Digital Governance as Recombination: The Institutional Generativity of Blockchain Protocols*

A. Jason Windawi
Department of Sociology, Princeton University

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Abstract

The rapidly increasing power of digital infrastructures to shape social action has fueled a growing body of research on the multifaceted relationship between digital technology and governance. The emergence of blockchain as a form of digital infrastructure centrally concerned with governance and institutions has also given rise to a broadly interdisciplinary literature, albeit one that has largely operated outside of the literature on digital technology and governance. This paper seeks to bridge these perspectives by bringing the paradoxes and affordances of related digital technologies into the same frame with a detailed study of governance in blockchain. I do this by framing the study around a question motivated by the broader literature: how do the governance affordances of digital technology enable its users, developers and other stakeholders to navigate the tensions created by the technology's generativity and fluidity? I study this phenomenon in the context of blockchain technology, an emergent form of digital infrastructure for which governance institutions have long been a focus. Rather than ledgers or cryptocurrencies, I focus my analysis on the role of blockchain protocols, a central mechanism for establishing the roles, rules, incentives and other aspects that define blockchain governance. Using a framework I developed for this analysis, I find that blockchain protocols combine the technology's innate affordances with the controlled generativity of open source and the stabilizing control of algorithms into a unique blend that I term institutional generativity. This institutional generativity is at the heart of the technology's ability to target longstanding institutions as well as its rapid iteration on the forms it creates.

Keywords— governance, blockchain, Ostrom, innovation, open source, institutions

1 Introduction

Blockchain technology is an emergent form of digital infrastructure in which governance plays a particularly important role. Governance institutions have been a central concern for the designers of blockchain technology from its inception, with the very first or "genesis" block of Bitcoin's blockchain

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inscribing a critique of the traditional financial system it sought to circumvent: “The Times 03/Jan/2009 Chancellor on brink of second bailout for banks” (De Filippi and Wright 2018). This combination of institutional critique and the development of digital alternatives reflects blockchain technology’s deep roots in the emancipatory commitments of the cypherpunk movement (Brunton 2019; Swartz 2017). Timothy May’s manifesto for the movement referenced several technological advances that anticipated components of blockchain, including “methods [] based upon public-key encryption, zero-knowledge interactive proof systems, and various software protocols for interaction, authentication, and verification” (May 1992). The ongoing development of these and other technologies in distributed systems, cryptography and other disciplines created the building blocks for Bitcoin’s design (Narayanan and Clark 2017), which was one effort among many to create digital alternatives to fundamental institutions including money, contracts, property rights, law, voting and accounting (Back 1997; Dai 1998; Grigg 2004, 2005; Szabo 1997).

The unusual salience of governance to blockchain technology has been reflected in a growing interdisciplinary scholarly literature that has approached various aspects of the topic. In law, scholars have built on Lessig’s pioneering work on the relationship between law and code (Lessig 2006) to explore the extent to which the blockchain represents a new hybrid (De Filippi and Hassan 2016; De Filippi and Wright 2018; Werbach and Cornell 2017), as well as the viability of existing analogues in corporate governance as models (Reyes 2020). Scholars in management and the social sciences have focused on the ability of blockchain to enable new forms of contracting and other institutional innovations (Allen et al. 2020; Berg, Davidson, and Potts 2019; Lumineau, Wang, and Schilke 2021). Information sciences researchers have produced agenda-setting articles that introduce the technology and open doors for future inquiry (Beck, Müller-Bloch, and King 2018), with a particular emphasis on the operations of the technology itself.

This paper seeks to contribute to this work by adopting a different perspective motivated by two characteristic aspects of blockchain technology that have not historically been emphasized. The first concerns the fundamental tension between the stability required to create blockchain technology’s institutional effects (Allen et al. 2020; Berg, Davidson, and Potts 2019) and the reality that both the technology itself and expectations of their broader communities of stakeholders are profoundly fluid. To take only one example, Ethereum – a blockchain project that provides computational infrastructure for thousands of other applications – has been the subject of hundreds of proposed changes to its protocol 2017 and early 2021.[1] The second is more subtle, and has to do with the source of the technology's expansion across so many institutional domains, a set that is itself constantly expanding as the technology changes. While this latter aspect has been studied in the context of the generative affordances of the technology (Rozas et al. 2021), the source and fluidity of those affordances remains underspecified. While these characteristics of fluidity and generativity are implicit in prior studies of blockchain governance, they are central to a longstanding literature on the nature and governance of digital technologies and infrastructures. Situating my study in this literature allows me to draw out the relationship between affordances, governance and tensions specific to digital technology, while also putting my study in dialogue with existing work on digital technology and governance. I do this by framing the motivating question for this paper in the context of this broader literature: How do the governance affordances of digital technology enable its users, developers and other stakeholders to navigate the tensions created by its fluidity and generativity?

I make two other moves in this paper to answer this question. The first is to shift the emphasis from the more commonly studied ledgers and cryptocurrencies to focus on blockchain protocols. I define blockchain protocols as *the core technological logic, incentive system and code that jointly define the functionality of a blockchain project.* As such, protocols are digital artifacts through which the base materials of both the technology and its governance are negotiated and contested, bringing stakeholders, their competing interests and power into the construction of a digitized social contract (Rahwan 2018). Standardized protocols are also a necessary condition for the development and governance of layered infrastructure for blockchain, as they are for other forms of digital infrastructure (Tilson, Lyytinen, and Sørensen 2010; Wareham, Fox, and Cano Giner 2014). Blockchain protocols are thus among the most important artifacts linking the technology and its social organization.

Focusing on protocols similarly enables the second move, which is to construct a multilevel analytical framework that combines Ostrom's insights on institutional building blocks with the digital scholarship on affordances and tensions. In applying this framework, I find that tensions between change and stability are

1. https://eips.ethereum.org/all

(in keeping with Ostrom's polycentric framework) typically resolved by shifting the nature and stakeholders involved from one level to another. I also find, however, that blockchain projects also diverge sharply from this orderly framework given the governance affordance of institutional generativity, which is constructed at the field level rather than the level of individual protocols. The latter finding situates my study at the intersection of literatures on digital governance as well as the institutional dynamics of digital transformation, in addition to contributing to the literature on blockchain governance.

The paper begins with sections that introduce first the governance affordances concept in the context of digital technologies and infrastructures, as well as the recombinant nature of blockchain protocols. Section 4 describes the data, methods and analytical framework I deploy in the remainder of the paper. Sections 5 through 7 explore the various levels and variables of the analytical framework. Section 8 synthesizes findings, and section 9 concludes.

2 Tensions, Affordances and Change in Digital Technology

The fundamental nature of digital technology poses a challenge to governance research in that the very characteristics that define it also render its governance especially challenging. The generativity, fluidity and openness of the technology have each been theorized as contributing to digital technology's simultaneous functioning as both a means and an object of development (Faulkner and Runde 2019; Kallinikos, Aaltonen, and Marton 2013; Zittrain 2008). The relationship between the technology and change is thus a central concern, though it has been pursued in strands of literature that often don't interact.

Scholars studying the the governance of information infrastructures have theorized relationship between digital technology and governance as one in which the fluidity and generativity of digital technologies have given rise to tensions that both necessitate and shape governance decisions (Tilson, Lyytinen, and Sørensen 2010; Tiwana, Konsynski, and Bush 2010; Wareham, Fox, and Cano Giner 2014). Researchers have named these these tensions paradoxes given the seemingly contradictory demands they impose for simultaneously maintaining open generativity and control (the "paradox of control"), and enabling change without losing the structural benefits of stability (the "paradox of change"). Governance in this literature is a process of navigating the paradoxes created by the nature of the technology, often through the articulation of mediating structures such as platforms (Boudreau 2010; Boudreau and Hagiu 2011; Gawer 2014) or the "participation architectures" (Baldwin and Clark 2006; West and O'Mahony 2008) of open source software development. Other literature has directly linked the governance decisions necessitated by these tensions as shaping the ongoing evolution of digital infrastructures (Henfridsson and Bygstad 2013; Malhotra, Majchrzak, and Lyytinen 2021).

A separate stream of literature has tackled the implications of the nature of digital technology in light of the longstanding call for recentering technology itself in studies of technology and organization (Faraj and Azad 2012; Orlikowski and Iacono 2001). In particular, changing technology...both the technology itself and the social structures within which it operates are constantly changing, necessitating an accounting for change at both levels (Leonardi 2011, 2012; Kallinikos, Aaltonen, and Marton 2013). Scholars have used the lens of affordances, broadly defined to avoid both determinism and pure constructionism by specifying affordances as a relational function of the potential uses of a technology for a particular set of users (Faraj and Azad 2012; Hinings, Gegenhuber, and Greenwood 2018; Leonardi and Barley 2008; Orlikowski and Iacono 2001). Others have extended this concept of affordances to add constraints in the same relational context (Malhotra, Majchrzak, and Lyytinen 2021; Markus and Silver 2008). These affordances and constraints, these scholars argue, provide a tractable point of analytical focus for the study of technology that is constantly changing.

The complementary strengths of these two streams of literature suggest a theoretical way forward, with the addition of a refinement of the concept of affordances. For this study, I introduce the concept of *governance affordances* as a narrowing of the analytical lens to sites where stakeholders are engaged in a digital form of institutional work (Lawrence, Suddaby, and Leca 2009), though the sites and nature of that work are jointly determined by the nature of the technology and the interests and objectives of the stakeholders engaged with it. If digital governance is the process of navigating these paradoxes, and is linked to affordances as a relational function that links aspects of a technology to stakeholders, then it stands to reason that digital governance can be productively studied by linking digital governance affordances to decision-making that is (in keeping with the nature of digital technology) enabled for some and constrained for others by those affordances. This framework thus reframes the governance of digital technologies by examining the ways in which actors and technology together construct and enact governance as a means of navigating paradoxes of control and change. This leads to the question that animates this paper: how do the governance affordances of digital technology enable its stakeholders to navigate the tensions its fluidity and generativity create?

3 Blockchain Protocols as Digital Artifacts

The lack of settled definitions in the field of blockchain technology has led one practitioner to term it a "semantic wasteland" (Carter 2018). This ambiguity results in part from the fact that a blockchain itself – a time-stamped ledger of transaction data – is different from the larger entity typically referred to when using the moniker "blockchain," which typically includes some combination of an abstracted ledger, a peer-to-peer network of nodes running the same open source code, one or more cryptographic tokens and smart contracts.

In practice, most projects in the domain are driven by separate peer networks layered atop infrastructural blockchains, much as the majority of products built on any single technology platform outnumber the platform itself. This layering is enabled by smart contracts, which provide the basis for the extension of blockchain's reach as a technology into so many other domains of application. This is due to the generative potential of smart contracts, which are not only flexible in their specification (as code), but are also composable into increasingly complex recombinations that enable applications, decentralized autonomous organizations (or "DAOs"), tokens and other innovations. As a result, some of the most relevant forms of governance are a result not simply of blockchain ledgers but also of the ability to develop and recombine other technologies such as smart contracts and programmable tokens whose functioning depends on - but is distinct from - that of the underlying ledger.

This layered aspect, together with the need to account for the multiple components that make up "blockchain" as a technology, motivates my move to focus on protocols in this paper. Within blockchain, protocols encompass and shape the functioning of each of the components of the technology in a given application, as well as the interactions between infrastructural and application layers. I follow practice among developers of defining the term *blockchain protocol* more specifically to mean *the core technological* *logic, incentive system and code that jointly define the functionality of a blockchain project.* Once documented, typically in a white paper such as Bitcoin's (Nakamoto 2008), these protocols then circulate among stakeholders within and outside of the project, enabling coordination. Even private blockchain projects either still publish a protocol, or (more often) are built using existing open source protocols. Moreover, protocols are central to the ability of builders of the complementary applications smart contracts enable.

The central role of code in blockchain protocols gives them a clear affinity to algorithms, though that term implies a fixity that doesn't fully capture the fluidity of blockchain protocols. It also elides the fact that protocols, like other digital objects, are constructed from other modules (Faulkner and Runde 2019). As a result, blockchain protocols are more aptly described as *meta-algorithms* constructed from some combination of the following generalized components:

- **Base protocols.** Base protocols are typically published in academic or quasi-academic open access repositories in computer science and related disciplines. Most consensus algorithms begin as base protocols (e.g. variants of Practical Byzantine Fault Tolerance [Castro and Liskov 1999]).
- **Cryptographic primitives.** These building blocks include algorithms for hashing and digital signatures and can also include other security measures such as zero-knowledge and other forms of proofs (Wang et al. 2019). This work often begins as academic research before diffusing to practice, though the lines between the two are often blurred. In other cases, such as cryptographic hashing functions, the function may have been developed as part of a global contest sponsored by an agency such as the National Institute of Standards and Technology.[2]
- **Governance primitives.** In the context of protocols, these primitives are encoded mechanisms that establish rules defining the conditions for the creation and reward of monetary incentives. Examples include coded mechanisms for staking, delegation and network fees. While these primitives are technical to the extent that they are encoded, they also reflect and enable decisions about rules for social coordination.

2. NIST undertakes a broad spectrum of projects in cryptography, security and related disciplines. See https://csrc.nist.gov/projects.

- **Existing code libraries.** Blockchain developer communities are deeply enmeshed in the practices and structures of open source code development (Brunton 2019; Swartz 2018). As a result, nearly every component in this list exists in a code library on Github, whether as a standalone implementation or as part of the reference implementation of an existing protocol. This encoding makes these primitives freely available for other projects seeking validated and maintained infrastructure.

In addition to being natively open source, blockchain protocols are enmeshed with larger processes of open science based on active research and development of base protocols and cryptographic primitives by academics, practitioners, government agencies and corporations. Protocol designers are expected to capitalize on this ongoing research by using cryptographic and other functions with known risk parameters and credibility established by surviving ongoing attempts at breaking their security. This stance, known colloquially by the phrase "don't roll your own crypto" (attributed to Schneier 1998), reflects the scientific conventions of skepticism and verification (Owen-Smith 2001), along with the risk mindset of cryptography as a form of security. As a result, it is rare for a blockchain protocol to premiere an entirely new component in its construction.

This unusual combination of algorithmic and governance primitives as well as open technology embeds blockchain protocols in larger patterns of development and recombination. Figure 1 gives a stylized view of some trajectories of recombination based on Bitcoin's core code repository or "repo", and shows how it has been combined with other innovations developed to address perceived privacy shortcomings in Bitcoin's blockchain. The core Bitcoin repo, called "bitcoin/bitcoin" appears in green, as do the other code repos for other projects that form part of the trajectory. Items in red are base protocols, and enter the chart at points where they are merged into new protocols. Items in blue are cryptographic primitives (primarily hashing functions) and are shown similarly at their point of incorporation into the blockchain-layer protocols that appear in black text boxes.

[FIGURE 1 ROUGHLY HERE]

The trajectory shown in Figure 1 represents innovations developed in response to the perceived privacy shortcomings inherent in Bitcoin's blockchain. The earliest efforts in this vein, such as coinjoin (Maxwell 2013) and Zerocoin (Miers et al. 2013), were designed as additional layers for Bitcoin itself based on the functionality of Bitcoin's core code library on Github, namely bitcoin/bitcoin. Dash, an early and influential codebase fork of Bitcoin, adopted and modified coinjoin in order to deliver enhanced privacy, in part by incorporating the X11 hashing algorithm. While coinjoin was created by a practitioner, Zerocoin was created by a team of academics who later revised it to include innovations in zero-knowledge proofs, and named the newly revised version Zerocash. The former protocol remains influential for several cryptocurrency projects, while the latter became the basis for Zcash, among the most influential cryptocurrencies given its technological advances. The team of academics who developed Zerocoin and Zerocash have since created a new version of zero-knowledge proofs called "zk-STARKS", which is the basis of their new commercial project named Starkware Industries, which has its own Starkware protocol.

4 Approach

My approach is shaped by well-established insights from the literature, beginning with the risks to generalization of over-reliance on a single site or application (Kallinikos, Aaltonen, and Marton 2013; Malhotra, Majchrzak, and Lyytinen 2021). Instead I use a two-stage process that begins with the construction of a multilevel, multivariable analytical framework for the analysis of governance institutions, which I customize for a digital setting. I then populate that framework with insights gathered through an algorithmic ethnography of blockchain protocols (Christin 2020; Seaver 2017). This approach rejects the notion of algorithms as purely technical artifacts and instead treats them as parts of larger assemblages of diverse actors and code that are under constant construction, necessitating a broader analytical lens that incorporates this change and works across available sites and data (Seaver 2017, 2019). I draw on strategies of scavenging, or gathering material from as many sites and data types as possible, as well as comparison and triangulation across these sites and data types (Christin 2020; Seaver 2017). My primary data sources are a combination of Github, project-level blogs and white papers, and online fora such as Reddit and project-level discussion forums. This rich data allowed me to identify key moments of decision-making in particular cases at each of the three levels of governance in my framework, and to trace historical trajectories of both protocols and stakeholder involvement Glaser, Pollock, and D'Adderio 2021.

4.1 Ostrom + Digital Framework

My framework is grounded in, and adapted from, Elinor Ostrom's body of work on institutions (Ostrom 1990, 2003, 2005). Ostrom and her colleagues are perhaps best known for their extensive case studies of community governance of natural, common-pool resources, a context that others have extended to studies of blockchain as a form of commons governance (Rozas et al. 2021). I draw instead from Ostrom's later work in which she developed a generalized framework for the analysis of institutions as a solution to collective action problems including – but not limited to – those involving common-pool resources (Ostrom 2003, 2005, 2017). Rather than seeking a single model or theory, this work sought instead to account for the diversity of institutional forms by identifying the building blocks of institutions, which Ostrom defined as variables and nested levels within a general framework. I take these building blocks as a starting point for describing institutions, and adjust and revise the analytical framework for my own analysis.

The core of Ostrom's framework is a series of ***institutional variables*** that identify core aspects of governance institutions. A functioning governance system in Ostrom's framework clearly defines both ***roles*** and the specific ***rights*** allocated to each. In Ostrom's early work on natural resource governance, these rights varied among roles deriving from different aspects of access, use and decision-making. Ostrom's later work on man-made information commons in open science introduced additional categories for contributors (Hess and Ostrom 2003, 2007). The third analytical variable captures the centrality of ***rules-in-use*** for cooperation and collective decision-making in Ostrom's work on governance. These rules specify not only positions and associated rights, but also the rewards or sanctions that shape behavior; I term these ***incentives***. The final variable concerns the social roots of collective action in the collective expectations of communities, which provide a necessary basis of legitimacy for the cooperation that the institutions enable (and for the development of the institutions themselves). I term this final variable ***community consensus.***

Vertical nesting of decision levels is critical to Ostrom's conception of polycentric governance (Ostrom 2005). She distinguishes three levels of decisions that increase in breadth of impact and diminish in their frequency as the analysis moves deeper into the governance structure, reflecting the increasing entrenchment involved in decisions that involve expanding sets of stakeholders (Starr 2019).

In the first of the three levels, operational decision-making defines the day-to-day behavior of participants under normal functioning. When events necessitate changes to operational rules, governance shifts to a deeper layer that Ostrom defines as collective choice situations about changes to the parameters governing their normal operation. Decisions that can't be effected within the existing collective choice context push decision-making to the deepest, most entrenched level of decision-making, which Ostrom defines as the constitutional level. In traditional institutions, the powerful – and potentially destabilizing – effects of these decisions have engendered mechanisms that prevent them from happening too frequently, making them a kind of exceptional politics undertaken only when the "normal politics" of existing collective choice rules fail (Starr 2019).

I adapt this framework for a digital context by first by re-specifying the polycentric levels. From a governance perspective, Ostrom's operational level is closest in spirit to the governance by the collection of primitives that define the protocol, leading me to define it as ***operational governance by protocols*** in blockchain projects. Most practitioners mean something different than algorithmic governance when speaking about "blockchain governance" (Buterin 2017; Ehrsam 2017; Prewitt and McKie 2018; Zamfir 2018). In these settings, the focus is on decision processes for making changes and upgrades to protocols; in the language of algorithmic governance, this is the governance *of* protocols, as distinct from governance *by* protocols (DeNardis and Hackl 2015). In the context of this paper, I define decisions involving changes to protocol primitives as cases of ***collective choice governance of protocols***.

The deepest, constitutional level of Ostrom's framework is less obvious in the context of blockchain protocols. While it is relatively rare for projects to have formal constitutions, decisions involving changes to fundamental aspects of collective choice governance do occur and meet Ostrom's broad definition.[3] I define such ***constitutional transformations*** as decisions that involve significant changes to any of the four institututional variables.

The final aspect of the framework to add are the digital variables of interest. The first of these is the

3. For a list of such documents, see https://web.archive.org/web/20220210140017/https://github.com/thelastjosh/govbase/tree/master/documents/constitutions.

governance affordances of blockchain technology within a given polycentric level of protocol-centric governance, as I've defined these affordances above. The second is the ***nature of change*** linked to those affordances, a variable that can work both within and (in keeping with Ostrom's polycentric framework) across levels. The question of interest then the relationship between the affordances of a given level and the changes they both enable and constrain.

This hierarchical, nested framework provides the structure within which I explore each of the analytical variables. I use these variables to shape my analysis of the mechanisms of governance specific to each level; this also allows me to refine my later analysis of the hierarchical interactions between levels. Doing so requires filling in the conceptual framework in Figure 2.

[FIGURE 2 ROUGHLY HERE]

5 Level I: Operational Governance by Blockchain Protocols

By establishing the positions, rules and rewards/sanctions that shape behavior in blockchain networks, protocols function as algorithmic expressions of Ostrom's operational rules-in-use. They accomplish this function by abstracting and encoding the forms of coordination and control that define behavior within the protocol under normal operations, whether through a blockchain-layer protocol or through the articulation of smart contracts. Because of this, the nature of the underlying Ostrom variables are jointly determined by the specific combination of technological and governance primitives encoded in the protocol. Their encoded nature gives them governance affordances of control.

5.1 Roles and Rights

At the most fundamental level, roles in blockchain protocols can be grouped as subsets of network *users* and the *provisioners* of necessary resources for the network's functioning, typically those who operate nodes (meaning, those who own or rent hardware and run the protocol's code on that hardware). In keeping with the cypherpunk ethos of "one CPU, one vote," the original vision of Bitcoin was that every user of the system would also be a participant and would contribute a part of their computers' capabilities to its maintenance. This conflation is evident in the original Bitcoin white paper (Nakamoto 2008), in which users are mentioned twice while nodes are mentioned 39 times using agentic language (e.g. "nodes can leave and rejoin the network at will," or "each node collects new transactions into a block").

The roles and rights surrounding nodes in in blockchain systems have grown more complex since Bitcoin, largely because of a sea-change in the functions of blockhchain networks introduced with the launch of Ethereum. Where Bitcoin was designed purely as a means of facilitating peer-to-peer payments, Ethereum was designed with the intent of providing a generative platform for the development of third-party applications and separately tokenized economies. In addition to providing security and decentralizing control, the peer-to-peer network in Ethereum was envisioned as providing a global virtual computer whose aggregated processing power would support a wide range of activities enabled by a combination of smart contracts and computation. This shift is reflected in the original Ethereum white paper, in which the term "user" is variously applied to those running nodes for the network, developers building applications for the network, and those seeking to transact using the blockchain (Buterin 2013).

Perhaps the most important development at the level of blockchain-layer protocols in the wake of both Bitcoin and Ethereum has been a shift toward bringing token ownership and network participation more closely into alignment through the articulation of roles based on an actor's willingness to bond or "stake" protocol tokens in order to participate in the ongoing production and operation of the network. The Polkadot protocol is indicative of the expansion of roles in protocols since Bitcoin. Polkadot is a combination of a blockchain-layer protocol (based on its sub-protocol, Substrate) as well as a means of integrating and working across multiple independent chains. As a result, the primary function is validating transactions on the independent chains (called "parachains") and the main or relay chain, though it is only one of four named roles in the protocol.[4] Stakers are token holders who want to participate in the consensus process but lack sufficient holdings to become Validators, who undertake the responsibility of validating blocks of transactions from parachains as well as participating in the consensus process for the main or relay chain. Nominators have the right to participate indirectly by nominating Validators. Collators translate between parachains and Validators by checking and bundling transactions into blocks,

4. https://web.archive.org/web/20211212232550/https://github.com/paritytech/polkadot/wiki/Polkadot-Roles-&-Actors

and Fishermen monitor the entire system.

5.2 Rules and Incentives

In keeping with their algorithmic nature, blockchain-layer consensus mechanisms are designed to coordinate decision-making via automated rules governing the proposal and selection of a new block of transactions as the next definitive one in the chain, as well as the selection of the authoritative version of history to which to append them. The core of operational decision rules in blockchain-layer protocols lie in the methods by which they bring the autonomous nodes in the network into agreement. These methods are typically gathered into a single consensus mechanism or algorithm.

The most widely studied consensus algorithm is Bitcoin's approach, in which full nodes compete for the right to produce the next block by providing evidence of having performed expensive computation or "proof of work." While this remains an important algorithm in the field, it is by no means the only approach. An increasingly popular alternative is Proof-of-Stake, in which the operators of full nodes first bond or stake some amount of tokens and are then selected to produce the next block based on a weighted random function of the size of their stake. Proof-of-Stake consensus protocols limit participation in the pool of consensus nodes to those whose holdings exceed a protocol-defined threshold, with a stakeholder's likelihood of being chosen rising with the size of their stake. Variants on Proof-of-Stake add a role for stakeholders opting to delegate their participation to other stakeholders.The most widely used variant of Proof-of-Stake involves delegation by stakeholders to a subset of nodes.

At the level of blockchain-layer protocols, the work of coordinating decentralized activity draws heavily on economic mechanism design and cryptographic methods that create incentives and (when possible) sanctions for the behavior of full nodes while also maintaining security. The design of these incentives and sanctions is largely driven by research at the intersection of economics and computer science that blends advances in the economic design of markets with computational advances in algorithmic game theory (Jackson 2014; Nisan et al. 2007; Roth 2002; Roughgarden 2010). The basis of this work is the use of game theory to model and create incentive mechanisms for individual behavior that aggregates to beneficial outcomes. Rather than imposing sanctions, much of this work relies on creating incentives for individuals to converge on the same decision. This mode of encouraging convergence is grounded in extensive research into the tendency of individuals to coordinate around shared points of reference or so-called Schelling or focal points (Schelling 1981; Sugden 1995) .

In the blockchain field, incentives, rewards and sanctions are linked to the use of cryptographic tokens for purposes that go beyond exchange and payments and instead attempt to create increasingly complex systems of incentives to guide participants' behavior. These mechanisms combine the potential of code-based money to constitute new systems of coordination with the ongoing advances in mechanism and market design described above. This combination of methods, often gathered under the neologisms of *cryptoeconomics* or *token engineering* join financial market mechanisms with cryptographic and game theoretic methods that allow for much more finely grained and targeted incentives and penalties for each of the roles specified in the protocol (Cong, Li, and Wang 2019).

The addition of programmable tokens specific to each blockchain expands the space of possible designs by adding monetary incentives and sanctions that are denominated in a currency whose value is (in theory) also tied to the health of the network. Bitcoin's designer(s) Nakamoto introduced the metaphor of gold mining as a physical analogy for the process of performing computational work that secures the network in return for a reward of money created or minted to compensate for that computational work. These "mining rewards" serve a double purpose in that they both encourage those with hardware to commit it to the network, and also provide an encoded schedule for the creation of new Bitcoins.

Bitcoin's linkage of money creation to rewards for miners laid the groundwork for a subsequent expansion in both the variety of approaches to incentivized block production (as described above) as well as the number of roles and actions linked to economic incentives. Although these vary and are an area of rapid scientific development, these algorithms share the characteristic of requiring some form of commitment to the network. As mentioned above, Proof-of-Stake makes the bonding or staking of significant amounts of tokens the baseline for participation as a node in the consensus process. Unlike mining in Proof-of-Work, staking requires putting some portion of the staked tokens at risk, creating the potential for sanctions (called "slashing") in the event the staker departs from the protocol's rules.

5.3 Community Consensus

Given their algorithmic nature, blockchain protocols define consensus narrowly within their normal functioning as an outcome of a well-functioning technological process. This replacement of the messy process of reaching community agreement with automated rules for machines is fundamental to the claimed ability of the technology to create authoritative records that are difficult to tamper with. By contrast, purely social consensus has historically been developed and manifested outside of these protocols, though it is of crucial importance to collective decisions about changes to the protocols themselves. I discuss these further below.

6 Level II: Collective Choice Governance of Protocols

As Ostrom recognized, this form of change is qualitatively different from the daily functions encompassed in operational rules because it requires reconciling the potentially divergent interests of a broader group of stakeholders. For blockchain protocols, these stakeholders extend well beyond network participants to include token holders, developers, application developers and others. The question of how these stakeholders get to participate, and in which stage of decision-making, is the central challenge of collective choice governance of protocols. Success often hinges on the ability to enroll these stakeholders in the process of arriving at *social* consensus on highly *technical* issues.

6.1 Roles and Incentives

Where blockchain protocols themselves specify the roles of *users* and various *provisioners* of network resources, the governance of protocols extends this role set to include other actors. The most central of these are *developers* who are involved in maintaining and revising the core code and functionality of the protocol. This group is typically subdivided into a core group of developers or “core devs” and smaller teams dedicated to particular parts of the protocol, in keeping with broader practices in open source. The interaction between these groups is perhaps the most fundamental determinant of the evolution of a protocol over time given the decision rules that govern their interaction.

Open source foundations are the central organizational actors in open source software projects. Prior studies have emphasized the role of open source foundations as boundary organizations that keep code and commerce distinct by housing the intellectual property rights and negotiating contracts with external actors (O'Mahony and Bechky 2008).[5] In recent years, however, open source foundations have expanded their role from buffering core contributors to cultivating and orchestrating larger ecosystems of projects. The Linux Foundation, for example, describes itself as "support[ing] the creation of sustainable open source ecosystems by providing financial and intellectual resources, infrastructure, services, events, and training."[6] This function gives such foundations two additional roles, the first of which is *funder* of development efforts. The second, closely related role is that of *network orchestrator* to the extent that the foundations use both their funding and other means of coordination to shape the development of larger ecosystems of related projects without assuming traditional forms of hierarchical control (Dhanaraj and Parkhe 2006; Majchrzak et al. 2018).

As with open source development more generally, non-profit foundations in blockchain are typically created to act as third-party, independent holders of intellectual property (IP) rights in protocols and their related names, and also tend to fund and coordinate much if not most ongoing development directly. Unlike open source, foundations are typically joined in this role by independently managed for-profit firms that also provide funding and other services. These for-profit firms are most closely engaged as well-funded *provisioners* of costly network hardware and computing capacity, as well as being *funders* of their own *developer* teams. These roles are especially important given the need for ongoing research and development.

6.2 Rules-in-Use

Collective decision processes regarding changes and revisions to protocols tend to closely follow established processes of open source. Research on open source software (OSS) development has focused on articulating the architectural structures and processes that enable open participation while tempering democratic aspirations with incentives for participation by developers with demonstrated skill. Open

5. For a self-description, see https://www.python.org/psf/summary/

6. https://www.linuxfoundation.org/. For the Linux grant program, see https://www.linuxfoundation.org/about/diversity-inclusiveness/infrastructure/. For Python: https://www.python.org/psf/grants/.

source communities operate under rules and processes that define contributing, debating and ultimately voting on contributions (Baldwin and Clark 2006; West and O'Mahony 2008). At their most general, these "participation architectures" (Baldwin and Clark 2006) define a process in which the processes of each stage and the progress between them are defined according to the standards of the community that establish a threshold of technological and project-specific knowledge for meaningful participation.

The process typically begins with a proposal submitted by developers following a project-specific template.[7] One of the most common trajectories for this process is to have the Core Developers vet proposed changes to the protocol and lead periods of public deliberation about those changes, but leave final decisions about implementation to provisioners who run the nodes that comprise the network. This format is often called *off-chain governance* given its lack of automation.

This proposal-deliberation-decision structure has become the default for Level 2 governance of protocols. Ethereum's process is typical. Ethereum's protocol governance process is triggered by proposed changes to the protocol. The process of submitting an Ethereum Improvement Proposal or "EIP" (defined, as is typical in OS improvement proposals, in the first EIP published to Github, or EIP-1) is closely specified in terms of the technical and editorial format of the document, and accords significant discretion to the six named EIPs editors. These editors are expected to operate according to rough consensus in Github discussion based on strictly technical criteria. Once an EIP is approved for broader discussion, it passes into the deliberation and (for Ethereum) the second decision stage. This deliberation stage occurs over a proliferating range of websites and social media accounts hosted by the Ethereum Foundation, related groups, and leading individuals in the developer community, as well as in largely public meetings whose minutes are posted in an open repository in the Ethereum organization's Github.[8]

While deliberation and viewing the core devs meetings are both open, actual decision-making is limited to a small subset of actors operating by rough consensus, a mode of decision-making pioneered by the Internet Engineering Task Force (IETF), a global organization of scientists and researchers working on various aspects of the Internet protocol and its related standards. The IETF's definition of rough

7. The Python community established this precedent in 2000 with the "PEP" or Python Enhancement Proposal" process. See https://www.python.org/dev/peps/

8. https://github.com/ethereum/pm

consensus combines a commitment to enfranchisement and open deliberation with assumptions of (and implicit deference to) the technical expertise of those participating.[9]

Once this group has reached a decision to change the protocol, the upgrade is encoded into a new, revised version and a date is established for the transition to the new code. The decision of whether or not to adopt the new version of the code and protocol is left to each node *provisioner*, on the expectation that they will have a strong incentive to remain in line with their peers in order to remain attached to the primary version of the blockchain rather than be stranded on an unprofitable branch.

More recent innovations attempt to bring this process *on-chain* and into the functioning of the protocol itself, though the broad outlines of the process remain heavily defined by open source traditions. Projects using this form of governance typically do this by assigning governance rights to the same node operators delegated block production rights. For example, the Tezos blockchain-layer protocol was designed to avoid the pitfalls of offchain governance by incorporating the entire process of developing, vetting and deciding on protocol amendments into the protocol itself (Goodman 2014). The process unfolds across four stages, each of which is enacted by the same delegated node providers or "bakers" who participate in the consensus process of producing new blocks. Proposals to amend the protocol can only come from bakers and are required to be in implementable code. If a quorum of 5% of votes cast by other bakers support the proposal, it moves onto the next "exploration vote" stage in which it must meet a higher quorum of support from bakers. Proposals which survive beyond this stage are implemented on a virtual network for 48 hours as a simulation of their impact on the actual network. This testing period is intended to provide the basis for deliberation by both the bakers and the larger Tezos community of stakeholders, though the mechanisms for this deliberation are not specified. The fourth and final stage of the process is a vote by the bakers, with the same quorum requirements as in the second stage (Arluck 2018; Goodman 2014).

6.3 Community Consensus and Legitimacy

Because traditional protocols using off-chain governance require the building of social consensus around proposed changes, they are vulnerable to situations in which there is no mechanism for arriving at

9. See Request for Comment (RFC) 2418, https://tools.ietf.org/html/rfc2418, later refined in RFC 7282, https://tools.ietf.org/html/rfc7282.

or measuring that consensus, let alone linking that consensus to decision-making. As a result, there are risks that decisions taken about changes to protocols will reflect only a subset of consensus. Success thus requires some mechanism for generating legitimacy for both the decisions taken as well as the process leading to those decisions. In turn, this means ensuring that the notion of social consensus has an operational pathway into decision-making.

The lack of such a pathway often becomes most obvious in times of crisis, perhaps most famously in events that led to the forking of Ethereum. The 2016 incident followed what appeared to be a successful launch of the first decentralized, autonomous organization, or "DAO," confusingly called The DAO. Launched as a venture capital fund whose investments would be decided democratically by its members using encoded mechanisms for membership and decision-making, the DAO successfully raised tens of millions of dollars in Ethereum tokens. Then the DAO smart contracts were hacked, leading to enormous potential losses that could only be overturned at the infrastructural level of the underlying Ethereum blockchain. This set the stage for a contentious discussion that hinged on whether the original code, however flawed, was a binding agreement. On one side of the debate were those who demanded that Ethereum maintain the immutability of its blockchain, arguing that "code is law" (Lessig 2006). The other side claimed that the scale of the hack posed an existential threat to Ethereum, and that the hard fork was the best way to move forward.

While one influential history of the event described it as a failure of algorithmic governance (DuPont 2018), the framework I use in this paper clarifies that the failure stemmed from a combination of the rigidity of the rules encoded in the smart contracts as well as the lack of alignment between roles and decision rules, resulting in a loss of legitimacy. The roles involved in collective choice of the Dao were particularly problematic given that its marketing materials named several "curators" who were also respected members of the Ethereum Foundation and Core Devs, implying a level of support and oversight of the smart contracts that wasn't true in practice. More subtly, the objective of reaching social consensus on any potential code changes was often referred to by community leaders, but was not accompanied by mechanisms for gathering and developing that consensus beyond the relatively constrained and code-oriented governance process.

While on-chain governance attempts to address this issue by making decision-making an explicit part of the process, that process is still shaped by the fact that the protocols and their code are open source, which introduces a distinct governance affordance due to the potential for "forking" or splitting of both the code and the project when consensus is out of reach. In a blockchain project-level fork, the departing group copies the code and creates a new ledger that shares the older ledger's history up to the point of the new ledger's inception. Doing so allows the departing group to enact whatever version of technology and governance they prefer but can't effect in the existing protocol. In such cases, the projects share a single history (memorialized in a single blockchain) up to the point of the fork - typically dated in terms of a specific block's formation - after which they become independent protocols and communities with independent tokens.

The centrality of open source to blockchain as a technology thus embeds what political theorist Unger terms "destabilization rights" as implicit governance affordances to actors beyond those charged with collective choice decisions (Unger 1987). Notably, these affordances are generically built into open source as a form of technology, but are also given new force by their availability for use by a broad range of stakeholders capable of mobilizing the economic, political and other resources necessary to act on them. While carrying risks, these destabilization rights may open up more radical alternatives in early-stage technological development than would otherwise emerge. The dual potential of forking as simultaneously a risk and a generative possibility gets to the heart of the deepest and most entrenched (and thus, most consequential) aspects of blockchain governance, which is its incorporation of instability.

7 Level III: Constitutional Transformations

The site of greatest novelty in blockchain is also the dimension of governance that sits least comfortably within traditional governance frameworks. In Ostrom's framework, the constitutional level of decision-making refers to decisions about changes to the framework governing collective choice decisions. The potentially transformative effects of such decisions lead to their being deeply entrenched (Starr 2019) in structures such as written constitutions and other forms of rules that are resistant to change under any other than extraordinary circumstances.

Such transformations remain the exception for most projects, and enroll significant change. I describe one such case in the context of Ethereum, below. The picture is different at the field level, however, which inverts this pattern by entrenching the potential for fundamental changes to the roles, decision rules, modes of social consensus and incentives that define Level 2 governance of protocols. This pattern, which I identify as a specific Level 3 affordance of blockchain protocols and call "generativity" is enabled by two patterns. The first of these is a field-wide commitment to decentralization that appears in practice as progress toward a goal via "progressive decentralization" rather than an immediate binary, and as a resulting willingness to experiment with new modes of governance. The second field-level factor is the rapid expansion in the scope and depth of governance primitives due to active research and development of a wide range of possible modes of governance, each of which can be incorporated into protocols as governance primitives.

7.1 Transformation of Roles and Decision Rules

In addition to being one of the most important blockchain-layer projects, Ethereum is also indicative of the dangers of anchoring an analysis of governance in one time period. The Ethereum community's widely publicized governance failures early in the project's history - primarily in the context of the 2016 hack of the DAO and subsequent split of the project and its ecosystem - would seem to cast doubt on the viability of blockchain governance. The project's more recent evolution, however, presents a fundamentally different perspective on blockchain governance.

The response of the Ethereum community to the DAO hack and other issues was to transform its governance, even as the project began a long process of shifting from environmentally disastrous proof-of-work to proof-of-stake as its mode of network consensus. From a governance perspective, members of the community formalized two groups to help bridge the work of the Foundation and Core Devs and the interests of the larger ecosystem in the evolution of Ethereum's protocol. The Ethereum Magicians and Ethereum Cat Herders were each formed to help with aspects of the process of developing new protocol components and building social consensus around their addition to the protocol.[10]

10. For a brief history of the Cat Herders, see https://web.archive.org/web/20211212204906/https://twitter.com/EthCatHerders/status/1404879458696314880; for the Ethereum Magicians, see https://web.archive.org/web/

These groups have become even more important in Ethereum's ongoing process of shifting its consensus mechanism. In addition to the fundamental change in network production roles (from miners to stakers), the transition has entailed an enormously complex set of changes across all aspects of the project and its protocol. The process is ongoing at the time of this writing, but has remained one that uses the participation architectures of open source to navigate the community's joint commitments to decentralization and technological progress. As one participant describes it:

> It's not anarchy. In line with Raymond's concept [of open source development], the work is largely led by a small team from the Ethereum Foundation which sets the pace and manages the main repository. But everything is being done transparently and openly, with the broadest possible participation. Sixty-two people have contributed to the specification, many more are involved in the nine client implementations in progress, others in R&D discussion on the ethresear.ch site, others still on the fortnightly developer calls (over fifty on a recent call), to name just some examples.[11]

While it is premature at the time of this writing to declare the transition a success, the importance of it for the present study is its demonstration of the controlled fluidity of both the protocol and the governance of it, and the evolutionary nature of protocol-centric governance.

7.2 Progressive Decentralization

Projects also often treat Level 2 governance as an ongoing, adaptive process that shifts as the range and salience of stakeholder groups change, and as new modes of collective governance become available. At the basic level, this process of progressive decentralization is undertaken in stages that reflect a shift from centralized control of a protocol by a foundation through a series of stages to an ultimate "exit to community" (Schneider 2018) that opens participation in governance to greater and greater decentralization, meaning greater control by a broadening set stakeholder roles (see e.g. Fu 2020). Although not universally, this change often involves the introduction of staked voting mechanisms into

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20201125194613/https://medium.com/ethereum-magicians/fellowship-of-the-ethereum-magicians-8711d4d781a6

11. https://web.archive.org/web/20210720202249/https://media.consensys.net/ethereum-2-0s-latest-strides-forward-13f63652e57d?gi=87ae65facc8f

projects once they have become established. Sometimes this involves the creation of a new token for an existing project that confers governance rights in that project, while in others the same token is used for all purposes within a project in order to link incentives more tightly.

0x is an example of the latter. After a first year during which the project's protocol was under the sole control of its core developers, the project's cofounder in 2018 wrote a blog post summarizing the project's research into various governance structures, as well as its long-term plan to shift control of the protocol from the founders (via the company they founded) to the larger community of stakeholders using and building on the 0x protocol (Warren 2018). That vision included introducing staked voting using the project's existing ZRX token as well as a series of projected milestones intended to mark progress toward broader stakeholder governance. The project updated this roadmap with another blog post in early 2020 that announced several new projected milestones and new plans that included a reworking of the governance process include an expanded set of roles, action rights and decision rules (Gonella 2020). These changes would expand the named roles from their original three – makers (of liquidity), takers (of liquidity) and relays – to include others including operators of mesh nodes, market makers and stakers. These latter roles are all related to expanding and deepening the liquidity the overall network is able to offer.

For larger and more established projects, progressive decentralization has taken the form of shifting control of their Level 2 governance from a foundation to a DAO, or a distributed autonomous organization composed of smart contracts that either automate aspects of managerial coordination or replace them with forms of token-based voting. While investment-oriented DAOs remain perhaps the predominant manifestation of DAOs by number, protocol DAOs that focus instead on the coordination of decision-making around protocols are the most consequential for the present study. This transition has been especially pronounced among high-profile projects with protocols that operate on the Ethereum blockchain, many of which have announced a shift to protocol governance DAOs or are already in the process.[12] These protocol DAOs typically encode some variant on open source participation architectures with their formal processes of making proposals and fora for deliberation, combined with encoded voting rules for decision-making, with participation typically (but not always) mediated by some form of

12. See e.g. https://augur.net/blog/augurdao/

governance token. Such moves typically expand the roles involved in Level 2 governance to include non-technical actors, while also codifying formal rules for token-based voting that differ from the rough consensus familiar to small groups of expert developers.

7.3 Generativity

The field-level commitments to progressive decentralization I describe above are integrally linked to an enabled by a separate field-level proliferation of tools and platforms that enable such transitions. While these take many forms, their primary points of commonality are the use of smart contract code to enable collective forms of problem identification and solving, as well as their modular development and openness for recombination into existing projects. This institutional characteristic of digital transformation is reflected in the expansion of platforms for the creation and hosting of DAOs, as well as the formalization of an increasing range of base protocols and other tools for coordinating particular aspects of decision-making. This latter aspect is driven by decentralized research and development that is only loosely coordinated by individual projects through webs of cross-funding at the level of ecosystems, in addition to academic research and the efforts of individual teams. Taken in total, this work operates at the level of the overall field rather than an individual ecosystem.

This pattern of distributed production of tools and components, when coupled with the field-wide commitment to progressive decentralization, creates a fertile opportunity set for the construction of new protocols and projects. For example, the dxDAO - an experimental token exchange created by prediction market Gnosis (one of the most prominent blockchain-enabled protocols building on Ethereum) - dxDAO runs on the DAOstack protocol, and also makes use of DAOstack's "holographic" consensus algorithm for its own governance. Holographic consensus proceeds from the assumption that attention is the scarcest resource. To manage this, the protocol separates voting (and thus voters' attention) from economic power, with the latter exercised through prediction markets used to "boost" proposals to voters' attention and also to signal market actors' views. Gnosis has also been the source of tools used by other projects' DAOs to manage aspects of decision-making, key among which is the Gnosis Safe, a multisignature wallet (analogous to a bank account or treasury requiring multiple signatories) whose code was relied on by more than 240 other projects as of February 2022.[13]

This ability to spin up novel combinations of governance structures and mechanisms also enables the extension of blockchain technology itself into the creation of new digital institutions such as stablecoins, a form of cryptocurrency that seeks to mimic the relative stability of traditional currencies. For example, Cement is a stablecoin (a token designed to serve as a reliable store of value by maintaining a relatively stable price) that has from inception been designed to be governed by a DAO, the CementDAO. In addition to its stablecoin, the project incorporates a distinct governance token (in addition to its MIX stablecoin) as well as two primary forms of staked decision-making that each confer participation rights in various aspects of the system's governance, primarily involving the composition and relative weightings of the components in the basket of other stablecoins in which Cement invests in order to support its stable price. DAO members collectively choose delegates who have in turn staked and locked the project's governance token, the BILD, in order to participate in the curation of a list of approved stablecoins in which to invest. Decisions about the construction of the portfolio are in turn made through a futarchy-based prediction market in which decisions are based on the market value of BILD (in MIX) established in paired markets, one for the proposal and one against it.

8 Findings

As a descriptive matter, the Ostrom + digital framework clarifies several aspects of protocol-centric governance. Most fruitfully, it identifies points of transition as occasioned by tensions of stability and control that tip the nature of governance from one polycentric level to the next. Operating at Level 1 is predicated on the ability of the protocol's operational roles, rights, incentives and rules-in-use to encompass the interests of the projects' designers, participants and other stakeholders. It is also predicated on the ability to maintain stable operations through a form of algorithmic control *by* the protocol, which in turn introduces a level of rigidity that ensures the stability and security that underwrite the viability of the value claims embedded in the ledger.

Because of this rigidity, changes to the protocols themselves have historically only been possible by

13. https://web.archive.org/web/20201115194723/https://github.com/gnosis/safe-contracts/network/dependents

moving down to Level 2, to the level of collective choice decisions about (or governance *of*) the protocol. Decision-making at this level is shaped by open source participation architectures and processes that attempt to strike a balance between participation by those with incentives (typically economic) to engage, as well as those who have scarce expertise to drive the decision-making process. In historically rare cases where the existing set of governance variables and protocol primitives are not able to navigate these collective choice decisions with legitimacy, the process moves a further step down the hierarchy to Level 3, where fundamental changes to the protocol and its governance are enacted. In exceptional cases, these changes can lead to forks, or splits in projects and stakeholder communities.

While this account sits comfortably within the Ostrom + digital framework, it is only partially aligned with the empirical reality I describe above due to its lack of fit with the dynamic nature of Level 3. Introducing the governance affordances perspective identifies the sources of this divergence as well as the ways in which they are being resolved. At the level of affordances, the encoded rigidities of Level 1, the destabilization rights of Level 2, and the institutional generativity of Level 3 pull in opposite directions, with the former anchoring protocols in one mode of operation and the latter two entrenching the ongoing potential for fundamental change. As with other digital forms of infrastructure, the primary manifestation of the paradox of change in the context of blockchain protocols involves this tension between opposing forces toward destabilization and control, and results from the sociotechnical governance affordances of the technology itself.

These tensions produce an inversion of patterns that have traditionally defined the study of digital infrastructures (Baldwin and Clark 2006; Boudreau 2010; Boudreau and Hagiu 2011; Gawer 2014; West and O'Mahony 2008). Unlike other forms of digital infrastructure, where the articulation of platforms and participation architectures serve to increase layers, blockchain protocols often work in the opposite direction by combining affordances in a way that potentially collapses the number of levels in the Ostrom framework. This pattern is predicated on the generative affordances of Level 3, as well as the direction of that generativity toward expanding the possible set of encoded governance primitives. These primitives can then either be recombined into existing projects or used to create entirely new ones. In either case, these primitives embed collective choice decision-making into the protocols themselves, in the process both changing Level 2 decision-making and potentially drawing it directly into the normal functioning of Level 1.

Attending to generativity also necessitates a shift in the relevant macro-level context for Level 3 from the project-level emphasis on individual protocols. Where traditional digital infrastructures are typically defined as part of larger ecosystems of actors (Adner 2017; Gawer 2014), the institutional generativity of blockchain protocols instead draws from larger patterns of behavior at the field level (Hinings, Gegenhuber, and Greenwood 2018).

9 Conclusion

This paper builds on prior advances in the literature on digital governance and infrastructures to develop a novel analysis of blockchain protocols and their role in the governance of blockchain technology that situates that technology in that literature. In doing so, it also contributes to the literature on digital technology and its affordances, while linking those affordances to the literature on governance in the context of paradoxes and tensions. It also contributes to both the literature on blockchain governance by providing a window into the source of the institutional characteristics of the technology.

That source, which I describe above as institutional generativity, points to several possible areas where further study of blockchain governance can contribute to work at the intersection of existing streams of work. The most relevant of these is a need for further research into the field-level mechanisms that underwrite institutional generativity, and their interaction with project-level governance. Theoretically, this points to a need for a more explicit linkage between the information systems literature on the governance of digital infrastructure and the institutionalist literature on digital transformation (Hinings, Gegenhuber, and Greenwood 2018; Mignerat and Rivard 2015). Empirically, understanding the the underlying sources of institutional generativity of blockchain protocols requires an expansion into the well theorized but understudied field-level terrain within which individual projects operate. This terrain is defined by the cross-cutting relations of project-level foundations, developer teams and other collectives, at times mediated through cross-funding and at other times funded through DAO and other community mechanisms such as Gitcoin, and awaits a comprehensive study.

The novelty of these structures also points to a need for caution in taking their stated functions and benefits as given. While the potential of the DAO structure to broaden participation gives some reason for optimism, the very fluidity and generativity of the technology point toward both adaptability and lowered barriers to exit. Put another way, incorporating DAOs does not negate inherent destabilization rights, and may in fact introduce new ones by enabling moves such as voting out influential members over political disputes (Newton 2022).

Finally, attention to the field level also emphasizes an important missing set of governance actors. In the absence of regulation, the other side of institutional generativity is widespread fraud and frequent scandals amidst the boom-time flow of funds into cryptocurrencies, NFTs and other forms of tokens. While the field-level commitments to experimentation and decentralization remain strong, they have yet to be counterbalanced by field-level mechanisms to ensure accountability and transparency. This gap is likely to invite further regulatory scrutiny whose consequences are likely to be positive for investors but less clear for the pace of both technological and institutional innovation.

References

Adner, Ron. 2017. "Ecosystem as Structure: An Actionable Construct for Strategy." *Journal of Management* 43 (1): 39–58.

Allen, Darcy W. E., Chris Berg, Brendan Markey-Towler, Mikayla Novak, and Jason Potts. 2020. "Blockchain and the evolution of institutional technologies: Implications for innovation policy." *Research Policy* 49 (1): 103865.

Arluck, Jacob. 2018. "Amending Tezos: Traversing the Amendment Process." Medium. Library Catalog: medium.com. Accessed March 4, 2020. https://medium.com/tezos/amending-tezos-b77949d97e1e.

Back, Adam. 1997. "Hash Cash Postage Implementation." Cypherpunk listserv. http://www.hashcash.org/papers/announce.txt.

Baldwin, Carliss Y., and Kim B. Clark. 2006. "The Architecture of Participation: Does Code Architecture Mitigate Free Riding in the Open Source Development Model?" *Management Science* 52 (7): 1116–1127.

Beck, Roman, Christoph Müller-Bloch, and John Leslie King. 2018. "Governance in the Blockchain Economy: A Framework and Research Agenda." *Journal of the Association for Information Systems* 19 (10): 1020.

Berg, Chris, Sinclair Davidson, and Jason Potts. 2019. *Understanding the Blockchain Economy: An Introduction to Institutional Cryptoeconomics.* New horizons in institutional and evolutionary economics. Northampton: Edward Elgar Publishing.

Boudreau, Kevin. 2010. "Open Platform Strategies and Innovation: Granting Access vs. Devolving Control." *Management Science* 56 (10): 1849–1872.

Boudreau, Kevin J., and Andrei Hagiu. 2011. "Platform Rules: Multi-Sided Platforms as Regulators." In *Platforms, Markets and Innovation,* 163–192. Cheltenham, UK: Edward Elgar Publishing.

Brunton, Finn. 2019. *Digital Cash: The Unknown History of the Anarchists, Utopians, and Technologists who Built Cryptocurrency.* Princeton, N.J.: Princeton University Press.

Buterin, Vitalik. 2013. *A next generation smart contract and decentralized application platform.* Ethereum White Paper. Ethereum. ethereum.org.

———. 2017. "Notes on Blockchain Governance." Vitalik Buterin's website, December 17, 2017. Accessed March 9, 2019. https://vitalik.ca/general/2017/12/17/voting.html.

Castro, Miguel, and Barbara Liskov. 1999. "Practical Byzantine Fault Tolerance." In *Proceedings of the Third Symposium on Operating Systems Design and Implementation,* 173–186. Accessed May 22, 2019.

Christin, Angèle. 2020. "The ethnographer and the algorithm: beyond the black box." *Theory and Society* 49 (5): 897–918.

Cong, Lin William, Ye Li, and Neng Wang. 2019. *Tokenomics and Platform Finance.* SSRN Scholarly Paper ID 3472481. Rochester, NY: Social Science Research Network. Accessed October 30, 2019. https://papers.ssrn.com/abstract=3478193.

Dai, Wei. 1998. "B-Money, An Autonomous, Distributed Electronic Cash System."

De Filippi, Primavera, and Samer Hassan. 2016. "Blockchain technology as a regulatory technology: From code is law to law is code." *First Monday* 21 (12).

De Filippi, Primavera, and Aaron Wright. 2018. *Blockchain and the Law: The Rule of Code.* Cambridge: Harvard University Press.

DeNardis, Laura, and Andrea M. Hackl. 2015. "Internet Governance by Social Media Platforms." *Telecommunications Policy* 39 (9): 761–770.

Dhanaraj, Charles, and Arvind Parkhe. 2006. "Orchestrating Innovation Networks." *Academy of Management Review* 31 (3): 659–669.

DuPont, Quinn. 2018. "Experiments in Algorithmic Governance: A History and Ethnography of "The DAO," a Failed Decentralized Autonomous Organization." In *Bitcoin and Beyond Cryptocurrencies, Blockchains, and Global Governance,* edited by Malcolm Campbell-Verduyn, 157–177. New York: Routledge.

Ehrsam, Fred. 2017. "Blockchain Governance: Programming Our Future." Fred Ehrsam, November 27, 2017. Accessed March 9, 2019. https://medium.com/@FEhrsam/blockchain-governance-programming-our-future-c3bfe30f2d74.

Faraj, Samer, and Bijan Azad. 2012. "The materiality of technology: an affordance perspective." In *Materiality and Organizing: Social Interaction in a Technological World,* edited by Paul M. Leonardi, Bonnie A. Nardi, and Jannis Kallinikos, 237–258. Oxford: Oxford University Press.

Faulkner, Philip, and Jochen Runde. 2019. "Theorizing the Digital Object." *MIS Quarterly* 43 (4): 1279–1302. ISSN: 02767783, accessed November 10, 2021.

Fu, Yondon. 2020. "Livepeer Governance Roadmap Proposal." Livepeer Blog. Accessed March 23, 2020. https://medium.com/livepeer-blog/livepeer-governance-roadmap-proposal-69a6e9e33f80.

Gawer, Annabelle. 2014. "Bridging Differing Perspectives on Technological Platforms: Toward an Integrative Framework." *Research Policy* 43 (7): 1239–1249.

Glaser, Vern L., Neil Pollock, and Luciana D'Adderio. 2021. "The Biography of an Algorithm: Performing algorithmic technologies in organizations." *Organization Theory* 2 (2).

Gonella, Theo. 2020. "0x Governance in 2020 and Beyond." 0x Blog. https://web.archive.org/web/20200311194040/https://blog.0xproject.com/0x-governance-in-2020-and-beyond-9e7703bc1c54?gi=cb874f86be58.

Goodman, L.M. 2014. *Tezos - A Self-Amending Crypto-Ledger.* White Paper. https://tezos.com/static/white_paper-2dc8c02267a8fb86bd67a108199441bf.pdf.

Grigg, Ian. 2004. "The Ricardian Contract," 25–31. First IEEE International Workshop on Electronic Contracting. IEEE. http://iang.org/papers/ricardian_contract.html.

———. 2005. *Triple Entry Accounting.* Rev. 1.7. Accessed February 2, 2020. https://iang.org/papers/triple_entry.html.

Henfridsson, Ola, and Bendik Bygstad. 2013. "The Generative Mechanisms of Digital Infrastructure Evolution." Publisher: Management Information Systems Research Center, University of Minnesota, *MIS Quarterly* 37 (3): 907–931. ISSN: 0276-7783, accessed November 4, 2021. https://www.jstor.org/stable/43826006.

Hess, Charlotte, and Elinor Ostrom. 2003. "Ideas, Artifacts, and Facilities: Information as a Common-Pool Resource." *Law and Contemporary Problems* 66 (1): 111–145.

———. 2007. *Understanding Knowledge as a Commons: From Theory to Practice.* Cambridge, MA: MIT Press.

Hinings, Bob, Thomas Gegenhuber, and Royston Greenwood. 2018. "Digital innovation and transformation: An institutional perspective." *Information and Organization* 28 (1): 52–61.

Jackson, Matthew O. 2014. *Mechanism Theory.* SSRN Scholarly Paper ID 2542983. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=2542983.

Kallinikos, Jannis, Aleksi Aaltonen, and Attila Marton. 2013. "The Ambivalent Ontology of Digital Artifacts." *MIS Quarterly* 37 (2): 357–370.

Lawrence, Thomas B., Roy Suddaby, and Bernard Leca. 2009. "Introduction: Theorizing and Studying Institutional Work." In *Institutional Work: Actors and Agency in Institutional Studies of Organizations,* edited by Thomas B. Lawrence, Roy Suddaby, and Bernard Leca, 1–28. Cambridge University Press.

Leonardi, Paul M. 2011. "When Flexible Routines Meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies." *MIS Quarterly* 35 (1): 147–167.

Leonardi, Paul M., and Stephen R. Barley. 2008. "Materiality and Change: Challenges to Building Better Theory about Technology and Organizing." *Information and Organization* 18 (3): 159–176.

Lessig, Lawrence. 2006. *Code: And Other Laws of Cyberspace, Version 2.0.* 2nd Revised ed. New York: Basic Books.

Lumineau, Fabrice, Wenqian Wang, and Oliver Schilke. 2021. "Blockchain Governance—A New Way of Organizing Collaborations?" *Organization Science* 32 (2): 500–521. ISSN: 1047-7039, accessed July 19, 2021.

Majchrzak, Ann, Terri L. Griffith, David K. Reetz, and Oliver Alexy. 2018. "Catalyst Organizations as a New Organization Design for Innovation: The Case of Hyperloop Transportation Technologies." *Academy of Management Discoveries* 4 (4): 472–496. Accessed November 2, 2021.

Malhotra, Arvind, Ann Majchrzak, and Kalle Lyytinen. 2021. “Socio-Technical Affordances for Large-Scale Collaborations: Introduction to a Virtual Special Issue.” *Organization Science* 32 (5): 1371–1390.

Markus, M. Lynne, and Mark Silver. 2008. “A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole’s Concepts of Structural Features and Spirit.” *Journal of the Association for Information Systems* 9 (10): 609–632. ISSN: 1536-9323. https://aisel.aisnet.org/jais/vol9/iss10/5.

Maxwell, Gregory. 2013. “Coinjoin: Bitcoin privacy for the real world.” Bitcointalk. https://bitcointalk.org/?topic=279249.

May, Timothy C. 1992. “The crypto anarchist manifesto.” Cypherpunk listserv, November 22, 1992. https://www.activism.net/cypherpunk/crypto-anarchy.html.

Miers, Ian, Christina Garman, Matthew Green, and Aviel Rubin. 2013. “Zerocoin: anonymous distributed e-cash from Bitcoin.” IEEE Symposium on Security and Privacy. Berkeley, CA: IEEE.

Mignerat, Muriel, and Suzanne Rivard. 2015. “Positioning the institutional perspective in information systems research.” In *Formulating Research Methods for Information Systems: Volume 2,* edited by Leslie P. Willcocks, Chris Sauer, and Mary C. Lacity, 79–126. London: Palgrave Macmillan UK.

Nakamoto, Satoshi. 2008. *Bitcoin: a peer-to-peer electronic cash system.* Satoshi Nakamoto Institute. http://nakamotoinstitute.org/bitcoin/.

Narayanan, Arvind, and Jeremy Clark. 2017. “Bitcoin’s Academic Pedigree.” *Commun. ACM* 60 (12): 36–45.

Newton, Casey. 2022. “The man who got fired by his DAO.” The Verge. Accessed February 21, 2022. https://www.theverge.com/22928769/web3-ethereum-name-service-ens-tokens-voting-dao.

Nisan, Noam, Tim Roughgarden, Eva Tardos, and Vijay V. Vazirani, eds. 2007. *Algorithmic Game Theory.* Cambridge, UK: Cambridge University Press.

O’Mahony, Siobhán, and Beth A. Bechky. 2008. “Boundary Organizations: Enabling Collaboration among Unexpected Allies.” *Administrative Science Quarterly* 53 (3): 422–459.

Orlikowski, Wanda J., and C. Suzanne Iacono. 2001. “Research Commentary: Desperately Seeking the “IT” in IT Research—A Call to Theorizing the IT Artifact.” *Information Systems Research* 12 (2): 121–134.

Ostrom, Elinor. 1990. *Governing the commons: the evolution of institutions for collective action.* Cambridge: Cambridge University Press.

———. 2003. “How Types of Goods and Property Rights Jointly Affect Collective Action.” *Journal of Theoretical Politics* 15 (3): 239–270.

———. 2005. *Understanding Institutional Diversity.* Princeton: Princeton University Press.

———. 2017. “Polycentric Systems: Multilevel Governance Involving a Diversity of Organizations.” In *Global Environmental Commons: Analytical and Political Challenges in Building Governance Mechanisms.* Oxford Scholarship Online: Oxford University Press.

Owen-Smith, Jason. 2001. “Managing Laboratory Work through Skepticism: Processes of Evaluation and Control.” *American Sociological Review* 66 (3): 427–452.

Prewitt, Matthew, and Steven McKie. 2018. “Blockchain Communities and Their Emergent Governance: Thoughts on Legitimacy and Narratives.” Medium, November 20, 2018.

Accessed March 9, 2019. https://medium.com/amentum/blockchain-communities-and-their-emergent-governance-cfe5627dcf52.

Rahwan, Iyad. 2018. "Society-in-the-loop: programming the algorithmic social contract." *Ethics and Information Technology* 20 (1): 5–14.

Reyes, Carla L. 2020. "(Un)Corporate Crypto-Governance." *Fordham Law Review* 88:1875–1922.

Roth, Alvin E. 2002. "The economist as engineer: game theory, experimentation and computation as tools for design economics." *Econometrica* 70 (4): 1341–1378.

Roughgarden, Tim. 2010. "Algorithmic game theory." *Communications of the ACM* 53 (7): 78–86.

Rozas, David, Antonio Tenorio-Fornés, Silvia Díaz-Molina, and Samer Hassan. 2021. "When Ostrom Meets Blockchain: Exploring the Potentials of Blockchain for Commons Governance." *SAGE Open* 11 (1): 1–14.

Schelling, Thomas C. 1981. *The Strategy of Conflict.* Reprint edition. Cambridge: Harvard University Press.

Schneider, Nathan. 2018. "Exit To Community." NOEMA. Accessed February 7, 2022. https://www.noemamag.com/exit-to-community.

Schneier, Bruce. 1998. "Memo to the Amateur Cipher Designer." Schneier on Security. https://www.schneier.com/crypto-gram/archives/1998/1015.html#cipherdesign.

Seaver, Nick. 2017. "Algorithms as Culture: Some Tactics for the Ethnography of Algorithmic Systems." *Big Data & Society* 4 (2): 1–12.

———. 2019. "Knowing Algorithms." In *digitalSTS: A Field Guide for Science & Technology Studies,* edited by Janet Vertesi and David Ribes, 412–422. Princeton: Princeton University Press.

Starr, Paul. 2019. *Entrenchment: Wealth, Power, and the Constitution of Democratic Societies.* New Haven, CT: Yale University Press.

Sugden, Robert. 1995. "A Theory of Focal Points." *The Economic Journal* 105 (430): 533–550.

Swartz, Lana. 2017. "Blockchain Dreams: Imagining Techno-Economic Alternatives after Bitcoin." In *Another Economy is Possible: Culture and Economy in a Time of Crisis,* edited by Manuel Castells, 82–105. John Wiley & Sons.

———. 2018. "What was Bitcoin, what will it be? The techno-economic imaginaries of a new money technology." *Cultural Studies* 32 (4): 623–650.

Szabo, Nick. 1997. "Formalizing and Securing Relationships on Public Networks." *First Monday* 2 (9). Accessed September 6, 2016. http://firstmonday.org/ojs/index.php/fm/article/view/548/469%23Contracts.

Tilson, David, Kalle Lyytinen, and Carsten Sørensen. 2010. "Digital Infrastructures: The Missing IS Research Agenda." *Information Systems Research* 21 (4): 748–759.

Tiwana, Amrit, Benn Konsynski, and Ashley A. Bush. 2010. "Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics." *Information Systems Research* 21 (4): 675–687.

Unger, Roberto Mangabeira. 1987. *False Necessity: Anti-Necessitarian Social Theory in the Service of Radical Democracy.* Cambridge, UK: Cambridge University Press.

Wang, Licheng, Xiaoying Shen, Jing Li, Jun Shao, and Yixian Yang. 2019. "Cryptographic Primitives in Blockchains." *Journal of Network and Computer Applications,* no. 127, 43–58.

Wareham, Jonathan, Paul B. Fox, and Josep Lluís Cano Giner. 2014. “Technology Ecosystem Governance.” *Organization Science* 25 (4): 1195–1215.

Warren, Will. 2018. “Governance in 0x Protocol.” Medium. Accessed March 4, 2020. https://blog.0xproject.com/governance-in-0x-protocol-86779ae5809e.

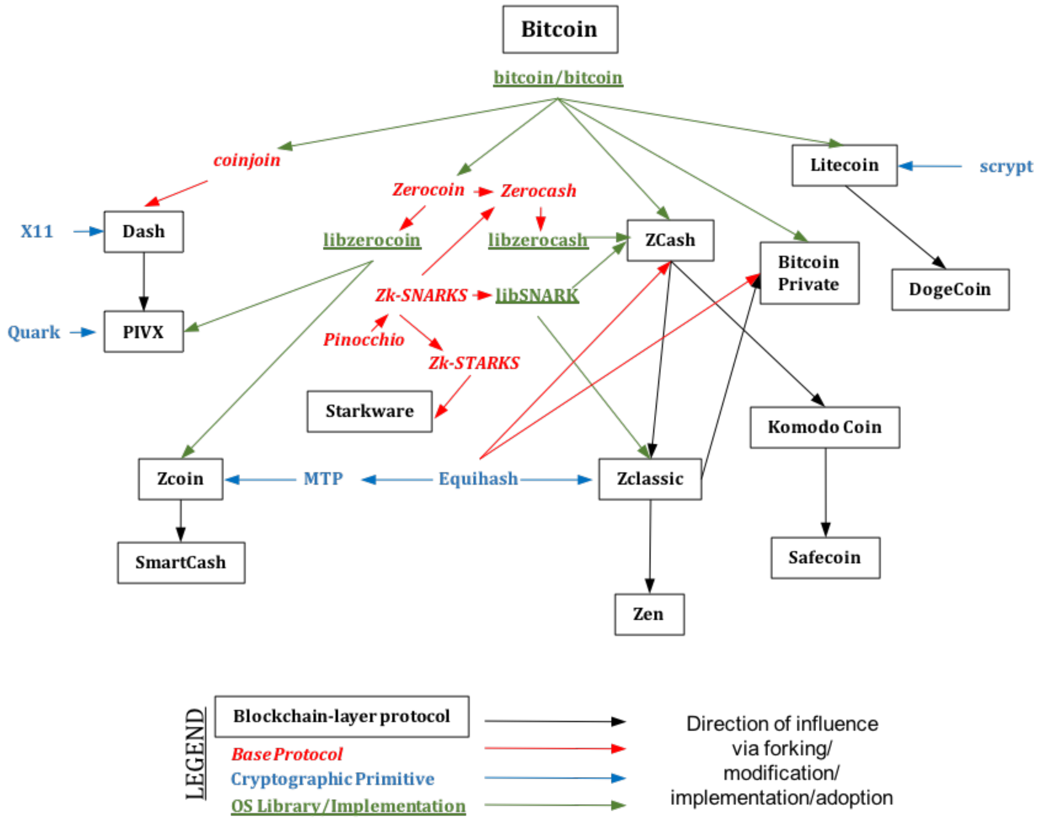
Werbach, Kevin, and Nicolas Cornell. 2017. “Contracts Ex Machina.” *Duke Law Journal* 67:313–382.

West, Joel, and Siobhán O’Mahony. 2008. “The Role of Participation Architecture in Growing Sponsored Open Source Communities.” *Industry and Innovation* 15 (2): 145–168.

Zamfir, Vlad. 2018. “Blockchain Governance 101.” Good Audience, September 29, 2018. Accessed March 9, 2019. https://blog.goodaudience.com/blockchain-governance-101-eea5201d7992.

Zittrain, Jonathan. 2008. *The Future of the Internet and how to Stop It.* New Haven: Yale University Press.

Figure 1: Assembling Blockchain-Layer Protocols



Sources: Github, project white papers.

Figure 2: Analytical Framework

		Ostrom Institutional Variables					
		Roles, Rights	Incentives, Rewards	Rules-in-Use	Community Consensus	Governance Affordances	Nature of Change
Ostrom Polycentric Levels	1. Operational Governance by Protocols						
	2. Collective Choice Governance of Protocols						
	3. Constitutional Governance Transformations						