Disrupting governance: The new institutional economics of distributed ledger technology

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Abstract.

Distributed ledger technology, invented for cryptocurrencies, is increasingly understood as a new general-purpose technology for a broad range of economic activities that rely on consensus of a database of transactions or records. However, blockchains are more than just a disruptive new ICT. Rather, they are a new institutional technology of governance that competes with other economic institutions of capitalism, namely firms, markets, networks, and even governments. We present this view of blockchains through a case study of Backfeed, an Ethereum-based platform for creating new types of commons-based collaborative economies.

Keywords: blockchain, distributed ledger technology, innovation, cryptoeconomics, institutional economics, governance, technological revolution

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1 What type of technology is blockchain?

Blockchain technology was invented in a whitepaper in 2008 by Satoshi Nakamoto, an alias, and was first implemented in 2009 in Bitcoin, a cryptocurrency. Blockchain—also known as *distributed ledger technology*—was not at first the centre of attention, but rather was the under-the-hood invention that enabled the digital currency and payments system to work without the need for a trusted central authority by using a distributed, cryptographically secure, and crypto-economically incentivized consensus engine. Section 2 below explains what blockchains are and how they work. Our purpose here, however, is not simply to introduce this revolutionary new general purpose technology to economists. We want to make a stronger argument, namely that blockchains are better understood as a revolutionary new institutional technology of governance.

The significance of this distinction comes down to the type of effect we are likely to observe in consequence of the adoption and diffusion of this new technology. To call blockchains a new general purpose technology puts them in the same class of technological trajectories (Schumpeter 1939) as for instance electricity, transistors, computers, the internet, mobile phones, and so on (Perez 2009). Just as smart phones and mobile media are a 'next generation' from personal computers, blockchains have been represented as the next generation of the internet (Swan 2015, Tapscott 2016). Blockchains are the technology that underpins cryptocurrencies, but there is a much greater range of applications to any situation involving public records requiring consensus (i.e. a ledger) that are still in nascent stages of exploration and discovery. So perhaps the technological impact of blockchains will be similarly large, disruptive and widespread: eventually comparable to computers or the internet.

Yet an economic analysis of blockchain technology needs to start by carefully considering just what sort of technology this really is. While blockchains can certainly be understood as a new general purpose information and computation technology, they are better understood as a revolutionary new institutional technology for economic coordination. The true significance of this new technology is not as the next in a line of transformative information technologies, each of which powers a productivity revolution: e.g. transistors, computers, internet, … blockchains. Rather, it is as the emergence of a new species of economic coordination: governments, firms, markets, relational contracting, … blockchains.

So, we can examine this new technology through a Schumpeterian lens of ICT productivity, or through an institutional lens of efficient governance. A general purpose technology-focused Schumpeterian economic analysis of blockchain will emphasize the gains in total factor productivity (TFP) to existing economic operations, as well as its creative-destructive effect on firms, markets, industries and jobs. But an institutionally focused analysis of a new coordination technology focuses on a different aspect, namely as blockchains as a foundational technology for new forms of governance for making rule-governed economic orders. In this governance-centred view, blockchains compete with firms, markets and economies, as institutional alternatives for coordinating the economic actions of groups of people.[1] But blockchain technology makes possible new forms of institutional innovation, which we illustrate with our case study of *Backfeed*—generic token-based reputational-scoring consensus-discovering engine, built on the *Ethereum* platform (De Filippi and Mauro 2014), for evaluating contributions to projects on a network.

'What type of technology is this?' is perhaps an unusual question to ask, but then blockchain is an unusual technology. For economists, most technologies can be evaluated from the perspective of a shift in the production function that realises a gain in total factor productivity. This same logic carries over to improvements in institutional technologies, as better institutions increase trust, lower transactions costs and improve the efficacy of economic coordination, raising the marginal efficiency of investment and exchange (North 1990). But blockchain technology, as the news magazine *The Economist* famously put it in 2015, is a 'trust machine'. Distributed ledgers are a technology for manufacturing consensus about facts that are instrumental to economic coordination, a role historically dominated in market capitalist economies by governments and large firms. The economic impact of this new technology can be more clearly seen when viewed from the perspective of institutional governance, rather than from the perspective of total factor productivity.

Section 2 reviews blockchain technology, how it works, and likely prospects. Section 3 distinguishes between technological and institutional innovations, making

[1] Institutions are of course a social technology (Nelson and Sampat 2001), and it is central to new institutional economics that institutional improvements cause improvements in TFP.

the case for why distributed ledger technology is best understood as an institutional innovation (i.e. a governance technology). Section 4 presents a case study of Backfeed, illustrating this line of argument, with further discussion in Section 5.

2 Blockchain Basics

"Blockchain technology" means a mathematically secured, chronological, and decentralized consensus ledger, or database, whether maintained by internet interaction, peer-to-peer network, or otherwise.

– Vermont (US, Legislative Code) *Rule of Evidence* 902 §1913 (2016)

A distributed ledger is essentially an asset database that can be shared across a network of multiple sites, geographies or institutions. All participants within the network can have their own identical copy of the ledger. Any changes to the ledger are reflected in all copies in minutes, or seconds.

– Walport (UK Government Chief Science Advisor) (2016)

2.1 What is a blockchain?

Blockchains were invented to solve a problem that had, prior to that point, utterly frustrated the effort to create digital money. The technology arrived as the main technical innovation behind Bitcoin and soon became, because of this breakthrough, the first successful cryptocurrency (Nakamoto 2008, Böhme *et al.* 2015, White 2015). The actual technology of blockchain combines mathematical cryptography, open source software, computer networks and incentive mechanisms. However, that list of ingredients is perhaps no more enlightening than to say it is the 'magic' behind 'magic internet money'. A better starting point is what blockchains do, what they compete with, and will potentially replace, namely *ledgers*. A ledger is a way of producing *consensus* about the facts that are necessary for commerce to function. Ledgers are the basic transactional recording technology at the heart of all modern economies.

A blockchain is a whole new approach to building and using ledgers, i.e. to producing consensus. Indeed, blockchains are increasingly known as distributed ledger technology (DLT).[2] The new part is to have figured out a way to securely and effectively use distributed ledgers, and thus to produce consensus without requiring centralized trust, overturning the old technology of ledgers that needed to be centralized in order to be trusted. A blockchain is a trustless distributed ledger.

The significance of this new technology follows from the fact that modern economies and societies are, ultimately, built upon ledgers. Moreover, the institutional and organizational outline of a modern economy is to a significant degree a consequence of those ledgers needing to be centralized (i.e. in government, in layers of bureaucracy, in large corporations, etc). This is why blockchain technology—while still new and experimental—is appropriately described as both a *general purpose technology* (*viz*. Bresnahan and Trajtenberg 1995, Lipsey *et al.* 2005), and a *disruptive technology* (*viz*. Christianson 1997).[3]

Ledgers are an ancient consensus technology of transaction, older than the 15th century Venetian Republic, which invented double entry bookkeeping; ledgers are as old as commerce, which is as old as numbers. The ledger is a technology of accounting, of keeping track of (i.e. consensus) about whom (or what) owns what, of who (or what) has agreed to what, of what counts as a what, and to record when any thing of value is transacted. Ledgers are instrumental to modern capitalism (Nussbaum 1933, Yamey 1949, Allen 2011). So a revolution in ledger technology is a deep shift in foundational mechanics of a modern economy.

The basic qualities a ledger possesses are clarity (i.e. legibility), consistency and consensus as a factual and agreed-upon recording of the basic datum of an economy: of identity, property, contract and value, and all in time. But the other basic quality a ledger must possess is *trust* in the ledger itself. A high trust ledger creates a low transaction cost economy, which is a precondition for economic efficiency and prosperity (North 1990, Nooteboom 2002). Trust is highest when the ledger is centralized and strong, and so ledgers for property titling, contracts, money and suchlike have long cemented government at the centre of modern capitalism. The need for high-quality trusted ledgers is, in this sense, the same expression of the need for high-quality central government institutions (non-corrupt, efficient) and large

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[2] More specifically, a blockchain is a particular type of distributed ledger (i.e. a cryptograpically secured distributed ledger). A distributed ledger is a particular type of database (i.e. a database maintained on a distributed network of computers.)

[3] See Buterin (2015), Wiles (2015), Tapscott (2016).

centralized aggregating organizations. But large central governments and large aggregator corporations come at a cost, both in overhead processes associated with statecraft (Scott 1998), and in distorted incentives (the subject of public choice economics). Manufacturing trust can be expensive.

New technologies can reduce the cost of central governance and government record and transactions keeping, and by the late 20th century many ledgers have been digitized.[4] But until the blockchain, these ledgers remained centralized. Distributed ledger technology may be instrumental in reinventing and rebuilding modern economies on something closer to a peer-to-peer platform that will require much smaller contributions from large central controlled organizations (Evans 2014), including most obviously from government, but also from 'aggregator' corporations (Tapscott 2016) that are typical in information businesses such as banking, finance, insurance, and communications. Blockchains are a new foundational technology of public record-keeping (i.e. a consensus ledger) from which to build rebuild existing economies, and upon which to build new types of economies. In one sense, blockchains are a technological improvement in the efficiency of current processes, something that can be observed in the enthusiasm for private (or 'permissioned') blockchains in banking and finance. But blockchains also open new possibilities for coordinating economic activity and so, as our Backfeed case study will illustrate, potentially compete with existing institutions of firms, markets and governments.

2.2 How do blockchains work?

A blockchain is a cryptographically secured and crypto-economically incentivized class of distributed ledger, or decentralized database. Many of the technical specifics need not concern us here, details of which can be found in the various white papers introducing the technologies (Nakamoto 2008, Buterin 2014b, Wood 2014b), and in books and articles surveying blockchain technology (e.g. Swanson 2014, Swan 2015, Pilkington 2016). However, several aspects of how blockchains work are instrumental to our perspective that they are best understood as a new institutional technology.

First, blockchains are ledgers (or databases) and anything that can be coded into a ledger can be recorded on a blockchain. The most obvious data are numbers

[4] Furthermore, these are often then placed on the internet, e.g. banking and finance, or searchable property titling.

recording units of account. But strings of numbers can be used to represent identities, or programs, and in this way ledgers can become units of computation. Blockchain protocols are mechanisms to arrive at consensus about which numbers or programs are the true and agreed upon ones, and once agreed upon and time stamped these enter as a block into a continuous chain, linked to all previous blocks (hence block-chain) all the way back to the genesis transaction.

Second, blockchains are a technology that lives on the internet, i.e. on networks of computers. In the same way the internet was the next generation beyond (unlinked) computers, blockchains are the next generation beyond the internet. Where the internet can go, blockchains can follow. What blockchains bring are *public ledger protocols*. What this does, in effect, is to turn the internet into a world computer (Wood 2015). This was not at first obvious in the seminal version of blockchain, built to solve a specific problem—namely the double-spending problem in digital money,[5] i.e. bitcoin—but by adding a general scripting language with programmable functionality blockchains can become a platform for creating 'smart ledgers' (Swanson 2014).

A leading example is *Ethereum* (Buterin 2014b, Di Filippi and Mauro 2014). If you think of Bitcoin as a specialized technology, a cryptographically secure transaction-based state machine, then Ethereum attempts to build the generalized technology (a virtual machine) on which all transaction-based state machine concepts may be built. It is a platform for zero-trust computing. Co-founder of Ethereum Gavin Wood (2014b) explains that:

> "Ethereum aims to be a superior foundational protocol, and allow other decentralized applications to build on top of it … [It aims to] provide a system such that users can be guaranteed that no matter with which other individuals, systems or organizations they interact, they can do so with absolute confidence in possible outcomes and in how those outcomes might come about."

The generalized Ethereum blockchain technology is the Turing-complete scripting language and protocols for building decentralized applications that run on the Ethereum blockchain.[6] In Ethereum agents can write and execute *smart contracts* (a

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[5] As a specific technology for digital cryptocurrencies, a blockchain (e.g. the Bitcoin blockchain) is a technical solution to the double-spending problem (the 'Byzantine General's problem') using a decentralized database with network-enforced processes based on a proof-of-work consensus mechanism for updating the database.
[6] The Ethereum blockchain contains a cryptocurrency called *Ether*.

self-executing digital contract), from which can be created decentralized applications including *Distributed Autonomous Organizations* (DAOs).[7] Smart contracts and DAOs enable the internet of things (IoT), which ultimately must require a decentralized register because its scale will vastly exceed any possible centralized ledger.

Observe that blockchains enable the basic technology of a public ledger to evolve into something more powerful, namely a public computer. Without reference to any mention of ledgers, cryptocurrency, hash rates or transactions, Vitalik Buterlin (2015), co-founder of Ethereum, offers a startling definition of blockchains:

> "A blockchain is a magic computer that anyone can upload programs to and leave the programs to self-execute, where the current and all previous states of every program are always publically visible, and which carries a very strong cryptoeconomically secured guarantee that programs running on the chain will continue to execute in exactly the way that the blockchain protocol specifies. … Blockchains are not about bringing to the world any one particular ruleset, they're about creating the freedom to create a new mechanism with a new ruleset extremely quickly and pushing it out. They're Lego Mindstorms for building economic and social institutions."

The notion of a 'magic world computer' is the idea that any application that runs on such a platform will be global in reach, i.e. without national or geopolitical boundaries, and extend without bound into the future. Blockchains are platforms for building bespoke economic coordination using distributed ledgers augmented with computationally embedded features such as programmable money (cryptocurrencies), programmable contracts (i.e. smart contracts), and organizations made of software (DAOs). These are the building blocks of new forms of economic governance.

Cryptographically secured blockchains are said to be a 'trustless' technology because you don't need to trust them for them to work. Blockchain technology is *trustless*, meaning that it does not require third-party verification (i.e. trust), but instead uses high-powered crypto-economic[8] incentive protocols to verify authenticity of a transaction in the database (i.e. to reach consensus). In contrast, centralized ledger technologies, as deployed by governments and large corporations, are trust-

[7] Buterin (2014a), Wood (2014a).

[8] 'Cryptoeconomic' refers to any decentralized cryptographic protocol "that uses economic incentives to ensure that it keeps going and doesn't go back in time or incur any other glitch" (Buterlin 2015). The proof-of-work bitcoin mining protocols are cryptoeconomic in this sense.

based technologies because you do need to trust them in order for them to work. The problem is that trust can be expensive to manufacture conventionally, requiring in the case of the nation state a monopoly on violence (Olson 1993), and an implicit promise (a social contract) not to abuse that power. The practical consequence is that enormous rents are locked up behind these centralized monopolies of trust. Trustless technologies are thus an important step in unlocking and releasing that value, and in overcoming the hazards involved in manufacturing trust.

Furthermore, by removing the need for powerful central third-party validation and enforcement mechanisms, cryptographically secured blockchain technologies are generally safe transactions environments, even in the presence of powerful or hostile third parties trying to prevent users from participating. The distributed cryptographic security in this way actually provides many of the features that powerful centralized ‘monopoly-on-violence’ governments have been able to provide in furnishing the necessary order for economic production, exchange and coordination to take place. But blockchains, as instantiations of open source platform governance, can achieve this with both maximum transparency (open source) and maximum scope for exit through the continuous possibility of a hard fork.

2.3 Current implementations and future prospects

At the time of writing (mid-2016), blockchain technologies are still experimental. The underlying platforms and protocols are still being developed, adapted and optimized. This is unfolding as a competitive process, yet one that is also notably also highly collaborative in terms of knowledge sharing. Private investors have been piling in. Most large corporations in banking and finance now have a specialist blockchain development team, something that barely existed even a year ago. Regulators and governments have begun to take the technology seriously, and are struggling to catch-up (Walport 2016). It is a frontier technology, with all that that implies.

What we know so far is that the technology works. The Bitcoin blockchain has been operating continuously since 2009, the Ethereum blockchain since mid 2015. Much of the entrepreneurial development is concentrated around applications of the form ‘X, but on the blockchain’ (Allen and MacDonald 2016). This is entirely reminiscent of the so-called dot-com boom in the late 1990s, which was ‘X, but on the internet', and before that, 'X, but on computers'. So what are these X's on the blockchain?

The seminal X was money. The first money on the blockchain was Bitcoin, then the hundreds of cryptocurrencies subsequently developed (although only a handful have significant valuations). This has now generalized to the idea of tokens (rather than money), reflecting the development that blockchain technologies facilitate the generalized notion of a record of a container for value (a token) and that money as we know it—i.e. centralized, government issued, non-programmable—is actually a very limited technology. Cryptocurrencies revealed that limitation. In our case study on Backfeed we will see how tokens can be created by a community to record value within any self-organized community.

The next X on the list is property, or assets, which is a generalization of money, the most liquid of assets. This starts with big-ticket less-liquid items such as real estate and property, then moves through shares in companies and other high value items (artworks, vehicles, etc), then will likely fully extend through the 'internet of things'. At some point, every thing that can be transacted could be on the blockchain. The implication is much more than just 'existing ledgers, now on the blockchain', and so with efficiency gains, but now with the prospect of the additionality that embedded blockchain technology, such as smart contracts, allows. An example is doorknobs. Put lockable doorknobs on the blockchain (as proposed by Slockit, a blockchain start-up), and now access to potentially any room, anywhere is transactable through peer-to-peer access permissioning. By reinventing the concept of a key, the blockchain technology opens subsequent re-imaginings of how access works. Another example is artworks, for example a particular music track (De Filippi 2015). Music on the blockchain enables fully automated micropayments systems by making a ledger out of access to a thing. And after assets—identity of things—comes identity of people: passports, licenses, certifications, and so on. And after that comes complex, unbundled combinations of people and things. In an important sense the limits of this new technology are the limits of imagination in the same way that once upon a time it was hard to imagine what use computers could be, or to see what things computers could be applied to, before it eventually became clear that the answer was everything. The same pattern unfolded for the internet, and now everything is on the internet. It is not unreasonable to think this same dynamic will play out with blockchain, which is also made of computers and the internet.

The techno-optimist case (Pilkington 2016) is supported by the economics of the learning economies underpinning distributed ledger technology.[9] This is the foundation of the emergence of a so-called *cryptoeconomy* (Evans 2014, Babbitt and Dietz 2015) as an economy unconstrained by geography and political and legal institutions in which blockchains rather than trusted third parties constrain behavior all transactions recorded on a decentralized public ledger, and in which DAOs are a common organizational feature of the economic order. A cryptoeconomy (based on cryptoeconomics, Zamfir 2015) envisages an economic and socio-political order[10] in which blockchain technologies are the foundational ordering principle of the economy.[11]

3 What sort of technology is blockchain?

3.1 Two sorts of technology

Blockchain is a new technology, and the invention, adoption and use of this new technology—i.e. the innovation, as a process of technological change—can be examined using economic theory. But there are two distinct (yet commensurable) approaches to the meaning of technological change: the neoclassical approach, and the new institutional/evolutionary approach. In the neoclassical production-function based approach, technological change is a change in factor productivity. In the new institutional/evolutionary approach, technologies also include 'social technologies', or institutions and organizations, as rules for coordinating people, and so institutional

[9] Distributed ledger technology runs down three exponential cost curves: (1) *Moore's law* (cost of processing digital information, i.e. speed, halves every 18 months); (2) *Kryder's Law* (cost of storing digital information, i.e. memory, halves every 12 months); and (3) *Nielsen's Law* (cost of shipping digital information, i.e. bandwidth, halves every 24 months) (Wiles 2015).

[10] MacDonald (2015) explains how this may lead to a political-economy rupture called cryptosecession. Similar domain claims can be made about cryptofinance (Harvey 2015) and cryptolaw (Wright and De Filippi 2015).

[11] Entrepreneur-driven technological competition is often met with political response. So we should expect that while centralized ledgers may not always be able to compete on cost, they can still compete through co-option of force, through enacting legislation or regulation to artificially drive up the cost of decentralized technologies—including by rendering them illegal (Hendrickson et al 2015, Lessig 2015).

change is also a type of technological change.[12] In the social technology approach, technological change is a change in institutional efficiency.

In the standard model, blockchain technology is factor augmenting. Its adoption drives economic growth by improving the productive efficiency of economic operations. This is both an intuitive and popular understanding of the rationale for the adoption of this new technology—namely that it improves efficiencies, or reducing inefficiencies, with a superior technology to achieve a particular task, e.g. as a payments system or asset transfer register. People adopt the new technology (a process called 'investment') because of these marginal productive efficiency gains. Technological change makes one or more input factors more productive.[13] The aggregate measure of technological change is thus referred to as multi-factor or total-factor productivity (TFP).[14] TFP is equivalently a measure of economic growth and real income, because the rewards of increased factor productivity accrue to the owners of those factors. Technological change in any general-purpose technology—say electricity, computers, or blockchains—is factor augmenting. The benefit of adoption of electricity or computers does not just accrue to the owners of those technologies, but under competition accrues to *all factors* that use those technologies because their marginal productivity has been enhanced.[15] This, in essence, is the standard economic explanation of why technological change drives economic growth as generalized prosperity and why economic growth is equivalently measured as total factor productivity.

Blockchain innovations increase total factor productivity by their effect on marginal factor productivity. They do so by reducing the production costs associated with any endeavour to produce a particular output. A prime example is private or permissioned blockchains that reduce the cost of doing a particular thing (such as

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[12] North (1990), Ostrom (1990), Nelson and Sampat (2001).

[13] In the standard neoclassical model, technology (A) is a function mapping input factors (K) to outputs (Y), Y=A(K). Innovation is modeled as the process of technological change, which is represented as a shift in the production function. Technological change is *factor augmenting*, such that its effect is that more output can be produced with the same quantity of inputs, or equivalently fewer inputs are required to produce the same output, over at least one dimension of input.

[14] Technological innovation affects TFP by improving the translation between K and Y. A new technology increases the efficiency of the translation, modelled as the production function shifting outwards (Y->Y'), or the isoquant shifting inwards (K->K').

[15] Technological innovations drive investment in new capital (both human and physical) by raising the return to investment in those factors, which occurs by raising the marginal revenue product of that investment. This is how total factor productivity increases in consequence of technological change.

reconciliation, or international money transfers). Here blockchain technology reduces a production cost by eliminating an intermediate cost in a production process. We can model blockchain as a technological innovation, as a species of productivity enhancing technological change, by treating it as the latest in a long line of general-purpose technologies. And while the specifics of the size of the aggregate effect and the exact form of the distributional gains and losses (what Joseph Schumpeter called 'creative destruction') are *ex ante* unknowable, as are the exact shape of all the entrepreneurial opportunities and forms of consumer surplus, or the rate of adoption-diffusion, what can be inferred is that the new technology will contribute to economic growth and prosperity because, by making existing factors more productive, it 'economizes' on scarce resources.

But there is another way that economizing can occur, which is by economizing not on production costs, but on *transactions costs*. This idea was first elucidated by Ronald Coase (1937, 1960) to explain the existence of the firm (a firm economizes costs of using a market, *viz*. transaction costs). The basic insight of new institutional economics (also known as transaction cost economics) was to ask why do some transactions occur in firms (hierarchies) rather than in markets? The answer was that because of transactions costs in dealing with uncertainty, asset specificity and frequency of dealings, some transactions are more efficiently conducted in hierarchies rather than markets (Williamson 1979, 1985). Transactions costs thus determine the efficiency of different governance institutions. The basic insight that transaction cost economics can bring to blockchain is to ask the same but now extended question: why do (might) some transactions occur in blockchains, rather than in firms or markets?

Transactions costs are the costs of coordinating economic activities, and reductions in transactions costs also have an impact on total factor productivity measures. However, the mechanism by which these have their effect is different. Effective institutional innovations reduce transactions costs of coordinating economic activities. Improvements in institutional orders reduce transactions costs, and drive investment in those economic orders, which eventually shows up as increases in economic activity per input unit, and so as total factor productivity growth. In the neoclassical approach, technological change lowers production costs. In the new institutional approach, technological change lowers transaction cost. So the question is—which type of technological change is blockchain? Which type of costs—

production costs or transactions costs—does it most significantly effect? Now blockchain is manifestly an information and computation technology—as a software protocol based on cryptography, a blockchain is a new technology for public databases of digital information—and it is also manifestly a general purpose technology. So at first sight it seems to be a productivity enhancing technology, which is to say one that economizes on production costs. Yet, when we dig deeper into the nature of these new economies, they are often revealed to be consequences of transactions cost efficiencies.

3.2 Why is blockchain not a technological (production cost) innovation?

With a productivity enhancing innovation, the new technology enables more to be done with less. This is the better-stronger-faster-cheaper model that is clearly observable in the technology of transformational processes such as the harvest yield of a piece of land, the power output of an engine, the performance per unit cost of a material, or the channel capacity of a pipe, irrespective of whether carrying atoms or bits. These measures of productivity carry through an agricultural, industrial, and an informational economy. Now, it is certainly possible to view distributed ledger technology in this way. Blockchains enable better end-to-end performance of a value transfer system, faster reconciliation and clearing of a transaction ledger, stronger security of an informational database, cheaper discrimination of access, and so on. These basic value propositions are widely recognized by many new adopters of the technology.

Yet where do these gains come from? It is not that the electrons now move faster, or that the processing engines are more efficient. Indeed, in many respects, and particularly with proof-of-work protocols, the opposite is true. Rather the source of the productivity gain often traces to an organizational efficiency gain. Blockchains economize on production costs by changing the organizational form by which value is created, often stripping out layers of activity that are no longer needed because trusted third-parties are no longer required, or can be achieved more efficiently using, say, multisig protocols (Tapscott 2016). These efficiency gains in the end-to-end achievement of a task, operation or process can certainly be interpreted as productivity gains, however the source of those productivity gains comes from the prospects of large-scale re-architecting of the organization of production with the substitution of large, slow and costly centralized-hierarchical systems for much leaner, faster distributed-consensus systems. The productivity efficiencies from blockchain technology are ultimately due to the organizational efficiencies that it enables. As a class of technology, what distributed ledger technologies do is decentralize. Centralization can be an efficient source of order and control at small scales, but all complex evolving self-organizing systems tend toward decentralization as they grow because coordination costs eventually overwhelm any centralized node, rendering the order of the whole system brittle and vulnerable. Loss of centralized control is a cost, but the benefit is that such systems become more robust. Distributed systems still require system-wide coordination, but this is achieved through adaptation, such as through the price system in a market (Hayek 1945). Blockchains create distributed systems by eliminating centralization that was previously needed for reconciliation or consensus in record-keeping on a ledger by providing an alternative distributed technology for that purpose.

This renders blockchains a new competitor to the central objects that economics studies, namely organizations and markets. When coupled with token systems (as we will see in the Backfeed case study below), blockchains make possible new institutional orders that operate at a micro scale, yet with the full coordination properties of what we would otherwise attribute to a self-organizing macroeconomy. Distributed ledgers are a technology for making entire economies where previously agents were technologically constrained to the types of economic order that could be generated only by firms, organizations, markets and governments.

3.3 Why is blockchain an institutional (transactions cost) innovation?

That blockchains are fundamentally an institutional rather than a technological innovation is not mere taxonomic semantics. This distinction matters because it focuses analysis on what is actually changing in the creative-destruction this innovation brings. What is changing is the technology of economic coordination and governance. And that means that the relevant margin of analysis is with substitute mechanisms of economic coordination and governance. To unpack the relevant margins of governance efficiency that blockchains have over firms, markets, networks, relational contracting, and governments, consider the underlying problem of the economics of efficient governance.

In the Williamson (1985) operationalization of Coasian transactions cost analysis, a hierarchical organization is a method for controlling opportunism in the presence of bounded rationality and asset specificity. This protection against opportunism gives rise to the transaction cost efficiency of hierarchies and relational contracting over markets. But the valuable prospect of blockchain, when operationalized with smart contracts and distributed autonomous organizations, is precisely to eliminate opportunism by cryptoeconomic mechanisms. This works by enabling a spot market exchange to carry forward indefinitely a pure promise; in other words, it returns the transaction to a market-like context, but with fewer of the costs of a market. This is revolutionary because it undermines the strong case for the economic efficiency of *hierarchies* (which exploits incomplete contracts) and *relational contracting* (which requires trust between parties) over markets. To the extent that blockchains can eliminate opportunism, they will be at a competitive advantage to traditional organizational hierarchies and relational contracts. So how do blockchains eliminate opportunism? In essence, by radical public transparency coupled with crypto-consensus mechanisms, executed automatically with smart contracts (Swanson 2014).

However, the obvious problem is that most in-the-world firms (*cf*. DAOs) are largely made of *incomplete contracts* (Hart 1989). Yet blockchains refer to a particular class of economic system made of *complete contracts*. This sharpens the distinction between blockchains, firms, relational contracts and markets. In the Coasian view, a firm is a 'nexus of contracts', but specifically as a nexus of *incomplete contracts* (Jensen and Meckling 1976, Williamson 1985, Hart and Moore 1990). Contractual incompleteness is the origin of the study of economic organization and governance because in a world with zero transactions costs, all contracts would be complete and all economic transactions would be market transactions. Incomplete contracting models (Tirole 1999) usually invoke transactions costs arising from: (1) uncertainty, or unforeseen contingencies; (2) costs of writing contracts; (3) costs of enforcing contracts. Uncertainty refers to information problems. Blockchain-enabled smart contract-facilitated transactions ought to experience fewer efficiency problems due to information asymmetries—adverse selection (*ex ante* to a transaction) and moral hazard (*ex post* to a transaction). But smart contracts could be effective ways to load significant numbers of low probability state-contingencies into contracts. To the extent that these could function like open source libraries insertable into machine-readable contracts, the complexity cost of writing contracts could scale linearly, and so lower transaction costs. However, at the same time, bargaining and haggling costs, both *ex ante* discovery and *ex post* renegotiation are likely to be unaffected by a shift to blockchain. Costs of enforcing contracts will depend upon the extent to which human discretion remains part of at least one side of the transaction.

In the new institutional economic analysis, organizational form is largely shaped by the need to control opportunism (Williamson 1985: 64-7). Opportunism has a proximate and an ultimate cause. The proximate cause is the conjoint pay-offs to idiosyncratic investment (asset specificity), a normal part of all economic production that requires coordination of joint inputs. But the ultimate cause of opportunism arises because of the intent and ability of agents to exploit trust. Williamson calls this 'self-interest seeking with guile', and emphasises the connection with bounded rationality. With full rationality, complete information and costless transactions, all agents can engage in comprehensive contracting, so no need for trust. But if information is imperfect, if transactions are not costless (i.e. conditions of bounded rationality), then trust operates at the economic margin of contracting. In this view, blockchains are a new mechanism to control opportunism by eliminating the need for trust by using crypto-enforced execution of agreed contracts through consensus and transparency. Opportunism is eliminated with distributed autonomous organizations. This extends the domain of the market and shrinks the domain of organizations. So, if the Williamson model of firms and markets is correct, and effective cooperative economic activity and investment is stymied by both threats and engagement of opportunism, blockchains will be a revolutionary institutional innovation. However, if governance exists for reasons other than opportunism, then distributed ledger technologies may be well be a new productivity engine, but not the institutional revolution argued here.

However, another possible avenue by which a blockchain governance revolution may unfold at the margin of the economic efficiency of organizations versus markets is due to Alchian and Demsetz (1972), who proposed an alternative transactions costs theory of the firm that emphasized *monitoring costs* in team production. When production is more efficient with shared inputs than non-shared ones, it may be more efficient to establish sets of agreements that characterize firms as the team use of inputs plus the centralized position of some party in the contractual arrangements of all other inputs, than to govern these transactions using markets. The Alchian and Demsetz model argues for the efficiency of centralized monitoring. However, what blockchains introduce is a new prospect of *distributed monitoring*, undermining the main argument for the comparative efficiency of the firm in the context of the generalized efficiency of production with shared inputs.

Both the Williamson model of the firm (opportunism) and the Alchian and Demsetz model of the firm (monitoring) furnish theoretical reason to expect that blockchain technology may erode the margin of the comparative efficiency of firms. If correct, then new institutional economics furnishes an analytic framework to consider how the mass adoption of this new technology might shape the evolution of, as Williamson (1985) framed it, the economic institutions of capitalism.

One particular window into this new world of decentralised organizations and distributed governance to coordinate individuals into higher-level plans and goals is Backfeed—an engine and platform co-founded by one of the authors (PdF) in 2014 that is designed to offer a new governance model to support the emergence of new institutional forms to be deployed on the blockchain.

4 Case Study: Backfeed

Backfeed introduces a social protocol on top of blockchain-based infrastructures to coordinate individuals through the creation and distribution of economic tokens and reputation scores. Its purpose is to eventually allow for the emergence of meritocratic systems and emergent alternative economies that can variously augment or substitute for extant modes of economic governance (i.e. provided by hierarchies or markets). At its core, Backfeed is an engine for decentralized cooperation between distributed agents. It implements a *Social Operating System* for decentralized organizations, enabling massive open-source collaboration without any form of centralized coordination.

Backfeed builds upon the power of open-source collaboration and enhances it with a distributed governance system for decentralized value production and distribution. The system is inspired from the model of *stigmergic* coordination found in nature, whereby certain species of animals—such ants, termites, birds, etc.—create complex social structures that do not rely on any hierarchical structure, but rather require individual agents to coordinate themselves indirectly by embedding traces into their own environment so that others can subsequently act upon it. The goal with Backfeed is to elaborate a system that can replicate the same model, but transpose it in the context of much more complex and sophisticated human organizations. This is where the blockchain comes in.

When combined together with the underlying blockchain infrastructure and smart-contract platform provided by Ethereum, Backfeed can be used to implement a generic decentralized governance structure for blockchain-based applications. Indeed, the Backfeed protocol allows for the collaborative creation and distribution of value in spontaneously emerging networks of peers. The system relies on a specific protocol that enables these distributed networks of peers to contribute freely and spontaneously to an organization, and to coordinate themselves indirectly in order to achieve the full potential of collective intelligence. A peer-to-peer evaluation system is used to determine the perceived value of each contribution in a decentralized fashion, in order to allocate influence and rewards accordingly.

In contrast to Bitcoin's proof-of-work consensus algorithm, which ultimately rely on algorithmically quantifiable and verifiable actions (i.e. computational resources donated to the network), Backfeed implements an alternative and more generic consensus algorithm called proof-of-value, which relies on human evaluations in order to discover the value of every contribution—as perceived according to the distinctive value system of each individual network. Individual members of a community or organization evaluate the contributions of others, who will be rewarded (according to the value they bring to the community) with economic tokens (transferable) and a reputation score (non transferable) that indicates the influence they hold within the organization. The reputation score can increase in two ways: (1) by making a contribution that is perceived as valuable by the community; and (2) by making a useful evaluation of someone else's contribution, that is in line with the community's value system. Hence, individuals are judged not only by their actions (or contributions), but also by their judgment (or evaluations) of the actions of others.

The result is a decentralized reputation system that dynamically distributes authority amongst community members in order to organically organize individuals into a meritocracy with a decentralized topology. The values of every individual that partake in the organization, weighted according to the influence that they each hold within that organization, will constitute—as an aggregate—the overall value system of the organization. As the dynamics of the organization evolve, with new contributors coming and old contributors leaving, the influence of every individual will change, and so will ultimately the value system of that organization.

All these components combined provide the basic building blocks for the deployment of so-called Decentralized Collaborative Organizations (DCO), organizations that are not controlled by any given entity, but rather consist of a large number of individuals contributing out of their own free will to a common (collaborative) project. One might argue that this kind of spontaneous and distributed collaboration already exists in the realm of open source software, where many developers collaborate towards the achievement of a common goal in a coordinated but decentralized manner. Perhaps, but open source software represents only a small part of modern society. A proper model for DCOs should enable decentralized large-scale and systematic collaboration in potentially every sector of activity: from content creation to online gaming and networked communications, from fundraising to financial transactions, from corporate management to organizational matters, and so on. Besides, without a proper incentive structure, Github did not manage to bring the model of decentralized collaboration into the mainstream, and has left the open-source movement as a niche even within the software development community.

As opposed to the traditional open source model, where people contribute for mere ideological reasons or for the purpose of increasing their social capital, in the case of any Backfeed-enabled DCO, decentralized cooperation can be achieved in a way that is both effective and sustainable over time. Contributions in a DCO are motivated by a specific system of economic and reputational incentives, and the resulting value produced by every contribution is shared among all collaborators through a specific evaluation protocol which lies at the core of the Backfeed protocol.

Imagine, for instance, thousands of people writing books and publishing them on their own, without any publisher or middleman; millions of people insuring each other, without the need to rely on centralized insurance companies; thousands of freelancers gathering together into a decentralized crowd-based journalism organization, thousands of citizens coming together to form a decentralized real-time ride-sharing or park-sharing network; and millions of internet users contributing to a decentralized social search-engine. By combining blockchain infrastructure with Backfeed's distributed governance model, this vision might revolutionize the way people work and organize themselves to engage in economic activity, in the broadest sense of that concept. In this sense, Backfeed can be seen as a tool capable of changing the nature of the blockchain from that of a *catallaxy* (i.e. a spontaneous organization driven solely and exclusively by market dynamics) into that of an *economy* (i.e. an open but more circumscribed organization driven by a uniform hierarchy of ends, and which incorporate its own economic or monetary system).

The same protocol also incorporates some of the characteristics of traditional organization, in that it require constant monitoring of everyone's actions, in order to constantly update the reallocation of tokens and reputation according to the perceived value of contributions and evaluations that everyone brings to the network. Yet, as opposed to the traditional model of governance based on *centralized monitoring*, where one central authority is in charge of monitoring and assessing the value of everyone else's action, in the case of Backfeed, monitoring is achieve in a distributed manner, through collective action and peer-to-peer evaluation, thus incarnating the concept of *distributed monitoring* at the governance layer, and in addition to the distributed consensus algorithm that is found at the blockchain infrastructure layer.

5 Capitalism evolving

Blockchain distributed ledger technology is a rare and special general purpose technology because it adds a further category to the suite of Williamson's (1985) 'economic institutions of capitalism'—namely, markets, hierarchies and relational contracting—with a *new type of economic order*: a Decentralized Collaborative Organization.[16] A Decentralized Collaborative Organization (DCO) is a self-governing organization with the coordination properties of a market, the governance properties of a commons, and the constitutional properties of a nation state. It is an organization, but it is not hierarchical. It has the coordination properties of a market

[16] See also Ostrom (2005), Hodgson (2015), Stringham (2015).

through the token systems that coordinate distributed action, but it is not a market because the predominant activity is production, not exchange. And it has the unanimous constitutional properties of a rule-of-law governed nation state, by complicit agreement of all ‘citizens’ who opt-in to such a DCO, and the automatic execution of the rules of that DCO through smart contract enforcement (Atzori 2015). An example of such a generalized platform for making DCOs is Backfeed in the case study above.

What is striking about DCOs, and a major animating feature of development on the Ethereum and similar platforms, is this revolutionary sense of a new type of economic order emerging ‘beyond capitalism’, on an open-source, open-platform peer-to-peer economy (Raymond 2001, Lessig 2004, 2009, Benkler 2006), exemplified in the notion of ‘collaborative commons’ (Rifkin 2014), ‘commoning’ (Bollier 2014) and ‘platform cooperativism’ (Bauwens 2005). Where once radical scholars wrote of the inevitable overthrow of capitalism by socialism, that impulse has shifted to the promise of P2P platforms and networks as the new vehicle to deliver a social transition beyond capitalism. This is the opposite extreme to the neoclassical economic model of blockchain as just another general-purpose productivity enhancing technology. That model, as we argued above, neglects the effect of distributed ledger technology on the structure of economic governance. But the revolutionary model is similarly misleading because it commits the opposite error of assuming that this is a pure governance substitution effect.

A better way, we suggest, to think of the long run effect of distributed ledger technology is that the innovation is neither a source of productivity *growth* in an institutionally unchanged economy, nor *revolution* in which blockchains, as governing institutions, replace firms and markets, but rather is an *evolution* of the basic institutions of capitalism, as a new variation that competes with the existing institutional species. An economy with blockchain technology is institutionally more varied and complex than an economy without it. From the new institutional economics (i.e. transactions cost) perspective, the relevant analytic criterion is comparative institutional efficiency (Williamson 1979, 1991; North 1990; Ostrom 2005). The most efficient institution to coordinate economic activity—cf. markets, hierarchies, relational contracting, blockchains—is the one that achieves the desired outcome at lowest transactions costs.

So there are two frontiers on which the extant order of market capitalism might evolve through the innovation of blockchain technologies: (1) the substitution (reallocation) of economic governance from firms, markets and relational contracts into blockchains; and (2) the integration of economic governance into activities not currently within the modern institutional economy because the transaction cost threshold is currently too high. The Backfeed case study illustrates both frontiers: showing the prospect of a new type of economic governance, made possible by the blockchain, can substitute for activities currently organized in firms and markets. But Backfeed also shows that this may bring economic coordination and governance institutions, with the tools for collective decision-making, allocation of resources, coordination, money, constitutions, and other instruments of governance, to spaces that currently are either poorly served or not served at all by extant coordination mechanisms of markets, hierarchies and governments. Indeed, it may well be that the long run most significant economic impact of distributed ledger technology accrues through this latter pathway, as effective economic institutions are adopted into domains that previously had relatively high cost or poor governance.

6 Conclusion

Blockchains, or cryptographically secured distributed ledger technology, is one of the most innovative new technologies of the 21st century. While still closely associated with cryptocurrencies such as Bitcoin, the underlying distributed ledger technology is widely seen as a new general-purpose information technology whose disruptive effect already extends beyond digital money to a broad range of economic and government activities that rely on consensus of a database of transactions or records, especially when augmented with so-called smart contracts (Walport 2016). Epochal technological revolutions from steam power, steel, electricity, oil, and computers have long driven modern market capitalism through creative destruction and productivity growth, and it is tempting to add blockchains to this list. Yet blockchains are different because their revolutionary significance is that they are an institutional technology of governance. These new governance capabilities that blockchains bring have the potential to offer far greater improvements to total factor productivity and economic welfare than the mere technological innovations typically considered, such as efficiency gains in payments settlements, for example. Economic analysis is at risk of fundamentally misunderstanding the long run consequences of distributed ledger technology unless it clearly grasps that this is a technology that revolutionises governance—it is an institutional technology more like 'the invention of the joint stock company' than 'the invention of the internet'. Blockchains are not just a new ICT but more fundamentally are a new mode of governance that competes with other economic institutions of capitalism, namely firms, markets, networks, relational contracting and governments.

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