open source communities, in blockchain-based platforms, the community encompasses individuals who communicate, interact, and develop relationships, in order to collectively attain a common goal through an IT-supported virtual space (Lee, Vogel, and Limayem, 2002; Preece, 2000; Tardini and Cantoni, 2005). The main distinction between an open source community and a blockchain community is that the latter comprehends a broader range of roles for the individuals. Precisely, communities around blockchain-based platforms do not only include the end-users that consume complements and the producers of those complements (complementors), but also the *developers,* which contribute through code and commits to the maintenance of the platform interface and components, and *validators*, which verify transactions and register them on the distributed ledger. Additionally, all individuals across these different groups can vote or decide for or against implementing changes in the platform in a decentralized and "democratic" fashion. This rationale is aligned with Davidson and colleagues (2016a) suggestion that blockchain forms *constitutional* communities around the platform.

The idea of collectives of people coordinating to achieve common goals beyond the boundaries of the firm is not new; indeed, there is a long history of users and communities as important drivers of innovative activity and new organizational forms (O'Mahony and Lakhani, 2011; Rao, Morrill, and Zald, 2000). The example of Apache, Linux, and Wikipedia, amongst others, show that collectives that communicate and engage in repeated interactions can efficiently coordinate to create socio-economic value (Benkler, 2017). Those individuals share not only similar needs, concerns, passion and interests, acting collectively in order to meet these needs (see Felin, Lakhani, and Tushman, 2017; Preece, 2000; Tardini and Cantoni, 2005; Wenger, 2011), but they also share values and beliefs (Preece, 2000; Tardini and Cantoni, 2005), which guide the way activities are conducted in those organizations. Indeed, many crowd and community-based organizations are considered social movement entities (Felin *et al.*, 2017) that present strong political, social and even revolutionary ideological aspirations where goals, values and beliefs are intermingled (Stallman, 2002). For example, on Steemit, a blockchain-based public content platform, community members have the common need to consume or produce content in a certain topic, sharing the belief that community members must appropriate the value of their contributions in producing, promoting, and curating content for others. These values and beliefs oppose the ones of similar platforms as

Reddit, Facebook, and Twitter (Steemit Whitepaper, 2018), in which the platform owner appropriates the value created by users and producers.

Research on open source communities reveals that participants' motivation intrinsically relates to the nature of the community activities. For example, activities that satisfy a need, fulfill values and beliefs, and have a self-rewarding nature, which encompasses intellectual stimulation, new skills development, and making a positive difference (Lerner and Tirole, 2002; Villarroel and Tucci, 2010). Such intrinsic motivation feed volunteers participation, cooperation, and coordination around a project and a common goal, sharing their knowledge without, in most of the cases, subjacent direct pecuniary incentives (Amabile, 1983). Having said that, in addition to intrinsic motivation, open source communities also enact reputation mechanisms, through which members get recognition, respect, and status among peers, what can translate in future rents in terms of improved job opportunities (Dahlander and Magnusson, 2005; Franke and Shah, 2003; Lakhani and von Hippel, 2003; Lee and Cole, 2003; von Hippel and von Krogh, 2003).

The debates about the underlying nature of community members' motivations is an ongoing conversation. While some argue that intrinsic motivation continues to play a significant role in fostering participation, others argue that all of these activates simply represent a type of selfish market logic, where members still seek for rents; yet deferred into the future (Lerner and Tirole, 2002). Indeed, empirical studies reveal that a few number of communities are successful at retaining their members and fostering members' repeated contributions (Ma and Agarwal, 2007). Most of the communities are unable to attract a considerable number of members or because self-selected members do not have the right set of skills or are not engaged enough to generate an interesting amount of content and interactions (Ma and Agarwal, 2007). One possible reason is that members, through time, start to manifest concerns with intellectual property and value appropriation, what may lead to diminishing incentives to participate on open source projects (Boudreau and Lakhani, 2015). At the same time, it is indeed difficult to measure and value members' contributions to meet their extrinsic motivation, as through pecuniary incentives. Measuring members' contributions is difficult because the process of finding and negotiating a price for each contribution and protect and license intellectual property could induce prohibitive transaction costs (Franke and Shah, 2003).

Contrary to open source communities, centralized proprietary platforms rely on pricing structures based on membership fees, cross-subsidisation pricing strategy, rent appropriation and revenue sharing to foster members' participation by leveraging on extrinsic benefits (Boudreau and Hagiu, 2009). However, researchers have already showed that strong extrinsic rewards for engaging in an activity might decrease individuals' intrinsic motivation, hence, negatively affecting the nature of interpersonal interactions and creativity (Amabile, 1985; Franke and Shah, 2003). While open source communities leverage mainly on intrinsic rewards, and centralized proprietary platforms rely mostly on extrinsic benefits, blockchain-based platforms harness incentive mechanisms anchored on both intrinsic and extrinsic benefits, which, however, vary over time (Davidson *et al.*, 2018).

In blockchain-based platforms, it is possible to distribute value amongst community members trough protocols, smart-contracts, and crypto-incentives (crypto-tokens and cryptocurrencies) with much lower transaction costs. The crypto-incentives are embedded in blockchain-based platforms functioning; key piece of their protocols and smart-contracts. Such protocols and smart-contracts link community members' actions to respective rewards. For example, when end-users consume the complements, they can spend tokens, but if they provide reviews, or promote or curate content, they can receive tokens for their contributions. Similarly, producers receive tokens in exchange for their complements, and validators of verifying transactions. As members' number of tokens is registered on the ledger, which is distributed and publicly available; the number of tokens earned function as a reputation indicator—members with more tokens earned are the members that contribute the most to the community. Additionally, tokens have a convertible value in crypto-currencies and fiat money. Therefore, all community members (users, complementors, validators, developers, and investors) that possess tokens, either by buying or earning them through contributions, have strong incentive to contribute and collaborate towards network growth and interface and components quality improvement as such factors can positively impact the value of their tokens.

For example, on Steemit, a public blockchain-based platform for content development, complementors are the people that create content, for which they receive a reward in STEEM Power (one of the platform's native crypto-tokens) based on the number of votes that they collect from audience. End-users, i.e. readers of the content, vote for or against the content, promoting and curating such content. Steemit operates on the basis of one-token for one-vote, which means that STEEM Power owners (end-users, complementors, and validators) that contribute the most to the platform, as measured by their account balance, have the most influence over how contributions are scored. Steemit validators, called witnesses, are the ones that create and sign blocks of transactions. Outside of Steemit platform, the STEEM token (which can be obtained through STEEM Power) can be bought or sold on exchanges, as well as transferred to other users as a form of payment (Steemit Whitepaper, 2018). While in the beginning, members tend to receive a higher number of tokens in order to foster community participation, these tokens tend to have low value in the beginning, and the opposite happens on the long-term.

Blockchain community members' benefits result from a balance between intrinsic benefits that they extract from using, complementing, developing the platform, and the potential extrinsic benefits from the future value of the tokens and reputation effects. However, as the community evolve in terms of the number of members, contributions, and interactions, member's benefits from these different sources may vary throughout time. Specifically, in the beginning, the members who join the community are the ones that present higher intrinsic motivation. Therefore, the high intrinsic benefits compensates the yet low extrinsic benefits (as the tokens have low value and there are low reputation effects) in the short-term. Members' intrinsic motivation increases as the level of interactions and contributions start to increase. The intrinsic benefits reach an optimal point when the number of participants is big enough to generate interesting and stimulating levels of contributions and interactions (Baldwin and von Hippel, 2011), but it is not too big that the sense of community in terms of shared needs, values and beliefs dilutes. If the number of community members increases too much, the sense of community slowly vanishes, coordination and complexity increase, discussions become extensive and intractable, and at this point, intrinsic motivation starts to decrease. However, extrinsic benefits (reputation and crypto-incentives) show a slightly different trend. While in the beginning, extrinsic benefits have little value as the community is small, hence the gain from reputation is not substantial, and the value of the token is minimal. As the community grows in the number of participants, contributions, and interactions, it tends to increase in value of the token and in significance of reputation. In this sense, whereas in the short-term, the intrinsic benefits compensate the low extrinsic benefits; in the medium-term, assuming that the community increases, the increasing extrinsic benefits may compensate the decrease in intrinsic benefits.

P3a. When gains from intrinsic benefits compensates the low extrinsic benefits in the short term, blockchain-based platforms are more advantageous than centralized platforms.

P3b. When the gain in extrinsic benefits outweighs losses from intrinsic benefits in the medium-term, blockchain-based platforms are more advantageous than centralized platforms

4. Discussion and conclusion

This paper explores the distinction between centralized and blockchain-based platforms, where the latter represent an extreme case of "open" platform. We compare and contrast these platforms' governance typologies across three dimensions, namely transactions, technology, and community involvement. The contribution of this paper lies on the identification of the main benefits and costs of each platform governance type, drawing on the conditions under which blockchain-based platforms are more advantageous than centralized platforms.

In previous sections, we highlighted that from a transactional perspective blockchain-based platforms are preferable over centralized platforms when reductions in the transaction costs–mostly driven by reduction in opportunism, and partially, uncertainty–are higher than increases in coordination and complexity costs. We can unpack each of these gains and costs related to blockchain to see further patterns of improvement, and consequent increases in the use of decentralized platforms compared to centralized ones. A first set of potential changes relate to the increased potential of adaptation given the current upsides and downsides of the blockchain. We are currently observing an adaptation process with many competing start-ups and "product" or "business model" innovations are competing to take advantage of the blockchain technology–we see a similar evolution in AI technologies, for example. The adoption of blockchain and its impact will be more evident as advances in both blockchain protocols and accompanying complementary innovations improve the technology infrastructure (Brynjolfsson, 2017). Increased adoption with such innovation complementarities between applications (or use cases) and the blockchain technology itself (Bresnahan, 2010), will make the technology even better in its benefits, for example, allowing decreased complexity and coordination costs as more conditions are added to protocol and smart contracts in order to improve contracts completeness.

Coordination costs can also relate heavily on the evolution of governance modes and experiences in blockchain-based platforms. Experimentation through application cases will help to delineate the most efficient and effective contracts according to the nature of the application. For example, DAO was an extreme important experiment on decentralized autonomous governance modes, which has failed due to a security breach in the code but opened an avenue for novel governance solutions that might also have contributed to the emergence of blockchain technology. Such evolution is similar to centralized platform models that result from years of institutional support and well-known organizing routines (Arruñada and Garicano, 2018). Blockchain technology evolution throughout forthcoming years might change dramatically the set of transactional gains and costs proposed in this paper. We hint that in the further years, the gains from adopting blockchain will increase; implying that such decentralized "market" platforms will be more suitable for an increasing number of applications, in contrast to centralized platforms, which might be advantageous for a narrower number of cases (Davidson *et al*., 2018).

Blockchain verification process and consensus mechanism can also prevent the network from failure and fraud without any need to a central regulator or even a trustable third party. This "trustless" and tamper-proof governance system, however, is costly to implement and can be inefficient vis-à-vis centralized platforms. The high and ever-increasing cost of verification via proof-of-work is a prime example, as described earlier. As a blockchain-based platform grows and number of validators (miners of Bitcoin for instance), the higher computing power and more massive energy is needed to solve the mathematical puzzle and create a new block. Hence, there is no clear prospect for a reduction of this cost of technology in the future. On the contrary, based on the computing power that has been added to the network, the difficulty of the puzzle should be elevated to keep the block creation costly and energy-intensive, thus, ensure the tamper-resistance of the network.

There are alternative verification and consensus mechanisms that try to find a remedy for the problems of proof-of-work protocol. Most importantly in the so-called proof-of-stake verification process, which has been introduced by Ethereum platform (Davidson *et al.*, 2016a). In such consensus mechanism, the computing power is replaced by the stake of validators—i.e. the amount of native crypto-currency that users possess. This process reduces verification costs, regarding computer power and energy consumption; however, it may boost costs and drawbacks in other dimensions. For instance, entitling the wealthiest validators to validate transactions and create new blocks endangers the decentralized nature of blockchain-based platforms. For instance, if most of the stake is in hands of few people; technically the (dis)verification of the transactions would be skewed towards few nodes, around which the governance of the platform will be centralized. Therefore, proof-of-stake while reducing the verification cost of technology, it may open of the risk of opportunism; hence, higher transaction cost. Further research shall investigate the main distinguishing dimensions amongst different consensus protocols, relative benefits and costs, and under which conditions a certain consensus mechanisms is preferable over the others.

We discuss that blockchain-based platforms are more advantageous compared to centralized platforms when the intrinsic benefits outweighs low extrinsic benefits in the short-term. We also defend that through time and as the community grows, intrinsic benefits would decrease, as extrinsic ones would increase. As long as intrinsic and extrinsic benefits balance each other, blockchain-based platforms would be the most beneficial form. This proposition might holds even when there are "hard forks" in the community. As the community increases, higher is the likelihood that dissonant voices start to emerge, leading to the emergence of minorities that differ in their needs, values and beliefs, what eventually will lead to a community split-up. For example, Bitcoin XT, Bitcoin Unlimited, and Bitcoin Cash are Bitcoin protocol forks that aim at increasing block sizes, which allows more transactions per second, overcoming one of the scalability problem of Bitcoin (Cryptocurrency facts, 2018; Gervais, Ritzdorf, Karame, and Capkun, 2015). Communities "hard forks" mean that the community will split in two (or more). Members that keep adhering to the original community format, they will increase their intrinsic motivations, as the dissonant voices left and the community got more homogeneous. However, as a part of the members left the community, the community size decreases, what will negatively impact the extrinsic benefits (token valuation and reputation effects). In this regard, the community would survive a "hard-fork" as long as the increase in intrinsic benefits outweighs the drop in extrinsic benefits.

The blockchain-based platforms tokenization mechanisms are useful not only to foster extrinsic benefits to enhance cooperation and collaboration but also to dynamically distribute authority amongst members in a meritocracy system (Davidson *et al*., 2018). The biggest challenge of such system is to design a protocol that score individual reputations and incentives that most of community members consider fair and attractive. Simultaneously, such algorithms also need to be resistant to intentional manipulation. If there is wide abuse of the incentive systems, the community members "lose faith" in the platform, decreasing participation. The incentive system needs to reach a balance between creating mechanisms to avoid abuse and opportunistic behaviour, but it also needs to be simple and clear, so members have clear expectation about their rewards. Reaching this equilibrium between simplicity and robustness might be difficult to achieve. Indeed, nowadays, most tokenization models comprehends multiple tokens with different natures, and extremely complex incentive systems, hard to understand and predict expected rewards. Such complexity denotes the lack of knowledge in selecting the most efficient incentives systems accordingly with the nature of the blockchain activity and goals. Quantitative and experimental research is much needed on this field in order to understand community members' adherence to different incentive systems.

It is worthwhile to mention that while we discuss the costs and benefits of blockchain based platforms in three separate dimensions (i.e. transaction cost, cost of technology, and community involvement), in principle, all three dimensions are intertwined. Improving in one area and bending the boundary condition in favour of blockchain-based platforms may be disadvantageous in another dimension. For instance, as mentioned earlier, applying proof-of-stake may overcome the massive cost of verification problem but make the platform more exposed to the opportunism of few wealthy validators. We hope that our paper provides a simplified, but clear, theoretical framework to assess the "optimal" points of adoption of a decentralized platform compared to a centralized one. Future research can provide a more holistic picture by linking theses three areas together and potentially exploring different dimensions not investigated in this piece.

Nowadays, we already witness several variations amongst blockchain-based platforms, where some are proprietary but keep decentralized governance and distributed data infrastructures, or others that are non-proprietary but the code and data infrastructure are closed and permissioned. We are passing through an experimentation period when "a thousand flowers are blooming" and we might be far from standardization. On the top of this variance amongst governance and data infrastructure dimensions, we can also find differences on the nature of the activities of blockchain-based platforms. For example, while some are purely transactional, as is the case of *cryptos* like Bitcoin, whose goal is to exchange and store value; others use crypto-tokens associated to services or products, called as utility-tokens, such as Steemit platform. This paper intentionally under explore such differences, focusing on the conditions under which blockchain-based platforms with both decentralized governance and distributed data infrastructure are likely to be more advantageous than centralized platforms. However, we encourage that further research focus not only on the main dimensions that distinguish different blockchain-based platforms, but also on under which conditions our propositions about transaction costs, technology costs, and community involvement have higher or lower traction.

This paper has the goal to inspire discussion and further research on blockchain-based platforms relative benefits and costs, offering a more contingent perspective on this new emerging technology. The three main sources of costs and benefits explored in the paper show key points for further empirical research that surely needs to test our propositions. Not only our propositions are individually showing some expected effects, but also taken together, they originate relevant interactive effects for further consideration. This paper is of theoretical and empirical relevance, as many blockchain based consortiums and start-ups are trying to uncover and build a "killer" decentralized platform to compete with centralized ones.

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