



RMIT Blockchain Innovation Hub

RMIT University

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Department of Foreign Affairs and Trade (Singapore)

Submission to the Australia and Singapore Digital Cooperation Initiative renegotiation of the Digital Economy Agreement of the Singapore-Australia Free Trade Agreement (SAFTA)

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Dear the Australia and Singapore Digital Cooperation Initiative,

My name is Dr Darcy Allen and I am a Postdoctoral Research Fellow at the RMIT Blockchain Innovation Hub (BIH) in Melbourne. I am writing to you regarding the negotiations surrounding digital trade and the Singapore-Australia Free Trade Agreement (SAFTA). Together with my RMIT colleagues, I'm pleased to submit some of our research on the future of digital trade in the region. Please find enclosed research on **how blockchain technology will shape the nature of trade in the APAC region, including implications for international policy and free trade agreements.**

Blockchain technology was invented in 2008 as the underlying technology of the cryptocurrency bitcoin (see Nakamoto, 2008). More generally, blockchain is a class of distributed ledger technologies that acts as new economic infrastructure for coordinating



trusted information between dispersed parties (Berg, Davidson, & Potts, 2019a; Davidson, De Filippi, & Potts, 2018), with applications now including law, health, identity, government services, registries and supply chains. Significant public policy implications arise from this new economic infrastructure.

In 2017, RMIT University established the RMIT Blockchain Innovation Hub (BIH). We are the world's first social science research centre focused on blockchain technology, and are now a world-leading authority on blockchain technology research from a theoretical, practical and policy perspective.¹ As a team of social scientists—including economists, lawyers and public policy experts—we analyse the implications of blockchain technology on the economy and society. For instance, how do firms change in a world with blockchain-based platforms? What is the impact of blockchain technology on our trading networks and partners? What are the policy and regulatory frameworks necessary for distributed ledger technologies to be adopted?

We are writing to suggest you consider the potential of blockchain technology as it relates to the Digital Economy Agreement of SAFTA in two main areas:

- (1) The use of blockchain as new economic infrastructure for trusted digitised **supply chain** information. The use of blockchain to govern and coordinate information about goods and services as they move between Australia and Singapore enables more **frictionless free trade** between the economies and across the APAC region.
- (2) The use of blockchain to store and verify educational and professional **credentials**. Blockchain can be used to store validated credentials such as university degrees (rather than through more centralised verification). This new credentialing infrastructure presents an opportunity to facilitate **labour mobility** between Singapore and Australia.

Please find below further details about the potential of blockchain in these areas, as well as two attachments containing further research. We offer any further assistance or information necessary to integrate these topics into the Digital Economy Agreement of SAFTA.

¹ In 2019, the RMIT Blockchain Innovation Hub was ranked 3rd in the world for cryptocurrency research by leading digital services firm Kaiko.



APPLYING BLOCKCHAIN IN SUPPLY CHAINS

Blockchain technology is currently being applied as new economic infrastructure for the governance of information along global supply chains. Invented in 2008, blockchain is a new way to govern digital distributed ledgers of information. Blockchains can be used to govern ledgers of information about goods as they move along supply chains. That information includes provenance, quality and stewardship of goods. The successful entrepreneurial application of blockchain to supply chains is likely to substantially reduce trade costs and frictions, expand trade, and therefore make us more prosperous.

As goods move information about those goods must move them. This means we must maintain ledgers of information about goods. To maintain those ledger records we currently use a range of different organisational forms, ranging from internal company databases to paper-based trade documentation as goods cross borders (e.g. certificates of origin). Having this trusted information is critical not just for consumers but also for producers and governments (see Allen, Berg, & Markey-Towler, 2019; Allen, Berg, Davidson, Novak, & Potts, 2019). Furthermore, demands on supply chain information grows as the complexity of the economy grows, and as governments require greater information to ensure compliance with domestic regulation (such as biosecurity restrictions or ethical considerations).

Blockchain technology presents an **alternative economic infrastructure for the coordination of supply chain information**. Rather than relying on centralised bodies—opening the potential for fraud or error—information about goods can be added and viewed through a distributed blockchain ledger. Information inputted into blockchains can also leverage off other frontier technologies such as the Internet of Things (IoT). These possibilities also expand to **automatic regulatory compliance** of goods as they cross borders, significantly lowering barriers to trade. Added to this, our research suggests that the use of blockchain for supply chains will substantially shape the future of trade through more premium prices, new forms of economic organisation and shifts in value capture along supply chains (Allen, Berg, & Markey-Towler, 2019; Berg, Davidson, & Potts, 2018).

Globally and regionally we are seeing **substantial investments** in blockchain-based supply chains. There is great potential for blockchain technology to be applied to track goods and services between Australia and Singapore, particularly given Australia's exports of perishable



high-information agricultural products. Many products exported from Australia are high-information products, where the value of those products is closely tied to having trusted information about product provenance, stewardship and history.

For this new economic infrastructure to be built, however, we anticipate several **policy and regulatory barriers**. Those barriers include whether governments recognise blockchain-based information to satisfy compliance with domestic regulations, the transfer of information across different blockchain applications (i.e. interoperability), the emergence of legal and technical standards, and the evolutionary problem of developing ‘crypto-friendly’ government policy that encourages entrepreneurial investment and experimentation (Berg, Davidson, & Potts, 2019b; Novak, forthcoming; Novak & Pochesneva, 2019). A not-for-profit association, the Worldwide Blockchain Innovation Association, was established in Australia based on our research on the need for international policy coordination around blockchain technology.²

We suggest that many of these regulatory challenges could be considered in the negotiation of the Digital Economy Agreement.

BLOCKCHAIN AND THE CREDENTIALING INDUSTRY

A further blockchain application we believe is particularly relevant to SAFTA are efforts to use blockchain technology to store **validated credential documentation**. Singapore has been a world-leader in this area, with the Singaporean government implementing an OpenCerts project across 18 education institutions.³ In Australia, RMIT University has implemented a trial for blockchain-based credentials for its students.⁴ These investments have implications for the movement of labour between the two economies.

There are many benefits to blockchain-based credential systems. Blockchain-based credentialing infrastructure can **lower the cost of traditional centralised credentialing systems** in two main ways. First, because institutions no longer need to provide paper documentation—credentials can be provided digitally. And second, by changing how

² See <https://wbia.io>

³ See <https://opencerts.io/>

⁴ See <https://www.rmit.edu.au/news/newsroom/media-releases-and-expert-comments/2018/jul/blockchain-enabled-badges-for-students>



credentials are verified. Rather than employees contacting centralised university or professional certification systems, they can verify that a certificate is legitimate by referring to the cryptographic hash of a certificate stored in a blockchain.

While applications of blockchain to credentials are nascent, we propose that the negotiations consider the potential of blockchain-based credentialing systems on **free labour mobility** between Singapore and Australia. The verification of credentials as people move across borders is a friction on free movement, and blockchain applications have the potential to ameliorate some of these costs through a new decentralised credentialing infrastructure.

OUR RESEARCH

For your consideration please find enclosed two of our papers on blockchain that may be of use for your negotiations:

- **Attachment 1:** ‘International Policy Coordination for Blockchain Supply Chains’ (Allen, Berg, Davidson, et al., 2019). This paper was published in *Asia & the Pacific Policy Studies* and outlines the economics of blockchain technology as applied to supply chains, with a focus on potential policy frictions and challenges. Those challenges include the development of standards and regulatory recognition of blockchain information. We argue in the paper for a global or regional policy forum to develop and coordinate blockchain standards and trials.
- **Attachment 2:** ‘Blockchain and Supply Chains: V-form Organisations, Value Redistributions, De-commoditisation and Quality Proxies’ (Allen, Berg, & Markey-Towler, 2019). This paper was published in *The Journal of the British Blockchain Association* and proposes some predictions for the future of trade, including shifts in the economic organisations of supply chains, changing quality proxies and niche product markets, and movements in where value is captured along supply chains.

Our team also has a wide range of other research around on the blockchain economy that we are happy to discuss and share with you. We welcome the opportunity to contribute further to the Australia and Singapore Digital Cooperation Initiative renegotiation of the Digital Economy Agreement. We would be pleased to offer any additional information. We look



forward to any opportunity you may have to investigate the use of blockchain in improving and strengthening the trading relationship between Australia and Singapore.

Yours sincerely,

A handwritten signature in black ink, which appears to read "Darcy Allen".

Dr Darcy Allen

Encl.

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International policy coordination for blockchain supply chains

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Abstract

From the adoption of the shipping container to coordinated trade liberalization, reductions in trade costs have propelled modern globalization. In this paper, we analyse the application of blockchain to reduce the trade costs of producing and coordinating trusted information along supply chains. Consumers, producers, and governments increasingly demand information about the quality, characteristics, and provenance of traded goods. Partially due to the risks of error and fraud, this information is costly to produce and to maintain between dispersed parties. Recent efforts have sought to overcome these costs—such as paperless trade agendas—through the application of new technologies. Our focus is on how blockchain technology can form a new decentralized economic infrastructure for supply chains by governing decentralized dynamic ledgers of information about goods as they move. We outline the potential economic consequences of blockchain supply chains before examining policy. Effective adoption faces a range of policy challenges including regulatory recognition and interoperability across jurisdictions. We propose a high-level policy

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forum in the Asia-Pacific region to coordinate issues such as open standards and regulatory compatibility.

KEYWORDS

blockchain, international policy coordination, institutional cryptoeconomics, supply chain governance, trade costs

1 | INTRODUCTION

Two innovations help explain the expansion in global trade from World War II until today: the standardized shipping container and global trade coordinating bodies.¹ The importance of both of these innovations comes through their reductions in trade costs: shipping containers reduced *transportation costs*, whereas global coordinating bodies reduced direct *regulatory costs*.² The effect was to make new markets possible, lengthen supply chains, alter trade patterns, and increase the diversity of goods. In this paper, we focus on the potential of blockchain technology to lower trade *information costs*. These are the costs of coordinating trusted information about the characteristics of goods for consumers, producers, and governments. When goods move, information about their provenance, ownership, and quality must also move with them. We examine how blockchain looks to reduce information costs by acting as new economic infrastructure before outlining the policy and regulatory challenges.

Our motivation to examine the blockchain supply chains stems from the increasing recognition of trade as an information cost problem. This focus on the information and regulatory costs of trade is demonstrated through recent efforts to develop single trade windows throughout the Asia-Pacific region. The 21 member-states of the Asia-Pacific Economic Cooperation (APEC) region have undertaken reform efforts over the last couple of decades to simplify international trade processes in the Pacific Rim. Notable among the reforms are the APEC paperless trade agenda, which broadly involves “trade taking place on the basis of electronic communications, including exchange of trade-related data and documents in electronic form” (Duval, Amandeep, & Utoktham, 2015, p. 108). A key element of paperless trade policy is the single window system (SWS), an electronic single-entry point for traders to comply with regulatory requirements of export and import in a more efficient manner (APEC, 2018b). Paperless trade has many potential benefits, including reduced cost of shipping goods, lower communications costs, lower paper handling charges, fewer errors and faster payment receipts, reduced trade finance charges, and lower inventories (Department of Foreign Affairs and Trade (DFAT) and Foreign Trade and Economic Cooperation (FTEC), 2001). Ultimately, paperless trade and SWS efforts are efforts to economize on the information costs of trade.

Although many technologies might be used to reduce information costs, our focus is on blockchain technology. Blockchain was invented less than one decade ago as a technology for creating the digital cash, bitcoin (Nakamoto, 2008). More broadly, blockchain enables the creation of distributed, immutable, and secure ledgers of information. Blockchains are a technology of governance of information and exchange (Davidson, De Filippi, & Potts, 2018). Blockchain

¹The authors thank participants at the APEC Study Centres Consortium Conference (ASCCC), 14–15 May 2018, Papua New Guinea.

²For instance, Jacks, Meissner, and Novy (2008) found that falling trade costs explain “roughly 55 per cent of the pre-World War I trade boom and 33 per cent of the post-World War II trade boom” (p. 529).

may act as a governance structure for a secure and trusted source of information for consumers, firms, and governments about goods as they move along supply chains and across borders (Allen, Berg, & Markey-Towler, 2019). Indeed, numerous actors involved in international supply chain relations, as well as those with an interest in trade facilitation more generally, have suggested that blockchain (and other distributed ledger technologies) have the potential to advance trade facilitation agendas focussing upon cross-border paperless trading.

The Asia-Pacific region stands to capture a significant share of supply chain information cost savings resulting from blockchain adoption. Several cases indicate that blockchain could deliver sizeable reductions in the cost of trading goods and services in the region. For example, Suominen (2018) recounts that Korean multinational company Samsung, an entity with an extensive supply chain network, is using blockchain to facilitate the transportation of 488,000 tonnes of air cargo and over a million shipping containers annually. Following this, it has been suggested that the company has reduced its shipping costs by one fifth. Jurisdictions such as China have been proactive in using blockchain to facilitate trade finance, and have reported tentative, yet positive, results in terms of performance improvements with respect to ease of tracking transactional flows (Ganne, 2018). Australia has seen a number of efforts to use blockchain to track perishable goods such as agricultural products (e.g. AgriDigital, 2019).

Although blockchain technology is nascent, its application to supply chains will have to interact with governments as goods cross borders. Some of the issues this raises are familiar, having been seen in previous paperless trade agendas. We outline some of these policy challenges and ones unique to blockchain adoption, including government recognition of blockchain information, and technical and informational interoperability. We point to the need for regulatory coordination and adaptation in facilitating this entrepreneurial discovery process, including a high-level policy coordination forum in the Asia-Pacific region to develop open standards, propose new free trade agreements facilitated through blockchain, and encourage government regulatory recognition of blockchain-based information to comply with domestic regulations.

2 | TRADE AS AN INFORMATION COST PROBLEM

Trade costs are those costs incurred in addition to production costs (Petropoulou, 2005). Trade costs can be separated into three categories: transportation, regulatory, and information. The shipping container drove down the transportation costs of global trade. On 26 April 1956, a converted oil tanker, the *SS Ideal X*, set off from New Jersey to Houston, becoming the world's first successful container ship voyage (Levinson, 2016). In the decades to follow, the shipping container spurred a process of containerisation that was “one of the most important transportation revolutions in the twentieth century” (Hummels, 2007, p. 142). Prior to containerisation, the technologies of unloading and transporting cargo—such as wooden barrels and jars (see Twede, 2005)—have “hardly changed since the Phoenicians traded along the coast of the Mediterranean” (Bernhofen, El-Sahli, & Kneller, 2016, p. 38). International trade had been a dangerous, laborious, and inefficient process of packing and unpacking goods across modes of transport. Together with advances in other transportation technologies, such as air freight and the modernisation and development of trading ports, standardized shipping containers facilitated intermodal transportation networks that made transport cheaper.

Global and regional policy coordination bodies, such as the World Trade Organization (WTO), reduced trade regulatory costs. Formed in 1995 through the Marrakesh Agreement, the WTO emerged from the General Agreement on Tariffs and Trade (GATT). The GATT was

partially motivated by the potential of multilateral reductions in the direct regulatory costs of trade following the raising of tariffs, import quotas, licencing requirements, and foreign exchange restrictions following World War I (see Irwin, 1995).³ Coordinating reductions in trade barriers is necessary because each economy may be incentivized to strategically maintain their own trade barriers to protect domestic industries from international competition. International agreements align interests of governments to liberalize borders and embrace the benefits of globalization by acting as governance structures to reduce the transaction costs of negotiation (Goldstein, 2000). On many accounts, these efforts were remarkably successful, with the world-wide average of import tariffs dropping from 8.6% in 1960 to 3.2% in 1995 (Clemens & Williamson, 2004), with further reductions in regulatory trade costs since. Declining political trade costs made more mutually beneficial exchanges possible, spurring further globalization.⁴

The major type of costs facing supply chains today are not transportation or regulatory costs, but information costs. There are several reasons for this. First, information costs increase with the complexity, length, and volume of trade on supply chains. And second, as transportation and regulatory costs fall, the portion of information costs rises. Indeed, Anderson and Van Wincoop (2004) find that the costs of bringing goods across borders now exceed transportation costs. Information costs include the costs of enforcing contracts, searching for trading partners and information about the nature, characteristics, and provenance of goods as they move along supply chains. This information identifies goods and provides them with distinguishable economic value (Berg, Davidson, & Potts, 2019).

Global supply chain information remains trapped in manually administered and paper-based coordination between silos of firms and governments. Information flows are still often organized as transfers between separate organizations, despite efforts to use new information communication technologies such as the internet to digitize supply chain information (see Section 4). Each firm in a global supply chain passes off information relating to a tradeable good to each other one step at a time, holding that information until it can be passed to the next actor on the supply chain, and adding to that information as the nature of the good changes. Moving goods and their information along a supply chain can be remarkably complex, requiring hundreds of different actors, including exporters, importers, logistics companies, shippers, retailers, and governments. Maersk recently found that a shipment of refrigerated goods from East Africa to Europe went through over 30 different people and organizations, and involved more than 200 interactions and communications (IBM, 2017). This documentation includes cargo manifests, which outline characteristics of the cargo such as its size, bills of lading, which focus more specifically on ownership of the cargo, and trade finance documentation. The complexity of information coordination on supply chains is not only slow and potentially error-prone, but raises the potential of opportunistic behaviour and fraud. As in all economic environments, some individuals have the incentive to act opportunistically, providing false information about the nature of those goods.

Trusted supply chain information is important because it is demanded by consumers, producers, and governments. Particularly, for highly differentiated or perishable goods, consumers demand information not only about who produced the goods, but also other information such

³To be sure, there have been many other international institutions developed to overcome other forms of trade costs, such as the *Law Merchant*, which lowered the cost of contract enforcement. For example, see Milgrom, North, and Weingast (1990).

⁴These are of course not the only two drivers of global trade. For example, a further factor could be the rise of vertical specialization across countries (e.g., see Yi, 2003), which may magnify the benefits of tariff reductions as goods incur tariffs each time they cross borders.

as how that good was transported, its age, and its quality. Consumers are increasingly demanding information about the legitimacy of certifications of products such as fair trade and organic. The long-term impact of better information about goods is a de-commoditization of goods markets, where new markets of differentiated goods can be created (Allen et al., 2019). Governments also demand information to satisfy domestic regulations, such as biosecurity or ethical standards. These information cost challenges suggest the need for new governance structures and methods of information coordination for global supply chains to lower trade costs and usher in the next wave of globalization.

There are therefore potentially large economic benefits from economizing on information costs. Indeed, the World Economic Forum (2013, p. 4) concluded that there are “far more significant impediments to trade than tariffs.” They found that reducing supply chain barriers to trade (not including tariffs) could increase global GDP by nearly 5% and global trade by 15%.⁵ In the Asia-Pacific region specifically, a small number of studies have been undertaken to estimate the economic impacts associated with the simplification of international trade. A 2018 study by the United Nations indicates that cross-border paperless trade may increase exports by between US\$36 billion and US\$257 billion annually, depending upon the degree of region-wide implementation, as well as reduce the time required to export (United Nations (UN) and Economic and Social Commission for Asia and the Pacific (ESCAP), 2018). An earlier study estimated that substituting paperless for paper trade documentation with respect to intra-APEC merchandise trade could yield cost savings in the order of US\$60 billion on an annual basis (Department of Foreign Affairs and Trade (DFAT) and Foreign Trade and Economic Cooperation (FTEC), 2001). The APEC Secretariat itself reports that APEC-region implementation of SWS and related initiatives has reduced export costs and time in recent years (APEC, 2018a). The notion that trade simplification can assist in the reduction of information costs is additionally supported by several individual-country case studies—including Japan, Republic of Korea, Singapore, and Thailand—referring to the transition towards paperless trade (APEC, 2011; Duval et al., 2015).

But how can we economize on information costs? From a new institutional economics perspective, the way information costs are economized is through different forms of governance (Coase, 1937; Ostrom, 1990; Williamson, 1985). We can use different forms of governance—such as firms, markets, and governments—to lower information costs in different ways and to differing effectiveness. For instance, we could vertically integrate an entire supply chain where all parties form a single hierarchical firm. In this example, trusted information may be more effectively administered through internal systems, but there are clear other costs relating to specialization. Alternatively, a supply chain might consist of a range of quasi-markets between different companies as goods move between them. Although this might have benefits in terms of incentive compatibility and efficiency, this organizational form might be more prone to monitoring costs and moral hazard. Each of these forms of economic organization economize on different elements of transaction costs in comparatively effective ways.

The potential governance solutions for the information costs of global trade ultimately depend on the technologies available and the capacity of entrepreneurs to apply those technologies. The internet, for instance, has been shown to increase international trade volumes by lowering information coordination costs (Freund & Weinhold, 2004). This has partly been due to its impact on the paperless trade agendas discussed earlier. Our focus is on blockchain technology and how it can form a new economic infrastructure for supply chain information governance. Blockchains

⁵The World Economic Forum (WEF) argue that reducing barriers to trade other than tariffs has a large impact because it eliminates resource waste rather than just reallocating resources.

may fundamentally shift the way current governance structures—such as firms and networks—govern supply chains to overcome information costs, opening up new institutional possibilities. Indeed, a 2018 study sponsored by the Cardano Foundation estimated that blockchain could expand world trade in goods by at least US\$35 billion per annum (McWilliams, Niculescu-Marcu, & Cruz, 2018), whereas a World Economic Forum study suggests that blockchain usage could result more than US\$1 trillion of new global trade over the next decade (WEF, 2018). In the following section, we turn to how such a blockchain-based infrastructure might work.

3 | SUPPLY CHAIN INFORMATION ON A BLOCKCHAIN

Blockchain is a new institutional governance technology for creating and maintaining distributed ledgers of information (Berg, 2017; Davidson et al., 2018; MacDonald, Allen, & Potts, 2016). First invented by Satoshi Nakamoto (2008) in its application of the cryptocurrency bitcoin, blockchain combines a number of existing technologies—including asymmetric cryptography, peer-to-peer networking, and append-only databases—to establish secure, distributed ledgers of information. The opportunity of blockchain is most visible from the understanding that much of a modern market economy consists of trusted relationships maintained through ledgers: citizenship, money, firms, and governments (Berg, Davidson, & Potts, 2018a; Casey & Vigna, 2018). Rather than ledgers of information being held within centralized hierarchies—such as governments or firms—blockchains enable decentralized ledger governance. Since its first application in cryptocurrencies, entrepreneurs have applied blockchain to many other ledgers including identity (Berg, Berg, Davidson & Potts, 2018) and voting (Allen, Berg, Lane, & Potts, 2018). Many nodes maintain the trusted state of a blockchain ledger through consensus protocols such as proof-of-work and proof-of-stake. Blockchain not only enables decentralized ledgers to be created, but incorporates incentive compatible mechanisms to maintain those ledgers through cooperation without the need for third party hierarchies. Given the information governance problems for global trade networks, can blockchains be used to lower the information costs better than current solutions?

Blockchain technology can track unique digital assets along supply chains, storing information about them as they pass between multiple parties. The information contained on the blockchain could include ownership data, time stamping, location data, and other product-specific data (e.g., see Abeyratne & Monfared, 2016). The information can be made available to producers, governments, and consumers to satisfy their information needs, and might help identify counterfeit goods (Hackius & Petersen, 2017; Kim & Laskowski, 2018). Blockchain may incentivize parties along a supply chain to provide the information “so that provenance can be evaluated even when no one party can claim ownership over all supply chain data” (Kim & Laskowski, 2018, p. 2). This is particularly important given that Alibaba estimates that global food fraud costs \$40 billion per year (Zhao, 2018), leading to a wide range of issues of food safety.

There are a number of current trials of blockchain-based supply chains. IBM and Maersk are trialling blockchain for supply chains using a permissioned Hyperledger blockchain.⁶ The trial involves a permissioned ledger where information about trade flows, financing, and contracts

⁶There are interesting governance questions relating to permissioned or permissionless blockchain applications. In a permissioned system, only selected users on the system can update the blockchain record. In a permissionless system any, node can contribute information. The former approach requires a level of centralisation to determine which individuals along a supply chain are authorized to upload information, whereas the latter approach may require further cryptoeconomic incentives to encourage the network towards consensus.

are updated and shared across the supply chain (IBM, 2018). There are also other pilots in specific areas, such as combatting illegal fishing.⁷ Rather than the current system of generating supply chain information between hierarchical forms of governance, these examples demonstrate how blockchain potentially enables a secure, decentralized and transparent ledger of digital assets along a supply chain—a new economic infrastructure for supply chains.

Blockchain technology is being combined with complementary technologies such as the Internet of Things (IoT) and smart contracts. GPS and RFID sensors connected to vessels and containers are being used to upload information such as pressure, temperature, and location to immutable blockchains (Tian, 2016). The technological complementarities between blockchain and the IoT partially overcomes one of the primary challenges of blockchain supply chains, and indeed blockchain generally, the problem of the quality of data entered into a blockchain (Apte & Petrovsky, 2016). Through the use of smart contracts, blockchain has the potential to improve accountability between the various actors across the supply chain. Parties can also enter into automatically executing smart contracts (see Szabo, 1997). These smart contracts could perform many functions including automatically changing the ownership of goods, executing payments, or even compensation or insurance payments for a late delivery to compensate relevant parties (Staples et al., 2017). Blockchain supply chains are also likely to create more liquid and efficient data markets. Better trade data could be mined through artificial intelligence to recognize patterns, drive efficiencies, and identify fraud. In this way, supply chains may merge towards “demand chains” (Casey & Vigna, 2018; Casey & Wong, 2017).

The question of the dynamics and organization of blockchain-based supply chains remains open. As Petropoulou (2005) outlines, changes in information costs shifts in the organization of supply chains, including the importance of intermediaries in matching trades across unknown parties. This could open up entirely new forms of economic organization, such as v-form organizations (Allen et al., 2019; Berg, Davidson, & Potts, 2018b). Further, we expect the adoption of blockchain will vary by product, industry, and jurisdiction, and by the granularity and nature of information required. As Harris (1995) has outlined, information and communication needs—and therefore trade costs—are greater for differentiated goods, and trade volumes in these products are likely to be more sensitive to changes in the costs of information and communication. Blockchain is therefore expected to be applied to those goods with comparatively high information costs, such as perishable goods in agriculture (Tian, 2016), high-end manufacturing (Abeyratne & Monfared, 2016), and pharmaceuticals (Apte & Petrovsky, 2016; Mackey & Nayyar, 2017). The nature of these goods is that although their subjective value to the consumer may vary greatly given its provenance and attributes, that information is not always easily verifiable at the time of purchase.

Blockchain, however, is now only one decade old. And its application to supply chains is even younger. How exactly blockchain forms a new economic infrastructure to meet the information demands of supply chains is an entrepreneurial question. In the following section, we turn to some of the policy barriers to this entrepreneurial process. In particular, our focus is on interaction between blockchain supply chains and the regulatory requirements and barriers of territorial governments.

⁷See Provenance (2016). In the pilot, fishers were registered on the system, were tasked with sending SMS messages to create a digital asset of the tuna on the blockchain when it was caught, and that asset was subsequently updated along the entire supply chain.

4 | POLICY AND COORDINATION BARRIERS

A survey of experts in the logistics industry found that the two most common answers to the question “what are the likely barriers for blockchain adoption in the logistics industry?” are *regulatory uncertainty* and *different parties have to join forces* (Hackius & Petersen, 2017). In this section, we examine the role of government in the current entrepreneurial process of developing new blockchain trade infrastructure. How will blockchain supply chains interact with different regulatory states? What are the policy principles necessary to enable this new economic infrastructure to be built? We provide an overview of some of the policy and coordination barriers, helping to give direction to policymakers in the Asia-Pacific region.

The policy barriers of blockchain adoption fundamentally stem from the inherent nature of trade as inter-jurisdictional. Goods moving across borders must interact with a range of regulatory environments, complying with various rules. Therefore, solutions to supply chain information problems must not only take into account the relationship between producers and consumers—thereby providing more trusted information about provenance—but also how these solutions will satisfy regulatory obligations within different jurisdictions.

Scholars of the regulatory state have emphasized how the trade and market liberalization has been concomitant with the development of more regulatory controls around market exchange. The “regulatory state” is a paradigmatic shift in the structure of political economy that has seen regulation (typically governed by independent statutory authorities separated from the normal lines of democratic accountability) replace older models of state intervention such as direct ownership (Berg, 2008; Glaeser & Shleifer, 2003; Majone, 1996, 2011). The regulatory state has also opened new issues into the regulatory domain, such as intellectual property, rules of origin, and labour and environmental standards.

The development of the regulatory state has critical implications for our understanding of trade costs, and the barriers to implementing blockchain trade infrastructure. Heavier regulatory burdens require more information about compliance across a wider range of attributes. Imported goods are usually required to comply with domestic regulatory requirements about provenance and quality of goods. The result is greater demands for information across the entire supply chain. Further demands for information come from the creation of international institutions seeking regulatory harmonization. As the World Economic Forum (2013) outlined, one of the key barriers to supply chains is heterogeneity across jurisdictions “... and even among agencies within any one country. A lack of uniform customs rules, for example, makes it significantly more costly for a company to operate in multiple foreign markets.” Global regulatory harmonization is information intensive. These information requirements are both at national borders—that is between states—and across jurisdictional boundaries—between multinational institutions, states, and subnational governments. As Casey and Wong (2017) note:

A complex array of regulations, maritime law, and commercial codes governs rights of ownership and possession along the world's shipping routes and their multiple jurisdictions. Marrying that old-world body of law, and the human-led institutions that manage it, with the digitally defined, dematerialized, automated and denationalized nature of blockchains and smart contracts will be difficult.

This challenge of regulatory compliance and incompatibility extends beyond blockchain and can be seen in previous efforts of paperless trade agendas and trade digitization. There has been only partial progress among APEC-member countries towards practical implementation of

paperless trading reforms. A comprehensive international audit has indicated that global trade facilitation progress remains uneven, with less developed countries (especially Pacific Island nations) enduring considerable difficulties developing infrastructure to facilitate the electronic flow of trade documentation (UN and ESCAP, 2017). It is noted in the same study that Southeast and East Asian countries (including APEC members) have achieved relatively high trade facilitation policy implementation rates, with an excess of 60% achievement rate in terms of trade facilitation across several measures (including paperless trade).⁸

Governments can be accommodative towards blockchain-based supply chains in many ways. The leading position taken by several countries in Asia and the Pacific, such as Australia, Japan, Singapore, and the United States, in imposing regulatory and fiscal policies in relation to blockchain could contribute towards a semblance of policy compatibility across countries. These countries have been assessed in recent studies to maintain policies of a blockchain-accommodative, “crypto-friendly” nature, motivated in part by perceiving blockchain innovation as a domestic economic development opportunity (Novak, 2018). For example, these countries have each adopted anti-money laundering (AML) and know your customer (KYC) regulatory standards, which is applicable to trade finance. The establishment of high-quality policy settings by crypto-friendly countries is suggested to encourage policy learning, and perhaps the emulation of similar policies by other jurisdictions in the region, in effect, inducing a diffusion of relatively-consistent policy responses to blockchain that is conducive to cross-border trade expansion.

There are several other regulatory issues that will create tension and should be addressed under the broad banner of crypto-friendliness. One of these is the legal recognition of blockchain-based information. Different governments have different requirements of how to comply with domestic regulations. Some of those requirements include the nature of how the information is provided (e.g., a particular form). This raises significant frictions around how governments recognize blockchain-based information about provenance as being sufficient to comply with domestic regulations. As Ganne (2018, p. 98) notes in relation to international efforts of classification, the way that information and contracts viewed as valid by customs and courts should seek to be technologically neutral. Governments should seek to be technologically neutral in how parties comply with domestic regulations. This neutrality also helps to ameliorate the issue of harmonization of requirements across different jurisdictions.

This problem of regulatory incompatibility also extends to the structure of data. Rather than just digitizing existing forms and processes—which has partially been the domain of previous paperless trade processes—blockchain enables new structures of data. This suggests that new forms of data contained within blockchains and other distributed ledger technologies will not necessarily satisfy regulatory requirements. Creating standards for data structures is necessary for several reasons, both from a technical perspective and from an information cost regulatory perspective. From a technical perspective, there are likely to be several different blockchain-platforms carrying supply chain information. The technical question is whether the data between different blockchains can interact. From an information perspective, standards are necessary in terms of data structure to comply with domestic requirements. This problem of standardization is common across many new technologies. We can see the need for standardization by looking at the modern shipping container and railway gauges, which

⁸On a closely related matter, international progress on paperless trade does not necessarily imply inter-country consistency on implementation, especially in the absence of tight coordination between policymakers to reduce trade information costs. As noted by the Australian Department of Home Affairs (2018, p. 5), more than 70 countries have developed and implemented SWS “but they vary considerably in their scope, complexity and sophistication.”

experienced adoption challenges through the entrepreneurial discovery process. Due to network effects, differential standards and fixed costs in the adaptation of existing infrastructure, technologies such as the shipping container took decades to spread across the supply chain. Standards were required to ensure the same container sizes and construction, and set the boundaries within which entrepreneurs could test and trial new applications of this technology. Importantly, containerisation occurred faster in developed countries compared with developing nations—an important issue for development in the Asia-Pacific region. A similar dynamic is likely in the adoption of blockchain-based supply chains.

There may be a fruitful role of policymakers in the Asia-Pacific region, and beyond, to address the potential lack of blockchain interoperability through the development of commonly-agreed technical and information standards. In an international trade environment, the transition towards standard consistency, or at least mutual recognition of variant standards, towards blockchain may reduce costs associated with interpreting and processing data winnowed through different blockchain networks. It is in this context that moves within the Asia-Pacific to promulgate blockchain interoperability, and data exchange are of significance. Australia and several other APEC members, such as Canada, China, Japan, Malaysia, Thailand, and the United States, are progressing new blockchain standards through the International Organization for Standardization (ISO; Eysers, 2018). Some key activities currently undertaken through the ISO negotiations include permission model standards, smart contracting, and consistency in application programming interfaces (Das, 2016).

The development of blockchain standards can take two broad paths. Standards could either be open or closed. Closed standards risk being developed and defined by an early dominant player in the growing blockchain supply chain industry. If a few small parties are able to control the development of the standards, this will ultimately limit the entrepreneurial contestability of building this economic infrastructure. A preferred solution would be the creation of open standards that enable entrepreneurs to view the rules of the game within which blockchain solutions can be applied, and to enable the later interoperability of supply chain solutions.⁹ Although it is not even clear yet what these standards will encompass, what is clear is that they must be international in scope, take into account differing jurisdictional environments, aimed to facilitate entrepreneurial discovery and be created with the input of a diverse number of stakeholders. Such policy entrepreneurship, however, must be coordinated.

We suggest that a process of coordination and policy entrepreneurship around blockchain-supply chains occur through a new high-level policy forum or governance body. The central roles of this body would be to develop open standards and commitments to regulatory recognition for the information governed on blockchain supply chains. Beyond existing international bodies (such as ISO mentioned above), such a new blockchain body might also assist with coordinating early-stage trials and special economic zones that are accommodative to blockchain-based supply chains. Indeed, these trials are necessary because the policy barriers themselves need to be discovered, rather than simply being negotiated away. That is, the role of the body would extend beyond setting technical standards to facilitating trials over the harmonization and recognition of blockchain-based data across various jurisdictions. The need for a dedicated blockchain

⁹For instance, as Levinson (2016, p. 137) outlines at length, in the case of the shipping container there was global coordination: "... the International Standards Organization (ISO), which then has thirty-seven nations as members, agreed to study containers ... The ISO project was meant to establish worldwide guidelines before firms made large financial commitments. Delegates from eleven countries, and observers from fifteen more, came to New York in September 1961 to start the process."

coordination body is also strengthened because blockchain is rapidly evolving—both the technology itself and the nature of the burgeoning industry—and this will necessitate fast-moving coordination. Further, the body's activities are likely to rely on a level of speciality and expertise around blockchain and other distributed ledger technologies across a wide range of potential applications, drawing on a range of different stakeholders from industry, government, and academia. Together, the nature of blockchain technology and the breadth of potential policy barriers and dynamics suggest the need for a high-level policy forum distinct from existing bodies.

5 | CONCLUDING REMARKS

Lowering trade costs expands the boundaries of mutually beneficial trade and propels the process of globalization. This process is critical in the process of Asia-Pacific economic development. Although the shipping container primarily economized on transportation costs, and bodies such as the GATT and APEC helped economize on direct regulatory costs, much of modern trade costs are now information costs. When physical goods are transported between parties and across borders, consumers, governments, and producers increasingly demand information about the characteristics of those goods. This information is costly to coordinate across multiple parties, particularly as supply chains become longer and more complex. New technologies can be used to lower trade costs, creating new forms of economic organization to produce, manage, and verify trade information.

In this paper, we examined the potential of blockchain technology—a new institutional governance technology for creating immutable, secure ledgers of information—to economize on the information costs of supply chains. Blockchain may not only make existing supply chains more efficient, but open up entirely new trading patterns and markets through governing deeper information about differentiated goods. The future of blockchain in supply chains will be propelled through a process of entrepreneurial discovery over several decades.

We then turned to a range of policy challenges that impact this entrepreneurial process of building new blockchain-based trade infrastructure. There are a range of problems that will face how blockchains interact with the regulatory state, including government recognition of data and transactions and technical and informational interoperability. We have identified the need for high-level international coordination between economies in the Asia-Pacific and globally. This forum would focus on connecting academia, industry, and government to discuss questions relating to open standards, the development of new trade agreements, and new trials for blockchain-based supply chains.

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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 make 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

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

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

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 $c_{ik}(p_{ij}(x_{ij}))$ and $c_{jk}(p_{ij}(x_{ij}))$, 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 $c_k(p_{ij}(x_{ij}))$ is the opportunity cost of writing this contract, the consulting firm has an incentive to provide the smart contract as long as

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

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 $\beta_i(x_{ij}|p_{ij}, \delta_j^b) \in [0,1]$ 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

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

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

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

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 $\beta_i(x_{ij}|p_{ij}, \delta_j^b) \in [0,1]$ exists for i about the provision of x_{ij} by j conditional on the provisions p_{ij} and an information set δ_j^b 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:

$$\begin{aligned} & \sum_{x_{ij}} \beta_i(x_{ij}|p_{ij}, \delta_j^b) [v_i(x_{ij}) - p_{ij}(x_{ij})] - c_{ik}(p_{ij}(x_{ij})) \\ & \geq \sum_{x_{ij}} \beta_i(x_{ij}|p_{ij}, \delta_j^b) [v_i(x_{ij}) - p_{ij}(x_{ij})] - c_i^T(x_{ij}) \\ & p_{ij}(x_{ij}) - [c_j(x_{ij}) + c_{jk}(p_{ij}(x_{ij}))] \geq p_{ij}(x_{ij}) - [c_j(x_{ij}) + c_j^T(x_{ij})] \\ & c_{ik}(p_{ij}(x_{ij})) + c_{jk}(p_{ij}(x_{ij})) \geq c_k(p_{ij}(x_{ij})) \end{aligned}$$

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

$$\begin{aligned} & \sum_{x_{ij}} [\beta_i(x_{ij}|p_{ij}, \delta_j^b) - \beta_i(x_{ij}|p_{ij}, \delta_j^i)] [v_i(x_{ij}) - p_{ij}(x_{ij})] \\ & \geq c_{ik}(p_{ij}(x_{ij})) - c_i^T(x_{ij}) \end{aligned}$$

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

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

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 $\beta_i(x_{ij}|p_{ij}, \delta_j^b) - \beta_i(x_{ij}|p_{ij}, \delta_j^i)$ held about the delivery of x_{ij} in its various forms. Any increase in the transaction costs $c_{ik}(p_{ij}(x_{ij})) - c_i^T(x_{ij})$ 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_j^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 through 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.