

# Ostrom amongst the Machines: Blockchain as a Knowledge Commons

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**Abstract:** Blockchains improve on previous ledgers on several margins, including transparency, immutability, and openness. Though cryptocurrency tokens such as Bitcoin and nonfungible tokens (NFTs) are now part of the popular lexicon, institutional analysis of blockchains is just beginning to blossom. We add to the burgeoning institutional analysis of blockchains and their governance by considering novel insights from Hayekian and Ostromian perspectives on blockchain governance. We contend that concept of taxis is especially useful to describe the origins of any individual blockchain and that the concept of spontaneous order is uniquely suited to analyze the competitive features of blockchains. A novel insight is that blockchains may arise without government design, but they are centralized entities. Ostromian analysis is especially useful to characterize blockchains as knowledge commons and to provide an empirical method to analyze how rules internal to and external to blockchains combine to explain the performance of any individual blockchain network.

## 1. INTRODUCTION

Cryptocurrencies and NFTs (nonfungible tokens) are now part of the popular lexicon. Bitcoin, the first cryptocurrency with commercial success, brought new confidence in distributed ledgers (Luther 2019). Since its initial offering, Bitcoin has taken off in significance. Perhaps as a result of concerns about the economy and with governments during the coronavirus pandemic, the price of Bitcoins reached an all-time high of \$63,000 in April of 2021, with a market capitalization of over \$700 billion, and new highs in October 2021.<sup>1</sup> NFTs burst onto the scene around the time Bitcoin was enjoying its meteoric rise. NFTs have already generated buy-in in popular culture with digital assets such as CryptoKitties (collectible digital cats) and with the highly-publicized purchase of Wu-Tang Clan’s “private” album, *Once Upon a Time in Shaolin*, by PleasrDao, a crypto-collective hoping to make the album available to the public (Vee 2021).

Though cryptocurrencies are probably the best-known application of blockchains, public and private blockchains, such as Ethereum, Hyperledger Fabric, Corda, and Ripple, allow for applications to be developed on top of the blockchain. These include financial applications notary services, smart contracts, and DAOs (decentralized autonomous organizations). These developments, especially smart

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contracts built on the Ethereum platform, create opportunities for different types of contracting whereby agreements are self-executing once the terms are agreed on. These have had ripple effects on law. Unlike traditional written contracts, which are often characterized by *incompleteness*, smart contracts presume the inclusion of all terms and definitions, thus prioritizing contractual *completeness* to a greater degree. Smart contracting illustrates how blockchains create new opportunities for experimentation with different forms of governance, including not only commercial arrangements but also different voting rules among self-organized communities (Allen, Berg, et al. 2019).

Several broad themes emerged as people engaged more deeply with blockchain, including exploration of uses of the underlying technology (blockchains) beyond digital currency, emergence of the idea that blockchain is a philosophy of freedom as much as a technology, and the pluralistic character of blockchain, with many distinct blockchains or blockchain networks, each having a unique set of technical, economic, and social characteristics. Accordingly, blockchains can be thought of as a new *institutional* technology alongside firms, governments, and relational contracting as a building block of the economy (Davidson et al. 2018). Blockchains are significant because they record information about people, property, and contracts without the need to rely on trusted third parties, especially governments, firms, and courts, to validate the information contained in those ledgers. Though blockchains involve some degree of trust in those who establish the blockchain, with permissionless (or public) blockchains, trust is placed in blockchains' powerful consensus algorithms, enabling new opportunities for contracting without relying on hierarchies (Berg et al. 2019) or trusted third-party intermediation.

Despite an outpouring of research into blockchains, the institutional analysis of blockchains is just starting out. For example, there remains debate about the nature of blockchains. Much of the discourse on blockchains sees them as synonymous with decentralized coordination. However, blockchain is not the only decentralized coordination mechanism, and it is not the first decentralized ledger. More significantly, from a governance perspective many blockchains are centralized. This is not only the case with permissioned blockchains, which are organized much like conventional firms, but also with public blockchains, whose leadership typically consists of entrepreneurs and programmers with the ability to shift the evolution of a given public blockchain's rules (Alston et al. 2022).

The defining feature of a blockchain is that it is an append-only cryptographic log rather than its being centralized or decentralized *per se*. Blockchains are distributed, shared ledgers in which all the entries in the ledger are stored in a chain of blocks. This chain is ever-growing as new transactions (entries in the database) occur, in a network of connected nodes that are appended to the chain through the creation of new blocks. Since blockchains can only be appended, they can both provide for greater transparency than previous ledgers and also offer potential security improvements over traditional ledgers. The applications or uses of blockchains are not limited to cryptocurrencies, or even to ledgers themselves; there are applications of blockchain that provide for cooperation among agents that do not depend on a ledger. The diversity of uses illustrates that blockchains characteristically involve cooperation and collaboration in distinctive ways but are not necessarily decentralized, as they may have features more like a conventional firm. Blockchain's append-only feature has some novel advantages and enables blockchains to do things that had not previously been possible.

Our contribution in this paper is to compare and contrast Hayekian and Ostromian perspectives in the analysis of blockchain networks. Hayekian political economy is especially useful in clarifying the differences between governance of an individual blockchain and the market for blockchains. In Hayek's (1973) typology, an individual blockchain has features of a taxis. Much of the institutional analysis of blockchains adopts that view, including research which sees the formation of any given blockchain network as akin to a process of constitutional choice (Cowen 2019). A blockchain is established when programmers produce a white paper, and any given blockchain is governed by rules made there. Still, there are features of blockchains that fit more closely with cosmos, especially the relationship of any given blockchain to its "competitors." Though individual blockchains are taxis, the overall evolution of these blockchain networks is a cosmos. This proliferation of blockchains, especially in the cryptocurrency realm, enables "consumer choice"

and contributes to institutional innovation in blockchain networks seeking to attract and keep users in their network (Alston 2020).

Seeing blockchains as primarily taxis rightly shifts the focus to rules internal and external to blockchains. Here, a burgeoning Ostromian literature on blockchains is especially relevant. Some of the themes in this literature include the ways in which uncertainty is addressed through changes in a blockchain network's rules (Howell and Potgieter 2021), the kinds of rules that have emerged to address negotiation costs among users of blockchain networks (Allen, Lane, et al. 2019), and governance dilemmas arising from the necessity of linking blockchains to data in the real world through oracles (Poblet et al. 2020). Additional research considers whether blockchain networks are polycentric entities (Frolov 2021), and if so, the nature of those polycentric governance arrangements (Alston et al. 2021).

The research above, though not all explicitly based on the insights of Nobel laureate economist Elinor Ostrom, share the Ostromian concern with governance institutions in the real world. Rozas et al (2021) is among the first to explicitly apply Ostromian analysis to blockchains. Their focus is on how features of blockchain technology (tokenization, self-enforcement and formalization of rules, autonomous automatization, decentralization of power over the infrastructure, increasing transparency, and codification of trust) can support coordination in other decentralized communities, such as Commons-Based Peer Production (CBPP). In other words, they consider governance *by* blockchains, rather than governance *of* blockchains. Such analysis of governance by blockchains clarifies the ways in which blockchains can improve prospects for decentralized governance, in this case by improving prospects for already-decentralized social organizations to better achieve prospects for self-governance (Rozas, Tenorio-Fornés, and Hassan 2021).

We add to this Ostromian literature. We depart from a specific application of Ostrom's commons research to blockchain and explain why blockchains are best analyzed as knowledge commons, adopting an Ostromian theme on institutional governance but highlighting the distinctive knowledge and information attributes of the blockchain context. Blockchains are social institutions, not merely technological systems. We emphasize the ways in which the Governing the Knowledge Commons (GKC) perspective can be used to develop an empirical research program that embraces the diversity of blockchain arrangements. Together, these perspectives can explain the limits of human ability to design institutions for innovation and open up the black box of institutional design within the blockchain. In addition, our analysis clarifies the differences in Hayekian and Ostromian perspectives on blockchain, as well as argues that generally speaking, the perspectives are complementary.

## 2. HAYEK AMONGST THE MACHINES

### **Austrian Institutionalism**

Economists have long recognized that “institutions matter.” The New Institutional Economics (NIE) has been especially successful in defining institutions and how they matter. Working from within the NIE tradition, Alston et al (2018) define institutions as rules that “recognized entities (individuals and organizations) devise and enforce.” They define norms as behavioral beliefs that reduce uncertainty.

Austrians have a rich traditional of institutional analysis. Here, we explain why it aligns with the NIE definition of institutions, as well as how it offers some novel insights into the process of institutional change. These conceptual clarifications also serve to illustrate why an Ostromian perspective, with its emphasis on real-world analysis of complex organizations for self-governance, complements Austrian institutionalism.

Austrian institutionalists see individuals as purposeful agents whose actions to achieve their subjective goals contribute to emergent order (Cowan and Rizzo 1996). Human choice is central to this vision of institutionalism. The result is a more open-ended character of institutions than one may get from the constrained maximization view which sees the possibility of identifying “optimal” institutions (Kirzner 1997).

Institutional change—change in the enforceable rules, using the definition of institutions given above—is a result of an entrepreneurially-driven market process.

The definition of institutions as enforceable rules also provides a way to organize ideas about taxis and cosmos. According to Hayek (1973), made orders (taxis) are the product of members of groups choosing rules that specify consequences for specific actions. Made orders are thus artificial, as Hayek described them. Order, such as a firm, results from command through taxis.

A cosmos is a spontaneous order. The Austrians built on Adam Ferguson’s view that social institutions result from human action but not human design, which Carl Menger interpreted to mean that institutions are unintended creations of the human mind (Palagashvili, Piano, and Skarbek 2017). For Menger, order consists of pragmatic orders that were consciously designed (and enforced) and organic orders that cannot be explained as the result of the intentions of any individual human mind, such as market prices, morality, language, and money. Menger considers cities and states as organic in that any given complex human organization is reflects a process of reciprocal adaptation. Menger further distinguished state-made law (statutes) from law that emerged spontaneously. Spontaneous orders, or cosmos, result from deliberative behavior, but institutions can only be understood by abstracting from the specific choices of any given individual or organization (Boettke and Coyne 2005).

Hayek’s political theory, with its emphasis on limited government (see, for example, Hayek 1944), follows from this appreciation of spontaneous order. Rules are more appropriate than discretion when the social order that society wishes to preserve is more complex. This is a positive statement about how society is best able to preserve complex social orders, including those arising from the market process, *if* society wishes to do so. For the economist to impose this view on society would be inappropriate, given the knowledge problems identified by Hayek (1945) and his generalized opposition to planning expressed in *The Fatal Conceit* (1988). In analyzing taxis, Hayek distinguished between nomos (law) and thesis (legislation). Law consists of general rules that regulate future conduct of individuals in any number of unknown future situations. Legislation, in contrast, specifies specific actions in any given situation and are enforced; law, in Hayek’s sense, is not carried out, but specifies frameworks for making rules.

The above is useful in clarifying that the new definition of institutions provided by Alston et al is consistent with Hayek’s and Menger’s view of institutions as pragmatic orders and taxis, each enforceable rules that are products of human design. Spontaneous order is a concern with norms, such as morality, culture, and language, each of which influence behavior, but are not necessarily enforceable via sanctions and are did not originate from any conscious design. As we explain below, a concern with each type of order is relevant for analyzing blockchain networks.

### **Individual Blockchains as Taxis**

Blockchains have features of taxis in that they have designers. The white papers that set forth the technology had authors—Satoshi Nakamoto, whose white paper announced Bitcoin in 2008, was a pseudonym, but their white paper had a definitive author(s). Four people were the “authors” of Ethereum. Even permissionless blockchains, which allow potentially anyone to participate, are a product of institutional design and agreement on sets of rules (Alston 2020).

There is also an evident role for rules internal to any given blockchain (Bert, Markey-Towler, Novak, and Potts 2018). This is most obvious with a private blockchains, which are organized much like traditional firms in the sense that they may have internal decisionmaking hierarchies, and there are clear boundaries between insiders and outsiders, that is, between those who are permitted to participate in blockchain transactions and those who are not. To some extent, governments have in some instances view blockchain as rule-based rather than only as a technology, as some attempted to ban cryptocurrencies (Hendrickson and Luther 2017). Consistent with their rule-dependent character, middlemen have also emerged to facilitate individual transactions on blockchains (Spithoven 2019).

Summing up, in terms of institutional analysis blockchains are not simply a technology, but a novel constitutional choice, the result of a constitutional process such as any taxis described by Hayek, or later by James Buchanan in the public choice tradition (Rajagopalan 2019). That conclusion clarifies how some blockchains, especially permissioned ones, are not so different from firms, as institutionalists have long been analyzing such phenomena with a similar framework (Alston Forthcoming). We argue not that blockchains are firms, but that the two phenomena share an institutional character.

### *The Landscape of Blockchains are Taxis*

The entire system of blockchains has features of a cosmos. The blockchain (especially its underlying technology—public key encryption, one-way functions, consensus approaches - and philosophy) itself did not come from an individual, and its evolution reflects the cumulative consequences of individual decisions. There is no ultimate plan for the landscape of blockchains out there for blockchain developers and users to choose from. What this enables is Hayekian anarchism—a polycentric collection of venues and organizations to resolve and address disputes (Stringham and Zywicki 2011). Blockchains realize this Hayekian vision. Exit and voice within any given organization may be improved by blockchains (Berg and Berg 2020), up to and including crypto-secession (Allen et al. 2018). In addition, as entrepreneurship has a spatial aspect (Andersson 2005), blockchains are interesting as cosmos because their evolution creates and builds on opportunities for entrepreneurs to engage in peer-to-peer interactions across distances previously unheard of. Reliance on social trust is replaced, significantly, by reliance on resolution by the algorithms that constitute a blockchain.

Legal scholars interested in the evolution of law highlight the ways in which people are able to create their own rules to govern themselves, as well as the role of markets for rules in shaping the evolution of law (Hadfield 2016). Cowen's (2019) market-for-rules perspective on blockchains adopts this view. The market itself is a cosmos, with an open-ended character. The resultant institutions established are a taxis, but the participants are interacting in a market, much like firms—made orders—operate in a market. Blockchains thus illustrate a more general point that Hayek understood, which is that made rules exist along spontaneous orders (Pennington 2011).

### 3. EXTENDING THE GOVERNING KNOWLEDGE COMMONS APPROACH TO BLOCKCHAINS

Following the Hayekian tradition, we can think of a given blockchain network as a taxis, and the landscape of blockchains as a market that contributes, in open-ended fashion, pressure to change rules of any given blockchain. What is missing is a framework to empirically analyze blockchains. Below, we suggest the Governing Knowledge Commons research framework offers a general empirical approach to characterizing the diversity of rules governing blockchain networks. In addition, we see distinct advantages to recognizing that blockchain networks are knowledge commons.

We see the GKC approach as appropriate because of its emphasis on governance of shared non-depletable resources, as well as its emphasis on the designed or constructed character of those resources; on distribution and coordination relative to those resources as well as production and consumption; nested-ness; legal regimes and property rights considerations; interactions between insiders and outsiders; and dispute resolution. Each offers insight into blockchain networks generally.

Elinor Ostrom's (2005) design principles for commons settings focused on boundaries, the link between rules and needs, opportunities for participation, and the design of enforcement mechanisms, as well as the nested nature of governance. Those guidelines, and the Institutional Analysis and Design (IAD) framework that followed them, were anchored primarily in empirical analysis of cases of natural resource governance. They relied on the corresponding assumption that self-governing communities could sustain production of shared, depletable resources and surmount overconsumption (free riding) dilemmas posed

by the conceptual “tragedy of the commons.” Subsequently, Ostrom and Hess (2007) applied related reasoning to knowledge, which confronts related but distinct social dilemmas issues of underproduction, withdrawal of information, enclosure, inequitable access and distribution, coordination among producers and users, conflict, deception, congestion (insufficient availability at times of peak demand), and pollution (Hess and Ostrom 2007). They hypothesized that self-governed communities could be successful with respect to managing shared knowledge and information resources. Early adaptations of Ostrom’s work to knowledge characterized these arrangements as “new” commons (Hess 2008).

The GKC approach adopts the instinct behind this early work, that communal or collective governance of shared knowledge resources could successfully overcome social dilemmas and create successful governance institutions as alternatives to state- and market-based models. The GKC framework likewise adopts Ostrom’s perspective that the instinct can be validated empirically by close, systematic case-based research. It departs from Ostrom’s work, including both Ostrom’s guidelines for commons governance and the IAD research framework, by opening important research questions about the character of shared knowledge and information, about the types of social dilemmas that shared knowledge responds to and creates, and about the role of formal legal and legal institutions in constructing and shaping informal practice (Frischmann et al. 2014). None of those things formed a significant part of Ostromian approach to commons or shared resource governance. The GKC framework assembles those research inquiries into a strategy for investigating specific cases of knowledge commons governance in a systematic way, a strategy that is modeled on Ostrom’s IAD framework but that is not simply an extension of Ostrom (Frischmann et al. 2014).

In the GKC framework, cases of knowledge commons governance are highlighted because of their functional attributes rather than because of a definitional distinction that labels certain institutional arrangements as “knowledge commons.” The characteristic that distinguishes “commons” governance from the “noncommons” is institutionalized sharing of resources among community members (Madison et al. 2010). Identifying the resource and the community or collective are two critical, initial steps in a knowledge commons research project, but one of the key aspects of knowledge commons is how self-governance can be linked to other formal and informal governance mechanisms and the constraints on self-governance imposed by technology and other material constraints. Werbach (2018) describes an attack on the Ethereum blockchain known as The DAO in which the governance process involved rolling back transactions (essentially setting the ledger back to an earlier state). In such instances, governance processes involve interactions between human stakeholders that relate to but exist independent of the technologically-mediated governance processes that determine when blocks are added to a blockchain. The contents of a blockchain ledger involve executing and enforcing (in computer software) the terms of the contract that was defined algorithmically in advance, but the fact of the ledger—and the possibility that the ledger might “fork” and become two ledgers, with different contents—is a product of human decision making.

Just as Ostrom insisted that commons governance offers no panaceas or one-size-fits-all solutions to challenges of resource sharing, the knowledge commons literature questions simple solutions to the challenge of governing knowledge (Madison et al. 2010). The GKC program emphasizes that research on knowledge commons must be empirical as well a conceptual exercise (Frischmann 2013). The literature documents numerous and varied examples of community and collective self-governance of shared resources, often distributed across decentralized spaces. Successful distributed commons governance examples, such as open source software production and Wikipedia, illustrate cases where knowledge and information are naturally shareable, and where the absence of clear property rights does not inevitably lead to “tragedy” (Madison et al. 2009).

Some of the best-known examples of knowledge commons governance are peer-production networks, such as Wikipedia and Linux (Benkler 2013). Blockchain networks are another example of knowledge commons. In applying the GKC framework to blockchains, the unit of analysis is a blockchain network. Blockchain networks are digital resources that consist of technologies for innovation and a community that governs the production of outputs from the network. The GKC perspective suggests that further elaboration of the resources in question is appropriate, along with elaboration of the social dilemmas to which

each resource is subject. For example, a preliminary view of the resource question here is that a blockchain network is characterized by distributed but shared computing power (one resource, subject to coordination dilemmas, to free riding dilemmas, and to environmental externalities), by distributed but shared human labor (a second resource, involving designing and evolving the code that defines the network, subject to coordination dilemmas, depletability dilemmas, and free riding dilemmas), by the shared contents of the blockchain (the information documenting transactions in blockchain assets (a third resource, which combines pooled information about the transactions with shared information about each specific transaction within each specific block, subject to trustworthiness, traceability, and durability dilemmas). The community includes developers, users, and others who contribute to the emergence of the network. In GKC terms, “the community” ordinarily should be scrutinized to separate the roles, responsibilities, obligations, and contributions of different members of the community. Commons governance does not automatically entail an absence of hierarchy. Nor does it exclude risks of misbehavior or worse. The outputs of a blockchain are what it produces. For cryptocurrency networks, this includes digital currencies and may include architectures to write smart contracts, such as with Ethereum. Blockchain networks may also produce information that is used by individuals, where the information has features of knowledge commons (Allen, Davidson, et al. 2021). As with knowledge commons generally, a critical “product” of a blockchain network may not be resources themselves but may instead be the community or organization that the blockchain sustains. Unlike Ostromian commons, which typically exist to ensure a sustainable supply of biophysical resources, knowledge commons governance may exist to ensure the sustainable creation and continuation of a human community.

Like peer-production networks, blockchain networks arise in decentralized fashion and are governed by a community of users. For public blockchains, the community of users can be anyone who has the means to participate, which include some basic know-how and access to the Internet. For private blockchains, the community is defined by individuals, including developers and programmers, with definite boundaries. Public and private blockchains depend for this success on internal and external rules. These internal rules include protocols, which as noted constitute a realm of collective choice. The external rules include regulations and laws. In addition, the polycentric features of blockchains ensure that the outputs of any blockchain network depend in part on the competitive environment within which a given blockchain competes. Further, blockchain networks often depend on shared resources, such as the smart contract architecture provided by Ethereum, which can be used by other blockchain networks.

The multiplicity of shared resources evident in a blockchain network illustrate how governance institutions may be nested, or layered. Governance at one layer relates to but may be independent of governance at adjacent layers. In that vein, Dekker and Kuchar (2021) see markets as dependent on knowledge, some of which are governed as shared resources, that is, as commons. Blockchain networks often excellent examples of knowledge commons governance that operates within a market environment, both borrowing market strategies and interacting with market actors. Outputs such as cryptocurrencies are available to any market participants, and so they constitute market-supporting knowledge commons. Blockchain networks also provide a way to pool innovation resources, as emphasized in the innovation commons literature. As a species of knowledge commons, innovation commons are institutional solutions to innovation dilemmas, notably collective action problems (Allen and Potts 2016). In innovation commons, entrepreneurs pool innovation resources under defined governance rules (Potts 2018). Blockchain networks may perform precisely that function, enabling communities to collaborate to produce goods and services. Blockchains can be used by commons-based peer production communities to improve prospects for sustainable self-governance (Rozas, Tenorio-Fornés, Díaz-Molina, et al. 2021). These are not either/or interpretations; both market production and peer production via blockchain networks illustrate the strength of the knowledge commons perspective in understanding how blockchain addresses various social dilemmas related to shared knowledge and information.

The account is compatible with perspectives that emphasize private property rights over the outputs produced by blockchains. Transactions on public blockchains are effectively transfers of individual-

ed property interests within the overall institutional context of the blockchain, as suggested by Davidson, DiFillippi and Potts (2018). The GKC framework highlights the non-depletable character of the property in question and the fact that property interests are specific by combinations of computer code and positive law—both attributes being contingent and subject to design choices in the construction of the blockchain and adaptation and evolution during its performance.

In the next section, we describe in greater detail how the GKC framework may be employed to analyze blockchains. In doing so, we highlight some of the features of blockchain networks to illustrate the kinds of questions that the approach would ask. Consistent with the framework's overall approach, we suggest taking the following steps in analyzing blockchain networks as commons contexts:

- 1) Producing a detailed story of the origins of a blockchain network and its general features, including an account of the resource characteristics of the blockchain, the dilemmas that it may have been designed to solve, and the dilemmas that it may have created, and the community or collective engaged in producing, managing, and participating in its operation;
- 2) Producing a description of protocol choice, namely the rules governing the blockchain network;
- 3) Analyzing the extent to which the blockchain is nested in higher-level institutions;
- 4) Describing relevant legal and regulatory regimes governing the blockchain network;
- 5) Accounting for the structure of interactions between users of a given blockchain network and non-users, as well as between blockchains and other communities or market actors; and
- 6) Analyzing processes and procedures for addressing disputes on the blockchain network.

#### 4. OSTROM AMONGST THE MACHINES

##### **The Story**

Here, we consider how to proceed for each step by considering blockchain in general, with emphasis on the kinds of institutional comparisons that are significant. The story naturally begins by explaining how blockchain began, both generally and as to a specific blockchain. One need not search for the source of the Nile. The point of investigating the story is to understand the problems, or social dilemmas, to which blockchain, with its knowledge and information sharing features, was imagined to be an institutional solution, and to decode the roles and motivations of different actors in constructing the blockchain as they did. Depending on the character of the knowledge or information resource, such as a cryptocurrency or an NFT market, relevant dilemmas would involve questions of congestion, conflict, deception and fraud, efforts to create boundaries, inequities in who can participate, and efforts to distinguish one blockchain network from another. Inequities may be reflected in the intensive demands for understanding mining activities for Bitcoin, for example. Blockchains do not have boundaries in the usual sense of institutions and property rights, and there is much freedom for transactors to move from one blockchain to another (Alston 2020), giving blockchain networks a fluid character. Still, the non-depletability of information resources does not automatically correspond to non-excludability. Blockchains can be distinguished from one another, and some are clearly excludable. Public (or permissioned) blockchains can alter trust relationships between transacting parties by restricting who may execute transactions on the chain.

For analysis of public blockchains, the story may also begin by consideration of the white papers that showed the world how to deploy blockchain technologies. Bitcoin emerged with Nakamoto's (2008) white paper on Bitcoin. Subsequently, white papers were released that described smart contracts (Buterin 2014). Together, these enable innovation in the blockchain realm, including an architecture for DAOs, which create opportunities for self-contained blockchain networks that could include their own cryptocurrency and their own rules for a communities of users. The origin story of a blockchain network may reveal much in the way of its nested or layered character.

Description of a blockchain network may also include a review of the broad typology of blockchains (public or private) and how they relate to but are distinguished from other, similar systems. For analy-

sis of public blockchains, a starting point for analysis is the tremendous diversity of public blockchains. Public cryptocurrency blockchains are an important type, and within that category, there are many cryptocurrencies—thousands, in fact. Still, an important part of the story of these blockchains is their uniqueness compared to previous ledgers, particularly in that they are append-only distributed ledgers. Like other peer-to-peer systems, blockchains allow users to transact digitized, valuable, and tokenized assets. Unlike those systems, blockchains provide greater transparency and security because of their append-only features; public blockchains (including cryptocurrencies), are not reliant on centralized entities to record information.

Rozas et al (2021) summarize the core features of public blockchains as follows: transparency (no one can control information, and the blockchain produces a consensus among users in the network; all histories of transactions are public; the masses have access to the information); decentralization (all nodes in the system have a copy of the ledger, and the consensus algorithm allows for updating); user empowerment (anyone with internet connections have complete authority or read or re-write the blockchain); and immutability (no one can tamper with the system, as double spending will be rejected by other nodes). Those general features offer an excellent preliminary account of how blockchains respond to different social dilemmas associated with knowledge and information, how blockchains situate their solutions in communities and collectives, and how and particular blockchains depart from the core model.

### Protocol Choice

The second step involves analysis of the rules internal to a blockchain network. What is clear is that there is no one-size-fits-all ruleset for blockchain governance. Each blockchain may represent a somewhat different institutional context and may (but need not) represent an evolution (or specialization) of previously existing blockchains. New blockchains may even begin with the same code base (computer software) of a prior blockchain and modify it to implement it in a new institutional context. The story, or the analysis of the rules, would map the processes in detail. The rich literature on blockchain constitutions, as exemplified by Cowen (2019), Rajagopalan (2019), and Alston (2020), is especially apt and offers insight into better understanding of the design of these institutions. Such analysis, when married to the institutional detail identified in recent work seeking to establish a grammar of blockchain institutions (Allen, Berg, et al. 2021), provides a useful framework for empirical research into these rules.

Analysis should account for the open-ended aspects of creation of blockchain networks. The process of creating a new blockchain is normally the effort of a small team of people within that blockchain environment who then seek to have their innovation adopted by, and subsequently governed by, the full community. In most cases, the “community” consists of transaction validators (miners), software developers, and (typically) transactors with large stakes (coins) on the chain. The different labels clearly indicate their different default institutional roles within the blockchain network, though even within each group, there are many members of these teams, and subsidiary roles and responsibilities may vary. As Howell and Potgeiter (2021) explain, questions of membership and governance include membership status of different groups, including end users, transaction members, node members, software members, and donor members. They emphasize rules and relationship formalization, such as permissionless versus public blockchains. Such considerations are a significant aspect of the story of blockchains.

The analysis of rules internal to a blockchain may begin with the broad features, such as access (public or private). Public blockchains allow any user (usually anonymously or using pseudonyms) to access the network. On the other hand, in a private or permissioned platform, such as Hyperledger Fabric or Corda, only a limited number of users (usually with known identities) can access the network. This allows for identifiable users, where older users exercise access control to the new entrants.

Analysis of the blockchain’s protocol would also involve consideration of the consensus mechanisms. Unlike traditional governments and most markets, blockchains do not rely on trusted, centralized entities to validate transactions. Validating consistently and securely in a distributed environment, as with indi-

vidual actors located all over the world, constitutes a social dilemma, in that individual actors may be motivated to free ride on the efforts of others, by not participating, or to corrupt the system as a whole, by defecting.

Blockchain networks solve the consensus dilemma via a decentralized, algorithmic system that ensures that distributed nodes agree on the validity of the transactions in each block, and on the order in which blocks are appended to the chain, thus sharing that information throughout the network. Consensus algorithms are sets of rules that ensure that a consistent copy of the ledger is persistent across the entire blockchain network. The details of the implemented consensus mechanism in a blockchain platform depends on the type of blockchain (e.g., private vs. public), the network configuration (e.g., known user identities), and the type of digital asset being exchanged (e.g., cryptocurrencies, NFTs). Due to the popularity of cryptocurrencies and the considerable amount of applications being developed on top of blockchain-based platforms, a substantial number of consensus algorithms is being developed (Cong and He 2019).

Proof of Work (PoW) is the most widely known consensus algorithm in blockchain due to its use in Bitcoin. The goal of the algorithm is to validate transactions so they can be batched into blocks to be appended at the end of the blockchain. In order to append a new block, each node (known as a “miner” in Bitcoin) competes with other nodes to show that it has performed (i.e., mined) some amount of computational work such as solving a complex mathematical puzzle. Miners are typically compensated for their contributions in the form of tokens created when the new block is added. Miners may consist of or be operated by entrepreneurial firms, and rent-seeking by those firms—demanding additional tokens in return for commitments of greater computing resources -- has been identified a consideration that complicates governance of the blockchain by a consensus algorithm (Berg 2021).

One of the limitations of PoW is that it is resource intensive and therefore environmentally wasteful, as miners have incentives to form pools to harness computing power. As a resource-efficient alternative to PoW, Proof of Stake (PoS) operates on the assumption that nodes with higher stakes in the network are less likely to harm (i.e., attack) the system. In PoS, users with higher stakes (e.g., ownership of digital assets), rather than miners with greater computing resources, have bigger chances to become validators. Many alternative variations of PoS have been proposed in different blockchain-based systems. These include Delegated Proof of Stake (DPoS), Proof of Weight (PoWeight), and Leased Proof of Stake (LPOS). Further, many consensus algorithms have tried to combine the best of two worlds. New mechanisms are being developed as a hybrid version of PoW and PoS (e.g., Proof of Importance, Proof of Capacity, etc.). All of these systems share the core characteristics of PoW and PoS, with some variations, including representative democracy, different definitions of stake, and single leader selection.

Beyond differences arising from consensus, one could compare blockchain networks across several of the properties identified with blockchains, including immutability, transparency, persistency, resilience, and openness (De Filippi and Wright 2018). Another feature is decentralization. Though public blockchains are considered more decentralized than private blockchains, the extent to which public blockchains are decentralized is variable, and they have centralized aspects. Protocol choices influence the extent to which a network attains success on these dimensions, though as we discuss in considering insiders and outsiders, competitive features of the landscape of blockchains, and the ability to choose among public blockchains, or to establish new private blockchains, creates incentives to compete on each of the dimensions above. For example, a blockchain’s rules can be modified to provide for greater immutability. Indeed, The DAO hack resulted in a split into two blockchains, Ethereum and Ethereum Classic. Ethereum Classic promised greater immutability, as its members believed that the money stolen by the hacker should not be returned to remain aligned with the core belief in immutability.

### **Nested-ness**

The third step of analysis involves a description of the institutional contexts or “action arenas” in which a given blockchain network is situated, including its polycentric environment, or, if the analysis is con-

sidering a collection of blockchains, the nested-ness of the collection of blockchain networks. Polycentric systems situate governance responsibility relative to a resource (decision making, conflict resolution) in overlapping and distributed centers and actors, rather than in a single point of authority. Blockchains are polycentric in that sense: within any network, blockchains are governed by rules that provide the basis for interaction in political, socio-economic systems, while establishing the social positions that different individuals may occupy according to their rights, obligations and empowerments to act in specific situations (Markey-Towler 2018).

Alston et al (2021) take this as step further in arguing that polycentricity is the defining features of *any* blockchain network. Blockchains are nested in higher-level organizations and involve multiple interfaces with human elements. Those interfaces occur through oracles, third party services that provide interfaces between the blockchain environment and the outside world, collecting and distributing information about payments within a smart contract, for example, and authenticating data about the human world that is fed to that smart contract for processing. Because they acquire, consolidate, and process information, oracles are themselves centers of decision making responsibility and potential conflict and are therefore parts of blockchain's polycentricity. To the extent that governments regulate blockchains and via information law systems define property and related rights that co-exist with blockchains, governments, too, are part of blockchain's polycentricity.

### Legal and Regulatory Regime

The fourth step in applying the GKC framework is considering the specific legal and regulatory regimes relevant to blockchains. Focusing on the role of law in knowledge commons governance is consistent with Ostromian attention to self-governed communities; Elinor Ostrom paid special attention to formal rules in describing the performance of complex social systems (Cole 2017). Law plays a distinctive and unusually important role in knowledge commons governance because the relevant resources themselves typically have no material (or in Ostrom's phrase, biophysical) existence. Their existence as social objects is due in large part to how they are constructed, defined, and regulated by legal rules.

Thus, every blockchain network and every resource in a blockchain network exists in some respect in the shadow of the law. Some depend on the law for their identity. For example, the knowledge resources that constitute the blockchain network are defined and regulated by law. Blockchains are built on open source computer code, which means that they exist on a foundation of copyright law (as computer programs are governed by copyright) and open licenses (private property and contractual devices intended to preserve the code against cooptation by private firms). In another example, a "smart contract" on a blockchain network is a contract in conceptual terms in the sense that, and only to the extent, that the computer code instantiates an exchange that in conceptual terms would be legally enforceable if it existed only in the non-blockchain world. The utility of putting the smart contract "on" the blockchain is that various gaps and limitations of real world contract law are avoided, such as jurisdictional differences, cost of enforcement, and legal rules applied to contract interpretation.

Thinking about legal considerations also directs attention to the broad framework or constitutional rules governing blockchain. There is not a unified system of law governing blockchain to rival the Uniform Commercial Code, which provides a standard legal baseline for regulating commercial practices in the United States. Rather, patterns of legal acceptance and regulation of blockchains have developed on a sector by sector basis. Blockchains do not rely on statutes, as they emerged without any statutes. But statutes can make them illegal. Though some states have made blockchains illegal, many more have enacted statutes that give legal status to blockchain contracts, building on the conceptual observation above (Lemieux 2019). Generalized criminal and common law are also available. For violations, the enforcement would presumably come from a third-party enforcer, including the state. Here, the rich body of research on how computer code does well and does poorly when it encodes legal principles, per the evolving *lex informatica*

(Reidenberg 1997) and cryptographia (such as Werbach and Cornell 2017), can inform analysis of blockchains, including how legal rules are evolving in response to new challenges.

### **Interactions between Insiders and Outsiders in the Blockchain**

One of the features of blockchains is that they are relatively immune from outside interference. The “cypherpunk” community developed Bitcoin in part because of this feature and a desire to exist outside of the state. It remains challenging for outsiders to come in and destabilize governance, as the size of the distributed environment makes blockchain relatively challenging to control. Self-governance is a critical feature of a blockchain network and something that is difficult for outsiders to eliminate. If one is not a blockchain insider, one interacts with the blockchain via an oracle, that is, according to the blockchain’s protocols.

The chief alternative framing of insider/outsider interactions is based on competition. Blockchain networks compete with each other with respect to their features and qualities, such as processing speed and environmental impacts, in attracting and retaining developers and users. Alston et al (2022) highlight that these competitive features are essential aspects of blockchain governance. They extend research by Berg and Berg (2020), which considers competition among blockchain networks as the ground for discussions of exit and voice in blockchain governance. Quality and feature competition explains not only the emergence of new blockchains but also pressure for existing blockchains to adapt and change.

### **Dispute Resolution and Discipline in the Blockchain**

The final empirical step is analysis of disputes and institutions that address disputes. Forking, which in its basic form involves an existing blockchain network splitting, with the source blockchain carrying on in its prior form and a new, modified fork of that same blockchain taking independent form, is the paradigmatic outcome of a dispute in blockchain. A change to a blockchain can be initiated by anyone who proposes an upgrade in the protocol. It only fully succeeds if the whole network accepts the new upgrade.

Forking adds additional layers of technical and analytic complexity to knowledge commons analysis of a blockchain due to the decentralized nature of the system and the non-depletable character of the information resources in that system. With every fork, there is always a risk of a chain split into two halves. Hence, an owner of a cryptocurrency, for instance, would receive two new coins. Both currencies then start functioning as separate entities. As Arruñada and Garicano (2018) explain, the process of change differs in distributed entities compared to more centralized ones. In blockchain, the platform architect may play a limited role: the nature of the system is that all nodes can unilaterally determine which protocol they run, and whether they update it or not is their decision. Consequently, the challenge for blockchain-based systems lies in developing effective mechanisms producing soft forms of governance that accommodate decentralized decision-making (via potential splits) and by providing a mechanism to adapt to new circumstances.

Dispute resolution in blockchain networks thus highlights a key feature of knowledge commons governance. In a knowledge commons environment, governance consists largely of decisions about the identity and character of the community—are we members of this group, or of that group?—as well as decisions about the identity and character of the resource and how it is shared. With only a bit of rhetorical stretching, blockchain can be thought of as a crypto-democracy, with all of the strengths, limitations, power, and fragility that such a metaphor implies. The GKC framework is well-suited to extended that metaphor via specific empirical research into particular blockchain networks.

## **CONCLUSIONS**

The tools offered by scholars such as Hayek, Ostrom and Buchanan—Boettke (2021) calls this tradition the mainline of economics—provides powerful tools to study blockchains. Certain features of the evolution of

blockchain as an institutional technology can be understood as a spontaneous order. Others reflect taxis. A careful application of Hayek's insights avoids the mistake of seeing blockchains as inherently decentralized when in reality, many are made orders, or taxis.

A Hayekian perspective is also incomplete. An Ostromian perspective is useful to understand blockchain governance and, ultimately, how blockchains can be successful in providing us with opportunities, including cryptocurrencies and smart contracts. The Ostromian perspective is expressed here via the Governing Knowledge Commons research framework, an approach to empirical research that is built in the style of Ostrom but with careful and distinct attention to the different concerns of institutions built around knowledge and information resources. Polycentricity is woven into the fabric of GKC analysis. Together, these tools provide an especially useful approach to understand blockchains and analyze similarities and differences across blockchain networks.

The prospective aspect of our paper is to invite empirical research on the diversity of rules governing blockchains, and in the process, adding more to our understanding of the taxis side of blockchains. Such research is underway, as far as conceptual frameworks go. Darcy Allen and colleagues (2021) initiated conversations along these lines with their "Ostrom-Complete Grammar" of blockchains. That work is based on the insights that blockchains represent a tremendous diversity of governance institutions and that Ostrom's work offers a useful framework for capturing it. We see the GKC framework as providing perhaps a richer context beyond the institutional grammar of blockchains, as it retains the context-specificity of Ostrom's work (such as attention to relevant action arenas) without being bound to Ostrom's assumptions about resource attributes or the expected benefits of commons governance.

We see no need to choose among institutionalisms. As such analysis proceeds, Hayek's admonition that the more complex the order we wish to preserve, the greater the importance of rules, remains a significant background consideration as legislators across the world now begin to regulate blockchains. To the extent such regulation is seen as beneficial, it can and should be informed by Ostromian case studies of blockchains. Since the Ostroms' approach is complementary to Austrian institutionalism and the public choice tradition (Harris et al. 2020), we see such cross-fertilization of institutional perspectives on blockchains as useful starting point for further analysis of blockchains and their governance.

## NOTES

- 1 In January 2021, political unrest in Kazakhstan, one of the hotbeds of cryptocurrency mining, led to a substantial drop in Bitcoin's price after the government interfered with Internet access (thus slowing ability of miners to solve cryptographic puzzles). These events illustrate that Bitcoin may be seen as a solution to political instability, but also that its success appears to depend in part on government stability.

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