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Blockchain and Supply Chains: V-form Organisations, Value Redistributions, De-commoditisation and Quality Proxies

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Abstract

We apply institutional cryptoeconomics to the information problems in global trade, model the incentives under which blockchain-based supply chain infrastructure will be built, and make predictions about the future of supply chains. We argue blockchain will change the patterns and dynamics of how, where and what we trade by: (1) facilitating new forms of economic organisation governing supply chain coordination (such as the V-form organisation); (2) decreasing information asymmetries and shifting economic power towards the ends of supply chains (e.g. primary producers); (3) changing the dimensions along which we can reliably differentiate goods and therefore de-commoditising goods and disaggregating price signals; and (4) decreasing consumer reliance on quality proxies (e.g. production within national borders).

Keywords: *Institutional Cryptoeconomics, Institutional Economics, Supply Chain Management, Blockchain Supply Chains*

Introduction

Blockchain and other distributed ledger technologies are poised to act as new economic infrastructure for global trade networks [1]. As a technology for creating distributed ledgers of information, blockchain may act as the infrastructure on which information about goods are validated, stored and accessed. Blockchain might not simply make our existing supply chain structures more efficient, but transform how, where and what we trade. When the standardised shipping container was invented in the 1950s it didn't just made goods cheaper; it also altered trading patterns, opened up new trade networks, and made some traditional port infrastructure redundant [2]. In this paper we draw on the existing literature of blockchain-based supply chains [1, 3] together with the emerging field of institutional cryptoeconomics [4-6] to ask the question: how might blockchain-based supply chain infrastructure change our global trade networks? We first model the incentives necessary for supply chain actors to implement and build this infrastructure, before making four predictions:

- Blockchain will drive creation of new forms of economic organisation to coordinate the information problems along global supply chains, such as the V-form organisation [7, 8];
- Blockchain will help reduce information asymmetries (e.g. information about markets, prices and the structure of the supply chain itself) and therefore shift economic power towards the ends of the supply chain (e.g. primary producers and consumers);
- Blockchain will drive de-commoditisation of goods by offering deeper information for consumers to make more subjective value perceptions; and
- Blockchain will facilitate new proxies of quality—as distinct to that derived simply from production within national borders—and therefore a closer match between comparative advantages and production.

Blockchain as an institutional technology for supply chain infrastructure

When described simply as a new type of ledger, blockchain might seem to be little more than accounting technology. Such innovations, however, can have a profound impact on an economy's institutional structure. The ledger-centric view of the economy argues the importance of ledgers in mapping property ownership and relationships, along with other rights and responsibilities which underpin economic and political exchange [see 9]. Tracking inventories and ownership rights throughout complex organisational structures requires robust ledgers which can be reconciled and audited with relative ease. Changes to the nature of ledgers have long been associated with changes in institutions. The emergence of literacy in the ancient Near East enabled detailed records of taxation and expenditure [6, 10], while double entry bookkeeping contributed to the emergence of capitalism by facilitating distributed ownership of enterprise, the spread of risk, and the emergence of multinational corporations [11]. The propensity to exchange is closely correlated with the ready verification of property rights, along with a system of courts and law to enforce those rights [12].

Transaction costs have been used to account for organisational variety [13]. Coase [14] and Williamson [15] sought to explain why some transactions occur within a firm rather than a market.[i] The logic is that different institutions create alternate organisational structures to transact, and the choice of institution depends on several behavioural factors which give rise to transaction costs. For instance, people exhibit cognitive limitations (e.g. bounded rationality) and do not always act benevolently (i.e. people can be opportunistic).[ii] Transaction cost economics gains predictive logic by recognising that transactions exhibit different types and degrees of asset specificity, uncertainty and frequency of exchange which interact with these behavioural factors to give rise to transaction costs [16, 20, 21].[iii] From this perspective blockchains 'industrialise trust' by reducing the transaction costs which economic actors might otherwise face, thereby shifting the mix of transaction cost minimising institutions [23]. Institutional cryptoeconomics uses the transaction cost economics framework to explain how blockchain technology shifts the comparative efficacy of firms, markets, governments and civil society to solve economic problems [24-26].

There are three main types of trade costs that create frictions in supply chains: transportation, political and information costs [27]. Transportation costs have been lowered through transportation technologies including the shipping container [2, 28]. Political and regulatory barriers such as tariffs have been reduced through global coordination bodies such as the World Trade Organization (WTO) [29]. However, when goods move along supply chains, trusted information about those goods must also move with them. That information must be produced and maintained through economic organisation. Consumers demand information in terms of the legitimacy, quality and provenance of a product. That information enables consumers to differentiate products and to subjectively value them. Governments demand information about goods to comply with domestic regulations, such as biosecurity restrictions, minimum labour or ethical standards and sanctions compliance. Producers demand information about goods after they have sold them, including information about their consumers as well as the rents and actions of others along the supply chain (e.g. fraudulent activity in transit).

Information costs increase as organisational distance increases [30]. Goods have characteristics that are the product of production, financing, delivery, warehousing, regulatory procedures and a myriad of other processes in a supply chain. Except for in the context of a supply chain located wholly within a vertically integrated organisation, these processes might occur across tens, hundreds, or even thousands of discrete organisations. Apple, for instance, has 785 suppliers, across 31 countries [31]; their products are (officially) available for sale in most countries, apart from those subject to US sanctions such as North Korea and Syria, or where there is little demand, like in Afghanistan and Yemen [32]. As supply chains become longer and more complex, information changes hands more often and across more relationships [33], potentially leading to information loss or fraud.

Producing and maintaining trusted information about goods is costly. Private organisations produce some of this information, ensure its integrity, and communicate that information with others. Some supply chain information is produced through brand reputation, "repeat transactions … and social norms that are embedded in particular geographic locations or social groups" [34]. Siloed companies communicate information through paper-based bills of lading and ship manifests to maintain and update ledgers of information. When there is a lack of incentives for private companies to provide the information, they may be required to through legislation. Estimates of the administrative cost of this paperwork varies from 15 per cent of the value of goods shipped [35] to being equal to the cost of physically moving those goods [36]. The complexity of global supply chains also means that shipping goods involves a multitude of organisational interactions; Maersk found that a single shipment of refrigerated goods in 2014 from Africa to Europe involved 30 different individuals and organisations, with 200 separate interactions [37]. This process is not only costly, but due to the complexity and multiple interactions it is error-prone and open to fraud [38, 39].

Available technologies constrain what institutional solutions can be implemented to lower transaction costs [40]. Blockchain and other distributed ledger technologies create new potential for emergent governance solutions by storing transparent and tamper-resistant information about goods. This information could include ownership, location, environmental impact, and time stamping data [41]. The technology could be used, for instance, in the context of food safety and traceability, where provenance information can be consulted in real-time by consumers and regulators [see 3, 42]. Blockchain-based supply chains thus compete with other institutional governance systems (firms, markets and governments) to overcome information costs.

There is substantial interest from the private sector and from governments to develop blockchain-based economic infrastructure for global supply chains. This includes validating the legitimate ownership of goods traded [43], identifying counterfeit medicines [44, 45], tracking the trade of protected species [46] and managing food safety incidents [42]. Distributed ledger technologies are being adopted by firms including IBM, Maersk and Walmart as the economic infrastructure to achieve greater levels of assurance over the nature and provenance of goods as they move along supply chains [3]. For instance, in 2017 IBM and Danish shipping company Maersk announced their TradeLens blockchain solution [37]. Walmart has since announced their intention to use the IBM Food Trust platform to facilitate the sharing of provenance information by their leafy green suppliers in the wake of an E. coli outbreak [47].

Blockchain-based supply chains are likely to emerge in concert with other technologies, such as a permissioned network of actors who hold a QR code scanning technology that updates information on a private distributed ledger. This approach, however, raises questions of human involvement and the legitimacy of the data entered in the distributed ledger—the 'garbage in-garbage out' problem. Blockchains are unable to autonomously interact with real-world individuals or events and hence rely on 'oracles' to transmit data about temperature, contractual performance and so on [48]. Another approach will leverage more complex technologies in an attempt to input information via sensors [49], such as 'smart containers' where sensors upload information (e.g. temperature) to a blockchain-based distributed ledger. This represents a shift away from human-centred data input towards technology-centred data input, and might even see the dynamic adjustment of shipping routes and prioritisation based on the attributes of the goods shipped [50].

The precise nature of how blockchains will be applied within supply chain governance is uncertain. Adoption will likely require significant infrastructure upgrades or investments. In the following section we model the incentives for actors in a supply chain to adopt blockchain-based smart contracting supply chain infrastructure to get a sense of the factors from which that process will emerge.

Incentives to develop blockchain-based supply chain infrastructure

In this section we examine the necessary conditions that incentives for supply chain participants must meet for a blockchain-based supply chain to be built. The central institutional innovation for understanding blockchain-based supply chains is the smart contract. Proposed by Szabo [51], the smart contract is an algorithm which executes the provisions of a contract automatically upon the realisation of some state of the world. We could conceptualise a smart contract as follows. Upon the provision of some good or service x_{ij} by j to i, a smart contract executes automatic payment of some medium of exchange $p_{ij}(x_{ij})$, such as a cryptocurrency which is conditional on that good or service

$$p_{ij}(x_{ij}) = \begin{cases} p_{ij}^N & if\ x_{ij} = \{t_1 \dots t_N\} \\ \vdots & \vdots \\ p_{ij}^1 & if\ x_{ij} = \{t_1\} \\ p_{ij}^0 & if\ x_{ij} = \emptyset \end{cases}$$

with the property that $p_{ij}^N \geq \cdots \geq p_{ij}^1 \geq p_{ij}^0$.

We define goods and/or services x_{ij} to be delivered as bundles of attributes $\{t_1 \dots t_N\}$ in the style of New Consumer Theory [52, 53], although defined more broadly than physical attributes to include information about the goods and/or services such as time and location of provision as well as state of provision. Once a smart contract is struck in a blockchain-based supply chain system, it is broadcast to the network of nodes holding the blockchain and validated once it is included in a block on which consensus is achieved by the network. When the conditions for its execution (the provision of x_{ij}) are broadcast to the network by whatever means, the contract is then executed. The blockchain on which a supply chain is implemented thus takes the form of a 'smart ledger', not only of static entries, but of smart contracts ready to be executed upon the realisation of various states of the world.

From a network of such contracts between i and j, we observe the emergence of the "decentralised autonomous organisation"—a network of economic interaction which emerges from the striking of smart contracts, and operates through their execution [4]. Obviously, such decentralised autonomous organisations can take the form of supply chains where they are organised around the provision of goods and services to meet some consumption end.

Under what conditions is there an incentive for i and j to implement their portion of a supply chain with smart contracts recorded and validated within a blockchain? The question, of course, comes down to the value that smart contract provides to those parties compared to other institutions. Smart contracts are costly to write and require specialised technical knowledge, so we would expect the emergence of organisations, such as consulting technology companies with specialties in cryptolaw. Obviously an incentive has to be provided to the consulting firm to do so, which we denote as $c_{ik}\left(p_{ij}(x_{ij})\right)$ and $c_{jk}\left(p_{ij}(x_{ij})\right)$, the price i and j respectively pay to k to write the smart contract containing the protocol $p_{ij}(x_{ij})$ for them. Supposing that $c_k\left(p_{ij}(x_{ij})\right)$ is the opportunity cost of writing this contract, the consulting firm has an incentive to provide the smart contract as long as

$$c_{ik}\left(p_{ij}(x_{ij})\right) + c_{jk}\left(p_{ij}(x_{ij})\right) \geq c_k\left(p_{ij}(x_{ij})\right)$$

Let us suppose that the value that would be realised by i were j to provide them with the goods and/or services x_{ij} can be represented by a number $v_i(x_{ij})$ (for instance, marginal profit). In that case, given a distribution of beliefs $\beta_i(x_{ij}|p_{ij} \quad \delta_j^b) \in [0,1]$ about the provision of x_{ij} by j conditional on the provisions p_{ij} of the smart contract and an information set δ_j^b about j contained within the blockchain (such as satisfaction metrics and so on), and assuming a von-Neumann-Morgenstern incentive structure, the expected value obtained by striking the smart contract on a blockchain is

$$\sum_{x_{ij}} \beta_i(x_{ij}|p_{ij} \quad \delta_j^b)[v_i(x_{ij}) - p_{ij}(x_{ij})] - c_{ik}\left(p_{ij}(x_{ij})\right)$$

Were we to imagine that the cost to j of providing x_{ij} to i to be $c_j(x_{ij})$, and assuming a perfect correspondence between cost incurred and outcome in terms of provision of x_{ij} we could say that the value to j of striking the smart contract and providing x_{ij} to i is

$$p_{ij}(x_{ij}) - \left[c_j(x_{ij}) + c_{jk}\left(p_{ij}(x_{ij})\right)\right]$$

Now suppose that the same provisions $p_{ij}(x_{ij})$ would apply in an off-blockchain contract, that the same values $v_i(x_{ij})$ would obtain for i upon receipt of x_{ij}, and that the same costs $c_j(x_{ij})$ would be incurred for j to provide it. Suppose further that a distribution of beliefs $\beta_i(x_{ij}|p_{ij} \quad \delta_j^b) \in [0,1]$ exists for i about the provision of x_{ij} by j conditional on the provisions p_{ij} and an information set δ_j^i available to i about j. To execute the contract, i and j have to incur a cost of verifying that x_{ij} has been provided which we call $c_i^T(x_{ij})$ and $c_j^T(x_{ij})$, and we assume that there is a perfect correspondence between the incurring of this cost and verification. This cost is variously the cost of compensating management hierarchies for providing third-party verification in firms, or the cost of verification by third parties in markets [54]. In markets we would imagine that these costs fall on j most heavily as they concern brand building and guarantees of various kinds to convince i that x_{ij} has been provided such that they ought to execute payment $p_{ij}(x_{ij})$ within the contract.

We will therefore find that there is an incentive to adopt blockchain-based supply systems if three conditions are simultaneously met:

$$\sum_{x_{ij}} \beta(x_{ij}|p_{ij} \quad \delta_j^b)[v_i(x_{ij}) - p_{ij}(x_{ij})] - c_{ik}\left(p_{ij}(x_{ij})\right) \geq \sum_{x_{ij}} \beta(x_{ij}|p_{ij} \quad \delta_j^i)[v_i(x_{ij}) - p_{ij}(x_{ij})] - c_i^T(x_{ij})$$

$$p_{ij}(x_{ij}) - \left[c_j(x_{ij}) + c_{jk}\left(p_{ij}(x_{ij})\right)\right] \geq p_{ij}(x_{ij}) - [c_j(x_{ij}) + c_j^T(x_{ij})]$$

$$c_{ik}\left(p_{ij}(x_{ij})\right) + c_{jk}\left(p_{ij}(x_{ij})\right) \geq c_k\left(p_{ij}(x_{ij})\right)$$

The third condition suggests that we will observe incentives for consulting companies to adopt blockchain technology and begin writing smart contracts if their opportunity costs are adequately compensated. However, the first two conditions require a little more interpretation. If we rearrange them we find that i has an incentive to adopt blockchain-based supply systems if

$$\sum_{x_{ij}} [\beta(x_{ij}|p_{ij} \quad \delta_j^b) - \beta(x_{ij}|p_{ij} \quad \delta_j^i)][v_i(x_{ij}) - p_{ij}(x_{ij})] \geq c_{ik}\left(p_{ij}(x_{ij})\right) - c_i^T(x_{ij})$$

while j has an incentive to adopt blockchain-based supply systems if

$$c_j^T(x_{ij}) \geq c_{jk}\left(p_{ij}(x_{ij})\right)$$

The second—the conditions under which j will be incentivised to adopt blockchain-based supply systems—is a very simple condition. If they are going to achieve similar compensation relative to costs for supplying x_{ij} in either blockchain-based or firms/market supply chains, the question of their incentivisation to adopt blockchain-based systems comes down to the differential costs of verification in the two systems—by smart contract or third party. If verification costs that x_{ij} has been provided are lower in blockchain-based supply chains, there is an incentive to adopt them.

The first condition—the conditions under which i will be incentivised to adopt blockchain-based supply systems—is a little more involved as it involves, in particular, the differential beliefs $\beta(x_{ij}|p_{ij} \quad \delta_j^b) - \beta(x_{ij}|p_{ij} \quad \delta_j^i)$ held about the delivery of x_{ij} in its various forms. Any increase in the transaction costs $c_{ik}\left(p_{ij}(x_{ij})\right) - c_i^T(x_{ij})$ caused by the expense of writing a smart contract must be compensated for by an increase in the expected value to be brought about by this contract. If the provisions of the contract itself do not change, then that increase in the value expected to arise from the contract comes from the increased *beliefs* about the net positive values ($v_i(x_{ij}) - p_{ij}(x_{ij}) > 0$) and the decreased *beliefs* about the net negative values ($v_i(x_{ij}) - p_{ij}(x_{ij}) < 0$) that may be realised by a supply chain based on a blockchain. That, naturally, is brought about by the range of information δ_j^b that is available within a blockchain about j upon which beliefs can be formed relative to the range of information δ_i^i that is available to i within a market/firm context.

We have good reason to believe that these two conditions for incentivising the adoption of blockchain-based supply systems will become increasingly easy to satisfy over time, especially with respect to i, the "buyer" in this supply chain. In particular, we can expect that the cost of writing smart contracts will decrease markedly as consulting firms move down the learning curve and develop base templates. Moreover, such costs only need be incurred once when the smart contract needs to be written in the first place or altered, whereas verification costs must be incurred for each transaction in a market/firm setting. But it is in the wealth of information that is stored in a blockchain upon which to form expectations about the likelihood x_{ij} will be provided that we really see that incentives will emerge to adopt blockchain-based supply systems. Blockchain is *designed* to store information and validate it, which means we are very likely to see a better basis for more accurate beliefs to form about the provision of x_{ij} in various states by j within blockchain-based supply chain systems.

Predictions for the future of supply chain governance

New forms of economic organisation

Even if supply chain actors are incentivised to adopt blockchain-based infrastructure, this adoption process is likely to require significant coordination and cooperation across multiple actors. The evolutionary change from the current, and often paper-based, system towards a more digitised blockchain-based system requires technical and economic coordination between supply chain actors. On one hand there could be forced adoption along a supply chain due to some market power. We saw a recent example of this with Walmart. Alternatively, as suggested by our model of the incentives at play in blockchain-based supply chains, third parties, such as consulting firms, might be required to coordinate and supply the technology necessary. If this is so, as our model would suggest, we will observe a new form of organisation to facilitate supply chain coordination: the V-form organisation [8].

Berg, Davidson and Potts recently introduced the V-form organisation as an "outsourced, vertically integrated organisation tied together not by management and corporate hierarchy but by a shared, distributed and decentralised ledger – a blockchain" [8]. Rather than a multidivisional (M-form) company where operations are divided into self-contained business units and overarching corporate hierarchy [21, 55], a V-form organisation is a decentralised organisation of fully independent companies both coordinating and auditing their activities through a decentralised blockchain ledger, and having a common coordinating third party, such as a consulting firm or technology company, who brokers that collaboration [see also 7]. In terms of our model above, we will observe i and j striking smart contracts written by k within a blockchain based ledger rather than within an organisation where verification occurs in a command-and-control hierarchy.

The institutional possibility of a V-form organisation represents a qualitative change in supply chain governance. Consensus over facts along a supply chain—including information about the attributes of goods—can now be achieved through outsourcing to a decentralised blockchain ledger, rather than relying on vertical integration. Previously supply chain trust has been provided by hierarchy in the form of the M-form organisation. Existing supply chain organisations now essentially face a wider range of institutional possibilities: making trust (through vertical integration), outsourcing trust (through market exchange), or now achieving trust though outsourcing to a network (through a common distributed ledger). Over time we anticipate a move towards the outsourcing of trust to a distributed ledger.

Shifts in economic power through reductions in information asymmetries

Information asymmetries exist along supply chains in both directions: producers lack information about where their goods are eventually sold, and consumers lack information about the provenance of the goods they buy. A reduction in information asymmetries shifts economic power towards the polar ends of supply chains.

Producers lack information over who the final market consumers are, the price(s) at which those goods are sold, the behaviour of actors along the chain, and how rents are distributed across the various actors. A coffee farmer in a remote area, for instance, might lack information other than the price at which they sell the coffee to an intermediary, including information about their consumers and final prices. This lack of information about goods as they move generates information asymmetries. We expect information asymmetries to increase as the distance between actors increases, including for consumers (e.g. insufficient or reliable information regarding the provenance of the product). Reducing these uncertainties and information asymmetries may dramatically alter the value they place on those products.

Information asymmetries persist in supply chains for several reasons. Supply chain participants might lack incentives to produce and maintain information about goods as they move. Notwithstanding issues of fraud or error there are a range of coordination problems that prevent supply chain information from being produced. Transaction costs might make producing the information economically unviable. Blockchain might better economise on these transaction costs while overcoming the incentive problems that cause information asymmetries to persist. In terms of our model above, the information δ_j^i that i has about j upon which beliefs $\beta(\cdot)$ are based is stored in a blockchain which is designed to accumulate such information, and therefore is potentially of greater quantity and quality than the information δ_j^i that would be otherwise available to i.

If blockchain-based supply chains reduced information asymmetries we would expect shifts in economic power to the polar ends of the supply chain. Primary producers might gain bargaining power because they can identify final market customers (potentially enabling them to develop new patterns of trade and lower the rent of intermediaries). They therefore might be able to find more direct paths to market by better economising on the structure of a supply chain. Consumers, including those who are buying products as inputs into production, gain greater power along several dimensions. For instance, consumers might more easily restructure supply chains by dynamically switching between suppliers, and they might rely less on third-parties, such as restaurants, to provide verification of the characteristics of goods. The information produced through blockchain trade infrastructure might lead to greater competition between suppliers of similar goods regardless of existing trade relationships.

De-commoditising and disaggregating prices

Many goods in a modern economy are commoditised because of a lack of information to differentiate them from other goods. The prices consumers attach to those goods might not be fully reflective of their underlying (potential) value. One way to define a good is by its vector of attributes $x_{ij} = \{t_1 \dots t_N\}$. Consumers observe those attributes to make subjective perceptions of the value of goods $v_i(x_{ij})$. For instance, a fresher perishable good might be worth more to consumers. Alternatively, a good that is simply located in a different physical location has a different value to a consumer. Keeping all else constant, the higher perceived value of a fresher good would translate to a higher market price. Furthermore, the vector of attributes defining a good changes through time (e.g. the good is damaged in transit). Information about attributes is shrouded in uncertainty and must be produced and maintained through different forms of economic organisation. The uncertainty about the good is particularly high when the information is not easily verifiable through third party observation of the good before or even after it is consumed (e.g. credence goods).

It is unnecessary for a consumer to have the theoretically complete set of vector characteristics that define a good because some of those characteristics will be unrelated to the formation of subjective value. Nevertheless, blockchain-based supply chain infrastructure means consumers might not only be able to access cheaper and more trustworthy information about the goods that they buy, but also more granulated and detailed information on previously unobservable characteristics. That is, information about the vectors of goods that were either not previously produced or not previously observable due to transaction costs might become possible.

There are several implications of blockchain-based supply chain infrastructure on the operation of market prices. First, we anticipate a *de-commoditisation of goods*. Two products that were previously considered identical because of a lack of information about their differing vectors of characteristics might now be reliably differentiated. Those products might fall into two different markets. The second order effect of this is potentially more granulated prices that are more closely reflective of the underlying physical good. That is, a *disaggregation of prices*, perhaps splitting existing markets into new markets of premium and non-premium segments. The precise margins at which additional trustworthy information will shift the price of goods will emerge over time, and will be directly related both to the subjective perceptions of consumers buying those goods, and the entrepreneurial efforts of people seeking to create the blockchain-based infrastructure that will produce and govern that information. Finally, to the extent that market prices represent the aggregation of distributed and contextual information of market participants [56], we would expect over the longer term *more effective market coordination.*

Fewer quality proxies

Consumers regularly rely on quality proxies. These proxies range from production within national borders to brand association and reputation. As blockchain supply chain infrastructure is built, however, we would expect that consumers rely more on the underlying characteristics of the specific good they are buying—because of the fall in transaction costs of producing that information—rather than proxies. A smart contract $p_{ij}(x_{ij})$ of the form we have considered above naturally lends itself to being made contingent upon the vector $x_{ij} = \{t_1 \dots t_N\}$ of attributes that the good is verified to have, and can be designed to incentivise the provision of particular characteristics, rather than the consumer having to rely on proxies to inform choice between a range of simple contracts for goods.

A consumer seeking some minimum level of health and safety regulations, labour practices and food safety measures, may buy goods that are produced within national borders that have strict laws relating to those matters. The information that those proxies represent do not necessarily correlate directly with the characteristics of the product underlying it. This is not to say that either: (1) goods produced within those jurisdictions could possibly not meet those minimum standards; or that (2) producers in jurisdictions without those standards might decide to voluntarily take sufficient health and safety or other measures. This observation also applies to other proxies and desired attributes, such as brand reputation. One function of brands is to signal to consumers that an organisation has ensured the quality of that product—effectively confirming information about its vector of characteristics. These examples of national borders and brand reputation are examples of governance solutions to the problem of producing trusted information about the characteristics of goods.

While proxies might be economically efficient given some level of transaction costs—that is, where it is too costly to produce more detailed information about specific goods—blockchain-based supply chains might enable consumers to better contract for the supply of the underlying attributes of goods such as in the way we have modelled above. As proxies are replaced by more specific information about goods, then consumers will shift their consumption patterns—purchasing goods that more closely fit the criteria they are seeking. In the longer run this may change the goods that are produced in certain nations. Producers within economies who were previously held back by reputational problems—for instance, in developing economies which are beset by poor food safety reputations—might be better able to market their products to consumers using more detailed information. Furthermore, we would expect this to shift the production patterns of goods to more closely match the comparative advantages of economies.

Conclusion

We have made several contributions. First, we have outlined the potential of blockchain as economic infrastructure for the production and governance of information along supply chains. Second, we have modelled the necessary conditions for there to be incentives for such infrastructure to be built. Third, we propose that the building of this blockchain infrastructure might lead to new forms of economic organisation such as the V-form organisation, a shifting of economic power to the polar end of supply chains due to reductions in information asymmetries, the de-commoditisation of goods and the disaggregation of prices that assist market coordination, and reductions in the use of proxies used by consumers to value goods. In this way blockchain-based supply chain infrastructure won't just make existing supply chains cheaper and more efficient, but might fundamentally change the way that globalisation takes place.

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[i] Transactions costs in general refer to the 'friction' inherent in exchange [16] and are the "costs of running the economic system" [17].

[ii] Bounded rationality was first proposed by Simon [18] and refers to the cognitive and language based limits of rationality; economic actors are "intendedly rational, but only limitedly so" [19]. Opportunism in contrast refers to the way in which economic actors are generally guided by self-interest, and may act to selectively reveal, obfuscate, or otherwise manipulate information to their advantage; opportunism is what Williamson [16] refers to as "self-interest seeking with guile".

[iii] For instance, asset specificity ranges from uniquely idiosyncratic investments where those investments would be lost if the relationship was to be severed, to more general purpose investments that are more easily redeployed to other uses. Frequent and similar transactions are "often associated with internalization of economic activities" [22] in a hierarchical governance structure like a firm such that establishment costs can be amortised.

