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Blockchain and the evolution of institutional technologies: Implications for innovation policy

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ABSTRACT

For the past century economists have proposed a suite of theories relating to industrial dynamics, technological change and innovation. There has been an implication in these models that the institutional environment is stable. However, a new class of institutional technologies—most notably blockchain technology—lower the cost of institutional entrepreneurship along these margins, propelling a process of institutional evolution. This presents a new type of innovation process, applicable to the formation and development of institutions for economic governance and coordination. This paper develops a replicator dynamic model of institutional innovation and proposes some implications of this innovation for innovation policy. Given the influence of public policies on transaction costs and associated institutional choices, it is indicated that policy settings conductive to the adoption and use of blockchain technology would elicit entrepreneurial experiments in institutional forms harnessing new coordinative possibilities in economic exchange. Conceptualisation of blockchain-related public policy an innovation policy in its own right has significant implications for the operation and understanding of open innovation systems in a globalised context.

1. Introduction

Blockchain technology was invented in 2008 (Nakamoto, 2008). While it is undoubtedly still in the experimental phase of development and shrouded in technological, economic and political uncertainties, blockchain is nevertheless emerging as the core component of the next generation of the internet upon which digitally-native economic institutional infrastructure is being built (Berg et al., 2019a; Werbach, 2018). Blockchain technology (and other distributed ledger technologies that do not arrange data in blocks) is an internet-based digital protocol to operationalise a decentralised economy. Blockchain provides a digital platform for decentralised digital currencies (Abadi and Brunnermeier, 2018; Böhme et al., 2015; Narayanan et al., 2016), digital assets (through the token economy, Voshmgir, 2019), digital identity (through self-sovereign identity protocols), and so-called smart contracts (Szabo, 1994). These applications in turn enable innovations such as decentralised finance, decentralised digital platforms, and decentralised autonomous organisations (or DAOs) (Beck et al., 2018).

Rather than understanding blockchain as an example of digital platform innovation (as in Saadatmand et al., 2019), this paper treats blockchains as a technological architecture with distinct implications. ``Traditional” digital platforms (such as the social media and advertising platforms Facebook and Google) are firms that operate multisided markets (Rochet and Tirole, 2003). Despite the unique dynamics attributable to multisided markets, it is nonetheless still the case that those digital platforms are institutionally firms, insofar as they are governed centrally (where decision-making power is delegated from a large number of shareholders to a small group of managers). Blockchains, by contrast are digital platforms where `management' is distributed, or decentralised, across a large number of token holders, block validators (miners in the case of Bitcoin), and developers (de Filippi and Lovelock, 2016).[1]

It is that distribution of governance that makes blockchain an

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[1] Not all blockchains and distributed ledgers are fully decentralised. Permissioned, or private blockchains such as as TradeLens (built on the IBM and Linux Foundation's Hyperledger Fabric platform) considered by Saadatmand et al., 2019, trade-off decentralisation for speed and privacy. In this paper we restrict our analysis to public blockchains such as Bitcoin and Ethereum.

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``institutional technology'' (Davidson et al., 2018), distinct from industrial technologies. Industrial technologies are typically seen through a Schumpeterian lens: impacting on industrial productivity by adoption into firms (Nelson and Winter, 1982). By contrast, institutional technologies need to be seen through the lens of transaction costs and economic organization. As Catalini and Gans (2016) explain, the economic effect of adoption of blockchain technology is characterised by a lowering of verification costs and networking costs, both of which are forms of transaction costs (see also Luther, 2016). The primary effect of institutional technologies such as blockchain is on transaction costs of economic coordination and governance between *a network of* economic agents (Langlois and Robertson, 1995), rather than the productivity impact of innovation on *an* economic agent (such as a firm or household per se).

The innovation process of an institutional technology is different to that of an industrial technology. The blockchain innovation process is occurring through many sectors of the economy simultaneously and across different margins, including finance (Blandin et al., 2019), agriculture (Caro et al., 2018), trade and logistics (Allen et al., 2019a; Casey and Wong, 2017), healthcare (Zhang et al., 2018), creative industries (Mohan, 2019; Potts and Rennie, 2019) and government services (Jun, 2018). Since Nakamoto (2008) there has been substantial innovation around blockchain consensus mechanisms, constitutional design, programmable smart contracts on blockchains, and tokenisation. All taken together, this activity is usefully characterised as innovation in the digital technologies of governance through the emergence of experimental new protocol-based platform infrastructure to facilitate economic coordination.

Little attention has been given to institutional innovation in Schumpeterian models because institutions are traditionally slow to evolve (North, 1990). As an institutional technology, blockchain facilitates institutional entrepreneurship over new forms of economic coordination and governance. We can no longer abstract away from institutional evolution and still have a perspective on economic systems consistent with reality. Evolution of industrial technologies now takes place across multiple systems of institutional governance enabled by a diverse set of institutional technologies that evolve. This new class of technological change—the evolution of a technology of governance—requires new understandings of the dynamics of that change that are not represented well by standard replicator (Metcalfe, 1998; Metcalfe et al., 2006) or diffusion models (Bass, 1969). As institutional technologies are technologies of governance they require groups to adopt, not just individuals. Individuals choose institutional technologies based on the expected transaction cost of exchange and mutual expectations about adoption. Innovation in institutional technologies is at the competitive selection margin of lowered transaction costs.

If institutional evolution is best characterised as a new type of innovation with a new type of evolutionary economic process, then it also has implications for innovation policy. What Novak (2019) and Berg et al. (2019b) describe as ``crypto-friendly'' public policy is an adaptive policy framework to facilitate the adoption of blockchain policy by the varied interests engaged in innovative practices. In a context of innovation of institutional technologies, crypto-friendly policy *is* innovation policy. Governments should adopt crypto-friendliness as a generalisable principle for policy, enabling the process of institutional evolution and competition to take place. Here governments seek to minimize the costs of structural institutional innovation and adjustment, including the coordination of seemingly unconnected policy domains within and across nation-states. Public policies which serve to facilitate blockchain investment, adoption and use enable the emergence of entrepreneurial discoveries over institutions by multiple actors (i.e., suppliers, and users, of blockchain applications and solutions), augmenting existing open innovation theories which are largely restricted to product and process innovations (von Hippel, 2005).

The paper proceeds as follows. Section 2 introduces and reviews concepts of institutional technologies *vis-à-vis* industrial technologies and their innovation dynamics. Section 3 presents an analytical representation of the innovation process for blockchain in a simple replicator dynamic model. This model demonstrates the difference between industrial adoption and institutional adoption. Section 4 then characterises the main implications of institutional innovation as it relates innovation policy and crypto-friendliness, arguing that crypto-friendly policy is innovation policy. Section 5 concludes.

2. Evolution of institutional technologies

Institutional technologies are processes and mechanisms that enable systems of governance for economic exchange. Williamson (1973, 1985) analysed several institutional systems enabled by institutional technologies including firms, markets and governments. The Williamsonian analysis of these institutional systems is often linked to the tradition established by Coase (1937). Transaction costs are the rationale for systems of institutional governance other than voluntary free exchange in markets. While Coase emphasises the capacity of the firm manager to coordinate transactions because of *ex ante* transaction costs of price discovery, Williamson explains vertical integration as overcoming *ex post* transaction costs stemming from asset specificity and opportunism (Bylund, 2019). Williamson argues that transaction costs arise because contracts can never be complete, and states of the world will arise for which actions are not specified, requiring costly *ex post* renegotiation. Firms help to economize on these transaction costs by providing for a command and control hierarchy in which actions are ordered rather than negotiated, and disputes resolved by fiat. Similarly, governments enable institutional governance by the system of contract law that resolve disputes by fiat and provides for public goods by cheap coercion rather than costly negotiation. Adding to firms, markets and governments that Williamson analysed, we might also consider clubs (Buchanan, 1965) and commons management (Ostrom, 1990). Together, institutional technologies enable a wide range of systems of governance that comparatively economise on the transaction costs that we face in voluntary exchange.

While the transaction cost economics framework developed by Williamson might give us the tools to undertake comparative institutional analysis, governance structures are also open to institutional innovation. Just as entrepreneurs can create new products, they can also develop and apply new governance structures using institutional technologies, directing attention to the rules of the game themselves (Bylund and McCaffrey, 2017; Henrekson and Sanandaji, 2011). Firms, governments, clubs and commons were all once institutional innovations. New forms of governance must themselves be discovered, applied and tested as mechanisms to solve governance and coordination problems in economic systems. Similarly, in a development context, Leeson and Boettke (2009) refer to ``protective-tier'' entrepreneurship as the practice of developing systems to protect property rights, as compared to conventional ``productive-tier'' entrepreneurship. More broadly, institutional entrepreneurship can refer to groups of individuals and entities who, through collective action, seek to transform institutions (Aldrich, 2011).

Innovation in institutional technologies is rare: the joint stock company came about in the seventeenth century, while representative democracy is a creature of the nineteenth century. The technologies that provide the governance of firms, markets, governments, clubs, and the commons innovate only over the course of decades. Furthermore, our understanding of the dynamics of the adoption, diffusion and evolution of new technologies is shaped by the technological changes we observe in the real world. Between about the 1750s and the 1960s the most visible forms of technological progress were improvements in industrial production efficiency, obtaining greater output from fewer inputs (Landes, 1969). In the latter half of the twentieth century technological progress was most visible in the fields of information and communication, most strikingly the emergence of the internet as a platform for new socio-economic exchange (Parker et al., 2016).

From their understanding of the characteristics of these technological shifts, economists and other students of innovation have developed approaches to economic evolution such as adoption-diffusion models and replicator dynamics. The relative stability of institutions means that we tend to treat institutions as a constant in evolutionary dynamic modelling. This treatment is similar to how we treat cultural change as a variable that only shifts over the long-run, in contrast to the rapid evolution of industrial technologies.

With the advent of new institutional technologies such as blockchain, however, this implied institutional stability comes into question. Lowering the cost of institutional entrepreneurship raises important questions for the applicability of adoption-diffusion models and replicator dynamics. Blockchains are one such institutional technology that lowers the cost of institutional entrepreneurship. Blockchain-based institutions compete on different margins with existing institutions and enable the overlapping of different institutions within the same physical space (MacDonald, 2015, 2019; MacDonald et al., 2016). We can think of this as a new kind of *institutional polycentricism*, driven by institutional entrepreneurship (Allen et al., 2019c). Indeed, blockchain is being used as a new institutional technology to compete with existing institutions of money and payments, asset registration and transfer, identity, provenance and contracting, and other such foundational administrative economic infrastructure. In the following section we develop a model of the evolution of institutional technologies that characterises and theorises this form of economic evolution, revealing industrial-type models to be a special case of more general models.

3. Model

In Neo-Schumpeterian models of economic evolution, the core analytic conception is that the unit of variation, selection and replication is a complex industrial conception of knowledge (Dopfer and Potts, 2008). This knowledge is generally understood to refer to the technological capabilities of firms, thereby forming an industrial population (Nelson and Winter, 1982). Economic evolution is therein defined in the same way as in biology, as change in the population frequency of generic knowledge. Several factors are held constant in this evolutionary formulation of industrial dynamics. One is the institutional environment, I, which is generally understood to itself evolve, but on a much longer time scale. The institutional environment can be conceived of in the analytic game-theoretic sense as the rules of the game (North, 1990). In most models, this institutional context is assumed to be supplied by government. But institutions can also be supplied by private entrepreneurial actors who provide rules of governance to coordinate economic activity (Stringham, 2015). Blockchain technology facilitates the entrepreneurial supply of economic institutions as a new class of governance innovation at the economic margin of monitoring and network costs (Catalini and Gans, 2016).

Following Davidson et al. (2018), we call these *institutional technologies* (I), forming an institutional population, $I \in \mathbf{I}$. We say that there exists a population of diverse institutional systems $\mathbf{I}$ that is expanded by institutional entrepreneurs and which is acted upon by selection pressures to be reconciled into a set of institutional systems that are retained. We might think of this evolutionary process as characterised in a relatively familiar manner, adopting Fisher's population dynamics (Price, 1972).

We say that there exists a population of diverse institutional systems $\mathbf{I}$. Entrepreneurial action over institutional technologies (e.g. blockchain innovation) can expand this set. When entrepreneurial action is concerned specifically with the design and implementation of institutional technologies, these new combinations manifest in novel structures of interlocking rights, obligations and empowerments that constitute systems of institutional governance. This can also be understood to be concerned with, as Lachmann (1956) might have put it, contributing new combinations to the capital structure of the economy to fill gaps where opportunities are not being realised, except that this capital supports institutional systems rather than industrial production. This entrepreneurial process creates institutional variation. As agents choose institutional systems for contracting, differential adoption of particular institutional technologies defines an evolutionary process of variation and selection.

The transaction cost tradition of institutional economics informs us of the fitness characteristic upon the basis of which these selection pressures are exerted. In institutional economics, the fundamental unit of analysis is the *contract* (Williamson, 1979, 2002, 2005). We take a simplified approach to formal contract theory relative to Hart and Moore (1988), as formal contract theory is oriented toward the characterisation of optimal contracts, where we are concerned more with the characterisation of the institutional context in which they exist. We think of a contract between two agents i and j as a function $p_{ij}(x_t)$ that represents the payments to be made from i to j conditional upon the realisation of a particular state of the world x_t (including actions taken by j) at time t. We therefore think of a particular system of institutional governance, $I \in \mathbf{I}$ as an input into a production function that transforms that system into transactions costs $c_T(I)$ associated with the total mutual costs of writing, monitoring, negotiating, executing and enforcing a contract $p_{ij}(x_t)$. We will, for simplicity, assume transaction costs $c_T(I)$ are constant across all contracts struck within a system I. We say, following Coase (1937) and Williamson (1973, 1985), that institutional technologies that support such systems are selected based on the extent to which they mitigate transaction costs.

We may now characterise the evolution of institutional technologies using Fisher's fundamental theorem of selection, which states that the change of mean fitness characteristics is equal to the variation of that characteristic across the population. Hence, for the evolution of institutional technologies, the rate of change of mean transactions costs $E_{I\in\mathbf{I}}c_T(I)$ across the set of institutional systems is equal to the negative of the variance of those transactions costs $V_{I\in\mathbf{I}}[c_T(I)]$

$$-\frac{\partial}{\partial t}E_{I\in \mathrm{I}}c_T(I) = V_{I\in \mathrm{I}}[c_T(I)]$$

recognising that fitness improves as transactions costs *decrease*, and where variance $V[\cdot]$ is defined in the usual fashion

$$V_{I\in \mathrm{I}}[c_T(I)] = \sum_{I\in \mathrm{I}}\frac{|P(I)|}{|P(\mathrm{I})|}[c_T(I) - E_{I\in \mathrm{I}}c_T(I)]^2$$

$|P(I)|$ is roughly speaking the ``size" of the platform for which the system I provides institutional governance, defined as the cardinality of the set $P(I)$ of contracts struck which are subject to the system of institutional governance I, and $|P(\mathbf{I})|$ is the cardinality of the set $P(\mathrm{I}) = \cup_{I\in \mathrm{I}}P(I)$ of all contracts across *all* systems $I \in \mathbf{I}$. Mean fitness, mean transactions cost, is thus defined also in the usual fashion

$$E_{I\in \mathrm{I}}c_T(I) = \sum_{I\in \mathrm{I}}\frac{|P(I)|}{|P(\mathrm{I})|}c_T(I)$$

As with any other kind of evolution, the evolution of institutional technologies depends on the change in the size of the population with a particular characteristic. Here, evolution is brought about by changes to the size of the set of contracts $P(I)$ for which the institutional system I enabled by institutional technology provides governance. The elements of this set are determined by the contracting decisions of agents i and j. As these agents decide to differentially contract in one system over another, they exert evolutionary selection pressures on the set of institutional technologies.

In order to strike a contract, agents i and j must of course simultaneously agree upon the form of the contract $p_{ij}(x_t)$ to exist between them. However, if we have diversity in institutional systems within which that contract may be struck, then the choice of which institutional system to which the contracting relationship will be subject is a non-trivial one (Kaal and Calcaterra, 2017). Hence agents i and j must simultaneously agree on *both* the form of the contract $p_{ij}(x_t)$ to be struck between them *and* the institutional system of governance I to which that relationship will be subject in their contracting behaviour, which now becomes a tuple $a_{k=i,j} = \{p_{ij}(x_t)\ I\}$. If, and *only if* the choice of contract *and* the institutional system to which it will be subject can be coordinated between agents i and j, that contract will be struck and included in the set of contracts which are subject to the institutional system of governance to which i and j have decided to be subject. Hence, we have that

$$p_{ij}(x_t) \in P(I) \Leftrightarrow a_i^* = a_j^* \ \& \ I \in a_i^*, a_j^*$$

We can thus characterise the set of contracts struck which are subject to the system of institutional governance I at any given point as

$$P(I) = \{p_{ij}(x_t)\colon a_i^* = a_j^* \ \& I \in a_i^*, a_j^*\}$$

The rate of change of the cardinality of this set, upon which we have seen the evolution of institutional technologies depends, is given straightforwardly by

$$\frac{\partial |P(I)|}{\partial t} = \frac{\partial}{\partial t} |\{p_{ij}(x_t)\colon a_i^* = a_j^* \ \& I \in a_i^*, a_j^*\}|$$

If this differential is *positive*, the institutional system I and the technology which supports it is being differentially selected by the evolution of institutional technologies. If this differential is *negative*, the institutional system and the technology which supports it is being differentially *de*selected. This manifests at the population level through the Fisher equation in the convergence of mean transaction costs across the population of institutional technologies to those of the institutional technologies which are the most differentially selected.

3.1. Coordination and institutional evolution

What we can see from this characterisation of the evolution of institutional technologies, if we consider the dynamics that bring it about, is that it is contingent on *coordination*. Specifically, the outcome will depend upon both the technologies and costs of coordination on particular institutional configurations. In the standard evolutionary model, with just one institutional system in the choice set, these coordination costs go to zero. Coordination costs are in this sense an institution specific component of transaction costs under evolutionary selection pressure.

Furthermore, if agents i and j *cannot* coordinate their choice of contract and/or their choice of institutional system of governance to be subject to, then they will strike no contract at all. That is,

$$a_i^* \neq a_j^* \Rightarrow p_{ij}(x_t) \notin P(I)$$

The evolution of institutional technologies therefore progresses as coordination problems are differentially solved for particular systems $I \in \mathbf{I}$ within the population. Where coordination is achieved by agents i and j on the form of contracts to be struck $p_{ij}(x_t)$, and the system of institutional governance I to which those contracts will be subject, the set of contracts struck which are subject to that system will grow, and that system will be differentially selected by institutional evolution. Where coordination cannot be achieved by agents i and j on either the form of contracts to be struck $p_{ij}(x_t)$ or the system I of institutional governance to which they will be subject, the set of contracts struck which are subject to that system will not grow, and that system will be differentially non-selected by institutional evolution.

Institutional evolution is in this way characterised by the differential solution of problems of ``Schelling-point coordination”, following Schelling (1960). Given decisions made by agents j to enter contractual relationships subject to institutional governance, agents i must choose to enter the same contractual relationships subject to institutional governance and vice versa. There is thus a proto-network effect extant in the evolution of institutional technologies as we have characterised it. While further research ought to relax the assumption of constant transaction costs, as increasing transaction costs may counter-weight this effect, this is an instance of a bootstrapping problem for institutional entrepreneurs, as no institutional technology can be selected unless it is *already* being adopted by some agents. The cryptocurrency space, in prime instance, is characterised by this problem of coordinated adoption (often without communication). Hence, we expect the evolution of institutional technologies will be correlated across a population of users through differential adoption. Once a particular institutional system supported by institutional technology is being adopted as a system of governance for contractual relationships, it is more likely to be further adopted as a system for institutional governance as coordination problems are differentially solved with respect to it.

3.2. Transaction costs shape the evolution of institutional technologies

To investigate the dynamics of the evolution of institutional technologies further, we must make some assumptions about how i and j make decisions about the contracts to strike and institutional systems within which to strike them. We might suppose that, on average and over time, the tendency is for contracting behaviour to converge to the maximisation of expected value from contracts $p_{ij}(x_t)$ between i and j. The expected value of contracting behaviour $a_{k=i,j} = \{p_{ij}(x_t)\ I\}$ we can express, for our purposes, very simply. We suppose that the contract $p_{ij}(x_t)$ would yield expected profits of $E_{x_t \in X_t} \pi_k [p_{ij}(x_t)]$, with expectations taken across the states of the world $x_t \in X_t$ which exist within the known set thereof X_t. The contract $p_{ij}(x_t)$ we say is associated with transactions costs $c_T(I)$. For simplicity, we define these as a function of the institutional system alone and include value lost from expected profits $E_{x_t \in X_t} \pi_k [p_{ij}(x_t)]$. Since the expected value of contracting behaviour if coordination is not achieved is zero, we can, without loss of generality, say that the expected value $E_{x_t \in X_t} v_{k=i,j} [p_{ij}(x_t)\ I]$ of contracting behaviour $a_{k=i,j}$ is

$$E_{x_t \in X_t} v_{k=i,j} [p_{ij}(x_t)\ I] = E_{x_t \in X_t} \pi_k [p_{ij}(x_t)] - c_T(I)$$

This expected value is optimised in contracting behaviour $a_{k=i,j} = \{p_{ij}(x_t)\ I\}$, which consists of two arguments, the contract $p_{ij}(x_t)$ written between i and j and the institutional system to which it is subject, I. The maximisation of expected value in the *form* of the contract $p_{ij}(x_t)$ written between i and j we can think of as characterising a necessary condition for the solution of the coordination problem which will cause an institutional system I and the institutional technology which enables it to be selected. The form of contract $p_{ij}^*(x_t)$ which maximises the expected value of contracting behaviour is defined, straightforwardly enough, as

$$p_{ij}^*(x_t) = \text{argmax}_{p_{ij}(x_t)} E_{x_t \in X_t} v_{k=i,j} [p_{ij}(x_t)\ I] \Leftrightarrow E_{x_t \in X_t} v_{k=i,j} \left[p_{ij}^*(x_t)\ I \right] \geq E_{x_t \in X_t} v_{k=i,j} \left[p_{ij}^{'}(x_t)\ I \right] \ \forall \ p_{ij}^{'}(x_t)$$

This, roughly speaking, is Hart and Moore (1988) considered in the optimal contracting literature. Yet we are concerned only with the optimal form of contracting insofar as discovering it on average and over time to be coordinated between agents i and j provides the necessary condition for the coordination problem to be solved by which an institutional technology will be selected by the process of evolution.

The maximisation of expected value in the choice of *institutional system* I to which any contract between agents i and j we can think of as characterising a *sufficient* condition for the solution of the coordination problem which will cause an institutional system I and the institutional technology which enables it to be selected. The institutional system I, enabled by institutional technology, which maximises the expected value of contracting behaviour is defined as

$$I^* = \text{argmax}_{I \in \mathrm{I}} E_{x_t \in X_t} v_{k=i,j} [p_{ij}(x_t)\ I] \Leftrightarrow E_{x_t \in X_t} v_k [p_{ij}(x_t)\ I^*] \geq E_{x_t \in X_t} v_k [p_{ij}(x_t)\ I'] \quad \forall \quad I' \in \mathrm{I}$$

Or, reducing the problem further

$$I^* = I\colon c_T(I') \geq c_T(I) \quad \forall \quad I' \in \mathrm{I}$$

Now if the form $p_{ij}^*(x_t)$ of the contract which maximises the expected value of contracting behaviour, and the institutional system to which it will be subject which maximises the expected value of contract behaviour is coordinated, that is, $\{p_{ij}^*(x_t)\ I^*\} = a_i^*, a_j^*$, the coordination problem will be solved by agents who on average and over time converge to contracting behaviour that maximises expected value. Notice the conditions under which this will occur inform us further of the dynamics shaping the evolution of institutional technologies. The greater the extent that transaction and monitoring costs are minimised by any given institutional system $I \in \mathbf{I}$ then, the greater the extent to which coordination will be achieved on contracting behaviour, and so the more contracts struck within that institutional system, the more economic value created, and therefore the greater the extent to which that institutional system and the institutional technology that supports it will be selected by the process of evolution.

3.3. Traditional models of economic evolution as a special case

Traditional models of economic evolution in industrial technologies consider a special case with little diversity across the population of institutional technologies, so that coordination on the institutional system within which contracting behaviour is to take place is trivial. In such models of industrial technology evolution therefore, we have assumed that $\mathrm{I} = I$ and therefore

$$V[c^T(I)] = 0$$

In this case, it is trivial to consider contracting behaviour $a_{k=i,j} = \{p_{ij}(x_t)\ I\}$ as consisting of deciding both the form of the contract written $p_{ij}(x_t)$ and the institutional system to which it will be subject I, as there is only *the* institutional system within which to strike it. It is better to consider contracting behaviour as consisting of deciding only the form of the contract written, so that $a_{k=i,j} = \{p_{ij}(x_t)\}$. In this special case, the only evolution within the economy is that *within* the set of contracts $P(I)$ struck within *the* institutional system, and we might effectively ignore that such institutions are even relevant by suppressing them in the expression of

$$P = \{p_{ij}(x_t)\colon a_i^* = a_j^*\}$$

This set will then, in this special case where we have set the diversity of institutional technology to zero, fully characterise the economic system. Such evolution as occurs *within* the set of contracts arises from the dynamics of the set of contracts $\{p_{ij}(x_t)\}_{j \in N}$ which i strikes with other members of the population $j \in N$

$$\frac{\partial}{\partial t} \left| \{p_{ij}(x_t)\}_{j \in N} \right|$$

If we were to assume that the contracts $p_{ij}(x_t)$ were simple exchange contracts, and that i were to coordinate on any decision made by j about the form of contract to be struck between them, we would be able to recover, in particular, the Metcalfe (1998, 2008) models of the evolution of industrial technologies by specifying Fisher's fundamental theorem over the characteristics of the production technologies used by i upon which the striking of contracts are contingent. If, on average and over time, the tendency is for contracting behaviour on the part of j to converge to the maximisation of expected value from contracts $p_{ij}(x_t)$ between i and j, we would observe this evolution to be driven by the improvement of product attributes and prices through process and product innovation (Markey-Towler, 2016).

In an economic system with diversity of institutional systems implemented using competing institutional technologies, traditional selection dynamics operating on a diverse set of industrial technologies takes place within multiple institutional technologies that are *themselves* subject to evolutionary processes (as a kind of multi-level selection mechanism, Traulsen and Nowak, 2006). Selection occurs within those institutional systems implemented on institutional technologies as industrial technologies allow for new product attribute and price mixes in contracts, creating diversity of industrial technologies reconciled by market selection on the basis of attribute and price. At the same time, selection is occurring at the level of those institutional systems themselves as institutional technologies allow for new systems of institutional governance to which contracts will be subject to emerge, creating diversity of institutional technologies reconciled by selection working through transactions costs.

4. Blockchain crypto-friendliness as innovation policy

The model outlined in the previous section provides an institutionally-centred account of the extension of contract-laden coordinative possibilities within an economy via the suppression of transaction costs. Adjusting the costs of verification and monitoring of data integrity, and facilitating decentralised networks of exchanging economic value, blockchain is firmly conceptualised as a class of institutional technologies for contracting over the terms and conditions of realisable mutual gains. As noted the attributes of blockchain *qua* institutional class may be supplied by private entrepreneurial actors, whereas institutional form is conventionally assumed to be supplied by government. Even so, we do not preclude meaningful contributions on the part of policymakers in shaping the institutional feasibility of blockchain amongst the institutional governance set. In this section we see that public policy is a pivotal means to facilitate the development of blockchain as an institutional technology for large-scale economic coordination. Creating an accommodative environment for the evolutionary process of institutional technologies described above—a generalisable approach in blockchain known as “crypto-friendliness” (see Novak 2019)—should be understood as innovation policy.

Growth in the scale and scope of blockchain-related activities has drawn the attention of policymakers in recent years, translating into a range of taxation, regulatory and legislative responses (Werbach, 2018). To some extent, blockchain policy has been motivated by a desire to adapt distributed ledger technology in the securing of efficiencies in existing public administration and social services provision and, in other instances, to harness blockchain as a potential lever to realise broader economic development objectives. In recognition of divergent policy responses toward blockchain technology (Blandin et al., 2019; Novak and Pochesneva, 2019), it is possible to discern a framework for identifying degrees of policy accommodation toward distributed ledger technology. This phenomenon has been referred to in recent literature as ``crypto-friendliness” (Berg et al., 2019b; Novak 2019), with a more crypto-friendly environment representative of modes of policy development that facilitate an extensive adoption and usage by multiple actors (individuals, and groups encompassing both private and public sectors) within the relevant politico-jurisdictional settings.

Notwithstanding observational differences across political jurisdictions, the development of public policies with respect to blockchain appears inspired by a desire to accommodate this technology within the parameters of existing fiscal and regulatory practices and understandings. Given the potentially radicalising attributes of blockchain with respect to institutional configurations, policy efforts to fit blockchain technology within the incumbent policy apparatus may be conceived as attempts to minimise the costs of structural institutional adjustment potentially posed by this technology, or, drawing upon insights from public choice or Chicago School regulatory theories, to maintain capacities for economic rent generation through intermediated ledgers (Davidson et al., 2018). Juxtaposing this political project to accommodate blockchain within existing policy domains is a focus upon outcome-oriented policies in this space that ``seeks to intervene at the operational level of prices, quantities or income structures and flows" (Dopfer and Potts, 2008, p. 94). The discussion of crypto-friendliness within academic literature to date serves as no exception to this rule.

It has been widely recognised that public policies both influence, and are influenced by, the level of transaction costs and the way they are manifest (Dixit, 1996; North, 1990; Tadelis and Williamson, 2013). In his studies Oliver Williamson, for example, notes that in economic environments characterised by bounded rationality and asset specificity, and where transaction costs are being incurred by agents in the process of undertaking exchange-based coordination, public policies may bear a significant influence upon the incentive for contracting and other key facets of institutional choice. As noted previously, it is considered that blockchain promotes institutional innovation by driving transaction cost reductions, which in turn ease coordinative processes of exchanging economic value among networks of heterogeneous agents.

Institutional innovation is the introduction of novelties with respect to systems of governance for economic exchange, and innovation in this guise (as in any other) is represented as a process of lowering transaction costs. Accordingly, it is possible to extend the logic of crypto-friendly public policy to consider it as *innovation policy* with the profound potential to reshape the governance and coordination of exchange relations, and the institutions which therein support such activity, rather than simply an end-state intervention of allocational or distributional consequences affecting the relative economic positioning of certain individuals or firms.

To a certain extent there are complementarities between the institutional innovation approach outlined in this paper, and developments in innovation theory emphasising the characteristics of innovation as open-ended practices involving distributed actors with varied stakes in the production and dissemination of knowledge and capabilities (summarized by, for example, Diercks et al., 2019; Nambisan et al., 2019; Schot and Steinmueller, 2018). Facilitative policy treatment of blockchain *qua* crypto-friendliness is posited to provide incentive for entrepreneurial and innovative behaviour with respect to economic exchange possibilities. Policies that promote the adoption and use of blockchain technology also have the potential to stress-test experiments in institutional coordination and governance through blockchain applications, with attendant learnings from these acts of entrepreneurialism promoting the building of competences amongst developers, investors and users. Complementing this insight is the notion—extended from Hsieh and Wu (2019) regarding technological innovation within digital platforms—that policy crypto-friendliness may facilitate processes wherein ``outside-in" and ``inside-out" movements of meanings, practices and understandings of institutional development amongst complementing sets of participating actors operating amongst blockchain platforms (Saadatmand et al., 2019).

An appreciation of blockchain-related policy as a new arm of innovation policy leads to a consideration of the integrative nature of policy domains, certainly with respect to the treatment of economic action taking place using distributed ledger technologies. Whereas policy narratives and practices toward blockchain adoption and use in many countries largely appear to be conducted in an isolating, non-holistic fashion—for example, with respect to taxation, financial regulation, competition policy and public administration—the overarching policy structure of the crypto-friendliness criterion provides the basis for policymakers to identify interdependencies of policy settings, and diagnose discontinuities in policy, from the standpoint of contextualising efforts to enhance the coordinative and governance capacities of blockchain as an institutional technology.

Policy stances which, either in intention or effect, facilitate continuing blockchain adoption within the economy (with appropriate safeguards for consumers and other relevant parties in place) is highly likely to facilitate the polycentrically-ordered coordination possibilities outlined in this paper (also Aligica and Tarko, 2012). Testing of this hypothesis should consider the potential for policy makers to comparatively gain meaningful insights from the gradual operationalisation of blockchain-relevant policy in other jurisdictions, as well as the implications of legal, cultural and other contingencies which undoubtedly bear upon the feasibility of policy transferability between countries and even sub-national jurisdictions. In other words, responses by policymakers national (and sub-national) levels with respect to the institutional possibilities of blockchain is not only expected to provide opportunities for blockchain developers, investors and users to engage in regulatory arbitrage for the preferred ``crypto-friendly" policy environment (Novak 2019; Tarko and Farrant, 2019), but would potentially facilitate policy learnings with respect to institutional integrity and performance (Yu, 2011).

Blockchain is conceived as an institutional technology insofar as the platform enables actors to build, and integrate, new institutional solutions on top of the generic field of the (cryptographically-secured) platform. Opening the space for institutional affordances, blockchain technology is likely to contribute toward the acceleration of innovative *praxis* across disciplines and other boundaries, in both non-linear and global scales (Potts, 2016). In this regard a key challenge for the efficacy of crypto-friendly innovation policy is to duly recognise the international orientation and scale of blockchain participation, and the concomitant need for emergent coordination amongst policymakers to enhance the potential for transaction cost reductions and, thus, productive institutional reconfiguration. There is growing recognition amongst blockchain academics and practitioners over the need for improved policy coordination across jurisdictions (for example, in the case of trade logistics and supply chain coordination, Allen et al., 2019b), and it is hypothesised that practical coordinative action in the policy crypto-friendliness domain would enhance the institutional innovation potentiality of blockchain.

There are several ways that crypto-friendliness relates and integrates with recent developments in the theory of innovation policy, and the various ways that innovation policy is framed (Schot and Steinmueller 2018). For instance, a distinction has been made between the ``intensity" of innovation—or the level of engagement with innovative activity to address given opportunities or problems—and the ``direction" of innovation which shifts the application of innovative activity to address new (or re-emerging) opportunities or problems (Hopenhayn and Squintani 2017; Kulve et al., 2018; Mazzucato 2018). Blockchain technology embodies innovation of the latter directional calibre, insofar as contemporary innovation directionality aims to address the ``grand" economic, environmental, political and social challenges of the early twenty-first century. The uniqueness of blockchain technology, as posited in this paper, is that this digital infrastructure works to alter the direction of innovation *at the level of institutions*. Furthermore, our interpretation of crypto-friendly policy is consistent with the notion of ``catalytic" policy (Cantner and Vannuccini 2018), in which policy settings are established to temporally shifts innovation direction in favour of blockchain experimentalism. The stress is not upon ``picking winners" in innovation but creating a generic policy environment which encourages the self-selection of blockchain entrepreneurs to engage in, and implement the, innovation themselves. In a blockchain context, catalytic policies may come in the form of tax code clarity for cryptocurrencies, refined regulatory definitions for initial coin offerings and public sector use-case trials, and supported by such measures as ``regulatory sandboxing" to facilitate innovative acts without legal penalty (Finck 2018; Blandin et al., 2019; Novak 2019).

5. Conclusion

Previously institutional innovations have been the domain of historians, not innovation economists. This is because institutional innovations have been mostly discrete and rare events punctuated by decades or centuries of stability. They are therefore parametric in even long run economic models and correspondingly also in innovation policy analysis and design. The emergence of blockchain technology, however, raises important questions for this implied institutional stability. Blockchains are new digital platforms that lower the costs of institutional innovation by offering a decentralised economic infrastructure for the new economy. As the panoply of proof-of-concept blockchain trials and formal projects across the globe are testifying, blockchain infrastructure is providing new avenues for entrepreneurship and innovation amongst previously unforeseen domains of economic activities across firms, industries, sectors and nation-states. In this paper we outlined the implications of innovation in institutional technologies (*c.f.* industrial technologies) for the analysis of economic evolution, and the subsequent implications for the scope and application of innovation policy.

This paper presented a novel evolutionary economic model of institutional innovation by focussing the selection mechanism on the cost of contracting and thus furnishing a dynamic model of institutional evolution. Institutional technologies present a hard adoption problem. Our model captures the process of blockchain evolution, emphasising the coordination problems and network externalities around the adoption of institutional technologies. This demonstrates how the evolutionary processes of institutional technologies such as blockchain are unique, and necessitate a reassessment of how we think about innovation policy.

Our understanding of institutional entrepreneurship and evolution has several implications for innovation policy. First, crypto-friendliness—a measurement of policy accommodation for blockchain (Berg et al., 2019b; Novak 2019)—should be adopted as an aspect of a generalisable approach to innovation policy in the context of digital transformations. New institutional technologies, such as blockchain, must compete with existing organisations, such as private sector firms and public sector agencies. Innovation policy should seek to reduce barriers to the development and adoption of institutional technologies, and facilitative crypto-friendly policy is intended to reshape the boundaries of institutional forms through reduced transaction costs. This approach broadens previous understandings of blockchain-related policy—as fiscal and regulatory interventions influencing the ``surface-level" operating environment for blockchain developers, investors and users—to bring to light the impact of digital transformation upon deeper, ``beneath-surface" institutional change transcending organisational and political boundaries.

A further implication of crypto-friendly innovation policy is the elevated role of coordinating bodies for institutional development and adoption. The need for coordination in institutional development and investment is clear from the focus on development of standards around blockchain applications of global extent, as well as the industry focus on interoperability between different parts of the blockchain ecosystem. Furthermore, the bootstrapping challenge we outline in our model reframes the innovation problem as less about innovation systems design and more about coordinated adoption across groups. Which organisations play this coordinating role will emerge as the industry develops. While we anticipate much of this role will be played through international coordination bodies or third-party consultants, innovation policymakers should both acknowledge the importance of this coordinating role and seek to lower the costs of coordination and the formation of consortia.

Our theoretical contributions provide a useful framework within which to analyse the evolution of blockchain and other institutional technologies. As the costs of institutional innovation fall we expect to see greater entrepreneurial resources directed towards institutional entrepreneurship. Adding to the practical implications for innovation policy outlined above, we expect an increase in the range of empirical data and case studies shedding further light on this evolutionary process. Just as we have experienced a process of learning and discovery over the scope and application of innovation policy for industrial technologies, there will be a new wave of insights for innovation policy in a world of rapid institutional innovation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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