International Journal of Production Research

ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: http://www.tandfonline.com/loi/tprs20

Blockchain technology and its relationships to sustainable supply chain management

Sara Saberi, Mahtab Kouhizadeh, Joseph Sarkis & Lejia Shen

To cite this article: Sara Saberi, Mahtab Kouhizadeh, Joseph Sarkis & Lejia Shen (2018): Blockchain technology and its relationships to sustainable supply chain management, International Journal of Production Research, DOI: 10.1080/00207543.2018.1533261

To link to this article: https://doi.org/10.1080/00207543.2018.1533261

Published online: 17 Oct 2018.

International Journal of Production Research, 2018
https://doi.org/10.1080/00207543.2018.1533261

Blockchain technology and its relationships to sustainable supply chain management

Sara Saberi, Mahtab Kouhizadeh, Joseph Sarkis* and Lejia Shen

Robert A. Foisie School of Business, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA 01609, USA

(*Received 25 July 2018; accepted 26 September 2018*)

Globalisation of supply chains makes their management and control more difficult. Blockchain technology, as a distributed digital ledger technology which ensures transparency, traceability, and security, is showing promise for easing some global supply chain management problems. In this paper, blockchain technology and smart contracts are critically examined with potential application to supply chain management. Local and global government, community, and consumer pressures to meet sustainability goals prompt us to further investigate how blockchain can address and aid supply chain sustainability. Part of this critical examination is how blockchains, a potentially disruptive technology that is early in its evolution, can overcome many potential barriers. Four blockchain technology adoption barriers categories are introduced; inter-organisational, intra-organisational, technical, and external barriers. True blockchain-led transformation of business and supply chain is still in progress and in its early stages; we propose future research propositions and directions that can provide insights into overcoming barriers and adoption of blockchain technology for supply chain management.

Keywords: blockchain technology; supply chain management; sustainability; barriers; research agenda

1. Introduction

Modern supply chains are inherently complex comprising multi-echelon, geographically disjointed entities competing to serve consumers (Johnson 2006; Lambert and Enz 2017). Globalisation, diverse regulatory policies, and varied cultural and human behaviour in supply chain networks make it almost impossible to evaluate information and manage risk in this intricate network (Sarpong 2014; Ivanov, Dolgui, and Sokolov 2018). Inefficient transactions, fraud, pilferage, and poorly performing supply chains, lead to greater trust shortage, and therefore, a need for better information sharing, and verifiability.

Traceability is becoming an increasingly urgent requirement and a fundamental differentiator in many supply chain industries including the agri-food sector (Costa et al. 2013), pharmaceutical and medical products (Rotunno et al. 2014), and high value goods (Maurer 2017). Luxury and high value items whose provenance might otherwise be reliant on paper certificates and receipts can easily be lost or altered. In fact, lack of transparency in the supply value of any item prevents supply chain entities and customers from verifying and validating the true value of that item. The cost involved in handling intermediaries, their reliability, and transparency further complicate managing this traceability in the supply chain. Strategic and reputational competitive issues arise from these risks and lack of transparency.

For example, the salmonella outbreak case linked to Maradol-brand papayas, with hundreds of people in the United States has fallen ill, could disparage a brand and its supply chain. Although the centre for disease control reported the origin of the contaminated papayas;[1] not all shipments were traceable or could be recalled, while injurious results and safety concerns continued. Another case is the 2015 *E. coli* outbreak[2] within Chipotle Mexican Grill outlets, leaving dozens of customers ill. This outbreak caused significant image concerns for Chipotle, causing its stock prices to fall by up to 42%. Lack of transparency and accountability across Chipotle supply chains and capability to monitor multiple suppliers in real-time were some obstacles for Chipotle. These obstacles could have caused further contamination prevention even after its discovery.

Current supply chains rely heavily on centralised, sometimes disparate and stand-alone information management systems, that are within organisations; for example, enterprise resources planning systems, which has its own pitfalls. Supply chain entities require significant trust for relying on one single organisation or broker for storing their sensitive and valuable information (Abeyratne and Monfared 2016). Single point failure is another disadvantage of centralised information systems which leaves the whole system vulnerable to error, hacking, corruption, or attack (Dong et al. 2017).

*Corresponding author. E-mail: jsarkis@wpi.edu

Supply chain practice and strategy is also facing emergent pressures to consider and certify supply chain sustainability. Sustainability has been defined by the triple-bottom-line concept that includes a balance of environmental, social, and business dimensions when managing the supply chain (Seuring et al. 2008). An important strategic and competitive issue for sustainability in supply chains is the confirmation and verification that processes, products, and activities within the supply chain meet certain sustainability criteria and certifications (Grimm, Hofstetter, and Sarkis 2016).

Such issues evoke questions on whether current supply chain information systems can support information required for the timely provenance of goods and services, in a secure manner that is clear and robust enough to trust. The solution to these complicated problems lies in improving supply chain transparency, security, durability, and process integrity. The answer to this problem may be blockchain technology (blockchain). New technological developments and applications with the concept of blockchain technology make these improvement goals more organisationally, technologically, and economically feasible (Swan 2015; Abeyratne and Monfared 2016). Blockchain technology as a potentially disruptive technology incorporating characteristics of a decentralised 'trustless' database allows for global-scale transactions and process disintermediation and decentralisation amongst various parties (Crosby et al. 2016).

Some early use cases that exemplify possibilities and concerns with blockchain technology exist. One of the more popular cases involves Maersk and its partnership with IBM for it maritime container management through blockchains. In this use case, IBM mentioned that billions in savings could occur by having more accurate and trustworthy bills of landing attached to containers (Groenfeldt 2017). Interestingly, although billions of savings are mentioned, it is not clear that a full-fledged implementation was possible due to scaling issues. Additionally, from a sustainable supply chain perspective, Provenance, a blockchain service provider, has sought to integrate blockchain technology in the seafood supply chain. In this case, transparency and validity of sustainable practices were critical (Steiner and Baker 2015). Hence, whether there are concerns related to environmental, economic, or social issues, blockchain's potential uses have seen significant discussion in the professional literature.

Although the blockchain use cases have increased over the years, just as any potentially disruptive system or technology, blockchain faces various obstacles and barriers in adoption and implementation by supply chain networks. Blockchain is still in early stages of development with various difficulties from behavioural, organisational, technological, or policy-oriented aspects (Crosby et al. 2016; Lemieux and Lemieux 2016; Yli-Huumo et al. 2016). These issues will be important in scholarly literature discourse for a number of years. At this time the nascent practical issues are harbingers to scholarly debate and questions. The issues have yet to be addressed integrally and effectively. In this article, we initiate the debate with a focus not only on blockchain-based supply chain challenges, obstacles, and barriers but also on the blockchain adoption benefits and applications in the sustainable supply chain. The relationships to current theory, the need for potentially new theory and research are also discussed; with an outcome being some specific research propositions.

This paper is organised as follows. Blockchain technology is introduced in Section 2 and its application in managing a supply chain is described in Section 3. Section 4 presents the advantages of blockchain to maintain sustainability dimensions in a supply chain network. In Section 5, the barriers and obstacles facing blockchain technology implementation in a supply chain and supporting sustainability are reviewed and clustered into four different categories. Research directions and propositions are presented in Section 6. Finally, Section 7 concludes the paper.

2. Blockchain technology

Blockchain technology is a distributed database of records or shared public/private ledgers of all digital events that have been executed and shared among blockchain participating agents (Crosby et al. 2016). Its history can be traced to distributed ledger technology. Blockchain technology differs from most existing information systems designs by including four key characteristics; non-localisation (decentralisation), security, auditability (Steiner and Baker 2015), and smart execution (see Figure 1).

In blockchain, an agent creates a new transaction to be added to the blockchain. This new transaction is broadcast to the network for verification and auditing. Once the majority of nodes in the chain approve this transaction according to pre-specified approved rules, this new transaction is added to the chain as a new block. A record of that transaction is saved in several distributed nodes for security. Meanwhile, the smart contract, as a critical feature of blockchain technology allows the performance of credible transactions without third parties' involvement.

A major difference between the current design of the Internet and blockchain technology is that the Internet was designed to move information (not value) and to move copies of things (not original information). In blockchains, value is represented in transactions recorded in a shared ledger and secured by providing a verifiable, time-stamped record of transactions, which provides secure and auditable information (English, Auer, and Domingue 2016). These transactions appear through a verification process that is consistent with network consensus rules. Once the new record is verified and added to the blockchain, multiple copies are created in a decentralised manner to create trusting chain.

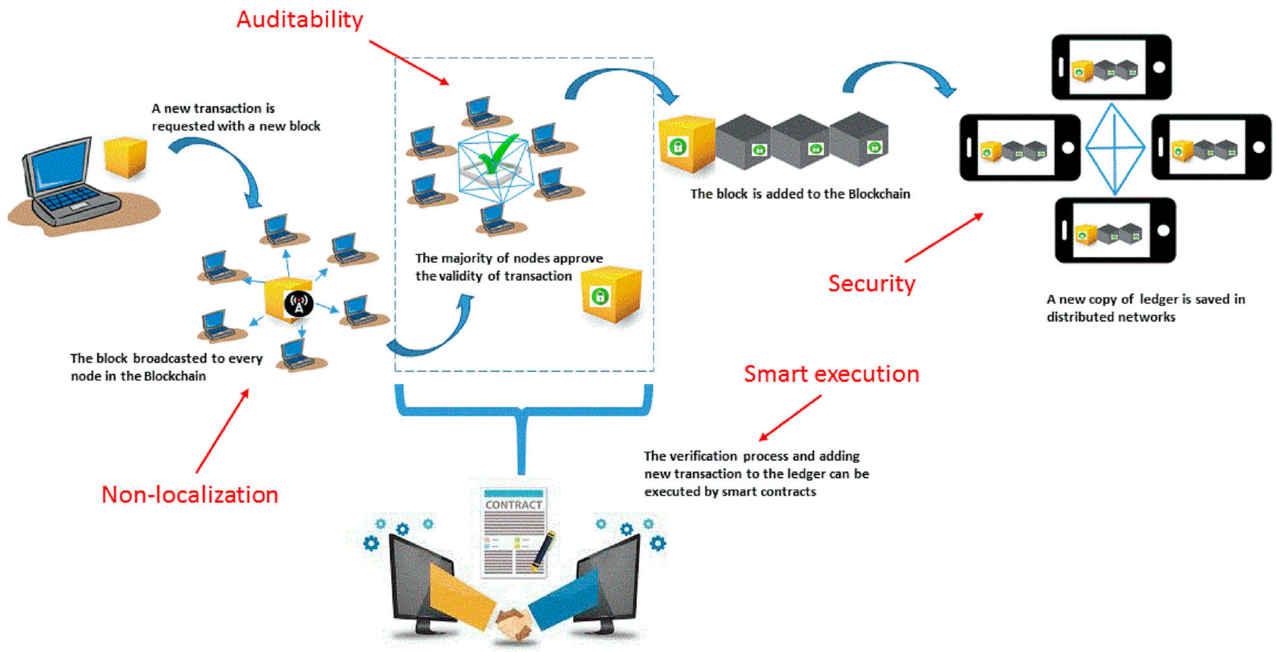

Figure 1. Steps in blockchain information and transactions.

Decentralisation is an important property of blockchain technology and is a check on any adulteration of information, thus increasing information validity. Removing collectively maintained records are impractical and verified records of every single transaction are accessible to the participants through distributed public or private ledgers (Crosby et al. 2016). A centralised database is more susceptible to hacking, corruption, or crashing (Tian 2016).

Trust is a main consequence of decentralisation since there is no need to assess the trustworthiness of the intermediary or other participants in the network (Nofer et al. 2017) and information is easily viewed and compared. This approach does not require any particular behaviour on behalf of the participants; instead, the underlying technology guarantees the integrity of the system even in the face of dishonesty or idleness. Participants are able to view the ledgers and analyse transactions. This feature provides transparency (Tian 2016) while simultaneously ensuring anonymity through preserving records behind cryptographics (Crosby et al. 2016). Blockchains can be generalised and used to implement an agreed upon set of rules that no one, neither the users nor the operators of the system, can break. They rely on a unique system architecture platform for applications involving multiple parties who require little trust in each other; for example, fragmented supply chains.

Depending on the technology application, blockchain design is different and can form public (permissionless) or private (permissioned) ledgers and networks (Ølnes, Ubacht, and Janssen 2017). Their design is different in terms of the network players and the rules to maintain the blockchain. In a private or a closed blockchain, the parties know each other and there is no anonymity, such as in a supply chain network with known entities working to produce and distribute products. In this case, there would be new roles such as certifiers, who provide certifications to supply chain network participants and maintain this private network. Alternatively, in a public or an open blockchain, to maintain trust with many anonymous users, cryptographic methods are applied to let users enter the network and record their transactions (Pilkington 2015).

Meanwhile, a new generation of transactional applications that establish trust, accountability, and transparency is fostered by means of blockchain technology; these applications are managed by a so-called smart contract. A smart contract is typically a software programme that stores rules and policies for negotiating terms and actions between parties. It automatically verifies that contractual terms have been met and executes transactions (Delmolino et al. 2016). The logic of a smart contract is executed by the network of players who reach consensus on the outcome of the contract execution. The contract executes its code whenever it receives a message, either from a player in the network or from another contract and updates the ledgers accordingly if the contractual terms of its public or private network are met (Peters and Panayi 2016).

Blockchain technology first gained popularity as a platform for managing Bitcoin, a digital cryptocurrency (Nakamoto 2008). Apart from the digital currency, blockchain technology is a new computing and information flow paradigm with broad implications for future development in supply chain management and logistics (Abeyratne and Monfared 2016; Tian 2016; Maurer 2017). It is this perspective that we take in the remainder of this paper.

3. Blockchain-based supply chain

Blockchains are, potentially, a disruptive technology for the design, organisation, operations, and general management of supply chains. Blockchain's ability to guarantee the reliability, traceability, and authenticity of information, along with smart contractual relationships for a trustless environment all portend a major rethinking of supply chains and supply chain management. In this section, we will dive deeper into the value proposition of blockchain technology and its applicability to goods and manufacturing supply chain, its structure, and possible new components for managing a supply chain.

How blockchain functions within the context of the supply chain are still open to interpretation and development. Unlike bitcoin and other financial blockchain applications, which may be public; blockchain-based supply chain networks may require a closed, private, permissioned blockchain with multiple, limited players. But, the door may still be open for a more public set of relationships. Privacy level determination is one of the initial decisions. Figure 2 shows a general graphic of one traditional supply chain transformation to a blockchain-based supply chain.

Four major entities play roles in blockchain-based supply chains; some not seen in traditional supply chains. *Registrars*, who provide unique identities to actors in the network. *Standards organisations*, who define standards schemes, such as Fairtrade for sustainable supply chains or blockchain policies and technological requirements. *Certifiers*, who provide certifications to actors for supply chain network participation. *Actors*, including manufacturers, retailers, and customers, that must be certified by a registered auditor or certifier to maintain the system trust (Steiner and Baker 2015).

Influences on the supply chain product and material flows also exist. Every product may have a digital blockchain presence so that all relevant actors can have direct product profile access. Security measures may be set in place to limit access, where only the parties with the correct digital keys have access to a product. There is a range of data that can be collected, including the status of the product, the type of product, and the standards that are to be implemented for a product (Tian 2017). An information tag attached with a product represents an identifier that links physical products to their virtual identity in the blockchain (Abeyratne and Monfared 2016).

One interesting structure and flow management characteristic are how a product is 'owned' or transferred by a particular actor. Actors gaining permission to enter new information into that product's profile or initiate a trade with another party will likely be a significant rule; where gaining permission may require smart contract agreements and consensus.

Before a product is transferred (or sold) to another actor both parties may sign a digital contract, or meet a smart contract requirement, to authenticate the exchange. Once all parties have met contractual obligations and processes, transaction details update the blockchain ledger. The records of data transactions would be automatically updated by the system when a change is initiated (Abeyratne and Monfared 2016).

The blockchain technology can highlight and detail at least five key product dimensions: the nature (what it is), the quality (how it is), the quantity (how much of it there is), the location (where it is) and the ownership (who owns it at any moment). In this way, the blockchain removes the need for a trusted central organisation that operates and maintains this system and allows customers to inspect the uninterrupted chain of custody and transactions from the raw materials to the end sale. This information is recorded in ledgers as transactions occur on these multiple blockchain information dimensions; with verifiable updates.

Blockchain reliability and transparency are meant to more effectively facilitate material and information flow through the supply chain; with automated governance requirements. This transformation may result in a broader shift from an industrial durable, commodity, products economy to an information, customisation economy. Production will rely more heavily on knowledge, communication, and information and not necessarily on materials characteristics (Pazaitis, De Filippi, and Kostakis 2017). For example, customers can track the detailed information of products which would increase costumers' trust associated with product characteristics (Tian 2016).

Smart contracts, as written rules stored in the blockchain, can help to define network actor interaction amongst each other and within the system. Smart contracts influence network data sharing between supply chain participants and continuous process improvement. For example, certifiers and standards organisations digitally verify actor profiles and products. Actors and products have their own digital profile on the network, which displays information such as description, location, certifications and association with products. Each supply chain player can log in key information about a given product and its status on the blockchain network (Tian 2017).

Smart contract governance and process rules in a blockchain-based supply chain can manage actor certification and approval and what processes they are allowed to access and are needed for execution. Actor data changes can occur depending on supply chain type, position, and trigger defined by a smart contract. The actors cannot change the rules without some form of consensus process (Maurer 2017). Another example of smart contract applications is in procurement. A smart contract between two trading partners can legally update the automated record of what goods were bought, sold, and delivered in real-time by end users across the line of business.

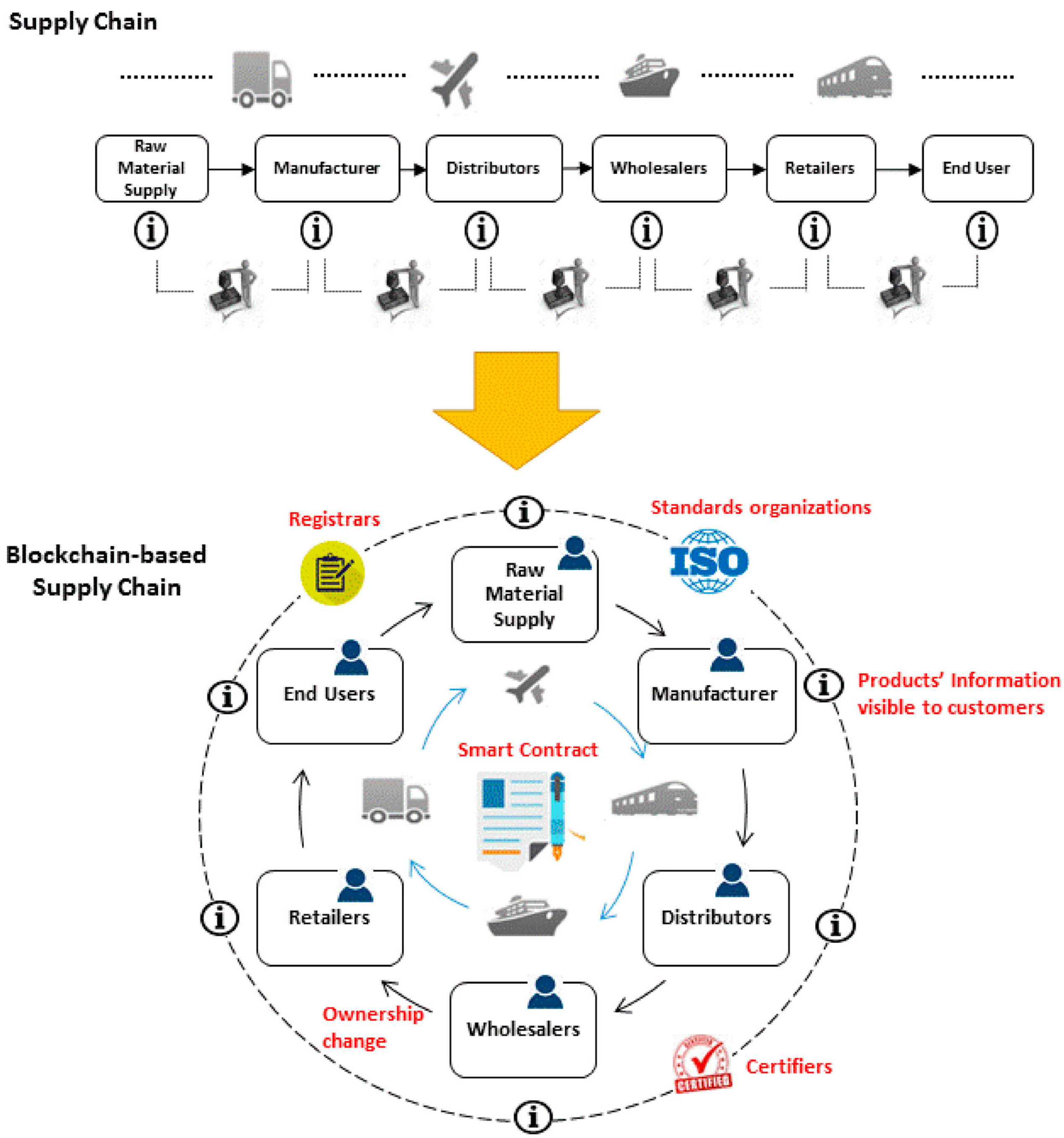

Figure 2. Supply chain transformation.

Smart contract process characteristics portend potential business process continuous improvement for supply chain processes. The potential for supply chain business process improvements can be situated in blockchain information that may capture performance metrics in ledgers; linking them to agree upon processes. This type of approach and information has great potential for supply chain design and real-time implications, beyond just product delivery and governance concerns.

Blockchain impacts both supply chain process and product management, and financial transactions between different network parties (Hofmann, Strewe, and Bosia 2018). A key potential blockchain supply chain advantage is the disintermediation of financial intermediaries, including payment networks, stock exchanges, and money transfer services (Tapscott and Tapscott 2017). This will make trading processes among partners more efficient. Inefficiencies in supply chain financial flows can be reduced through supply chain finance instruments and techniques such as reverse factoring and dynamic discounting (Seifert and Seifert 2011; Popa 2013); saving networks millions of dollars (Fanning and Centers 2016). Smart contracts are capable of organising financial arrangements and would ensure that sufficient funds are available to the projects and that everyone is paid in a timely manner (Hofmann, Strewe, and Bosia 2017). They provide a connection for transaction between different currencies or mix them from multiple sources in global supply chain in a secure and timely manner (Eyal 2017).

Although a broad variety of blockchain technology applications in the supply chain can exist, they are industry, product or service, or governance focused. To exemplify a practical blockchain supply chain application we turn our discussion to sustainable supply chains. Momentum is building towards sustainability solutions. Regulatory, consumer and community pressure on businesses and their supply chains to improve the sustainability of their supply chains and their products (Zhu, Sarkis, and Lai 2018). These facts prompt us to identify future supply chain implications in more detail by considering the effect of blockchain technology on sustainable supply chains.

4. Blockchain and sustainable supply chains

Blockchains as distributed, immutable, transparent, and trustworthy databases, shared by a community, can also influence sustainable supply chain networks. Tracking potential social and environmental conditions that might pose environmental, health and safety concerns is an important application focus for the blockchain (Adams, Kewell, and Parry 2018). Practical examples exist. Blockchains formed in China for carbon asset markets allows enterprises to generate carbon assets more efficiently in accordance with China's Carbon Emissions Reduction for the Paris Agreement[3]. A blockchain-based supply chain provides better assurance of human rights and fair work practices. For instance, a transparent record of product history assures buyers that goods being purchased are supplied and manufactured from sources that have been verified as being ethically sound. Smart contracts may be especially capable for rules of tracking and controlling sustainable terms and regulatory policy autonomously and enforcing or governing appropriate corrections.

Sustainable supply chains have gained significant interest amongst academics and practitioners (Fahimnia, Sarkis, and Davarzani 2015). Not only are business dimensions of the supply chain important for sustainable supply chains, but expanding the focus to environmental and social dimensions has made for a more generalisable and holistic perspective on the supply chain. The promising features of blockchain technology might be a panacea for such complexity in the triple-bottom-line of sustainability: economic, social, and environmental bottom lines. Thus, capturing and identifying sustainable supply chain examples can exemplify the breadth of blockchain technology application.

Blockchain technology can support data collection, storage, and management, supporting significant product and supply chain information. Openness, transparency, neutrality, reliability, and security for all supply chain agents and stakeholders can exist in this technological context (Abeyratne and Monfared 2016).

The food and beverage industry faces supply chain sustainability pressures. An interesting application in this context is the nexus of Radio Frequency Identification (RFID) and blockchain technology to equip a food supply chain with traceability system for real-time food tracing based on Hazard Analysis and Critical Control Points (HACCP) rules (Tian 2017). It can record supply chain events in the agricultural sector (Staples et al. 2017). Blockchain can aid supply chains to detect unethical suppliers and counterfeit products since all the information can only be recorded by authorised actors; these can cause serious social harm.

Economically, adopting blockchain technology can benefit a firm and its supply chain from different business dimensions affecting their economic performance. We provide some examples, out of many for making the economic business case for blockchain technology in the supply chain. Blockchains can result in supply chain disintermediation where fewer tiers result in transaction costs and time reduction, reducing business waste in the supply chain (Ward 2017). Blockchain technology can share instantly every modification of the data, allowing for potentially rapid deployment of products and processes while minimising human errors and transaction times. Blockchain technology can ensure the safety and authenticity of the data, which will reduce the cost of preventing data from deliberate and capricious alteration increasing supply chain risks and reducing business reliability (Ivanov, Dolgui, and Sokolov 2018). Besides, customers and government now ask for transparency within supply chain. Pioneering companies realised the competitive advantage of transparency (Ward 2017), which results in increasing customers' trust to purchase more and benefit the firm financially.

Blockchain technology has the potential to contribute to social supply chain sustainability. Making information stable and immutable is one way of building supply chain social sustainability. Given that information cannot be modified without consent by authorised actors, blockchains can prevent corrupt individuals, governments or organisations from seizing assets of people unfairly. Also, blockchain technology can block nefarious agents and hold the corrupt accountable for both social and individual misdeeds. Blockchain traceability helps sustainability through better assurance of human rights, and fair, safe work practices. For instance, a clear record of product history helps buyer confidence that goods being purchased are from ethical sources.

Blockchain technology also aids in environmental supply chain sustainability. It can do so from many different perspective applications. First, tracking substandard products accurately and identifying further transactions of the products can help reduce the rework and recall, which helps decrease resource consumption and reducing greenhouse gas emissions. Traditional energy systems are centralised while a peer-to-peer network based on blockchain technology for energy system can reduce the need to transmit electricity over long distances and subsequently save a big portion of energy wasted over long distance transmission. It would also reduce the need for energy storage which saves its resources. There are several power platforms based on blockchain technology to reduce the waste of the supply chain, such as Echchain, ElectricChain, and Suncontract (futurethinkers 2017).

Second, blockchains could be used to ensure that purportedly green products are environmentally friendly. The processing information for green products is often unavailable and difficult to verify. If the manufacturing process of a product is verified to be green in terms of greenhouse gas emissions level, environmentally conscious customers may be more willing to purchase green products. For example, Ikea has a desk product made from wood cut in a sustainable Indonesian forest. Ikea must follow the wood from the time it's cut through manufacturing to the final product to guarantee the desks really made from this specific wood. This process is complex but can be managed with blockchain technology. One such example is the Endorsement of the Forestry Certification programme which traces the provenance of around 740 million acres of certified forests all over the world using blockchain technology (Rosencrance 2017).

Another environmental supply chain sustainability example is related to carbon tax. In traditional systems, the carbon footprint of each product is difficult to measure. With blockchain technology, tracing the footprint of products of particular company becomes easier. It can help determine the amount of carbon tax should be charged of a company. If a product is more expensive with a large carbon footprint, the customers may buy a product of low-carbon footprint. This additional information and consumer or market pressure may cause firms to reevaluate and restructure their supply chain to reduce the carbon emissions to meet the demand of buyers. Blockchain technology can help reduce carbon emissions in the journey of products by providing the fundamentals for supply chain mapping and applying low-carbon product design, production, and transportations (de Sousa Jabbour et al. 2018a). The Supply Chain Environmental Analysis Tool (SCEnAT) proposes a framework to assess carbon emissions of each entity involved in supply chains and life-cycle of products (Koh et al. 2013). SCEnAT 4.0 is a new tool that integrates novel technologies such as blockchain, Internet of Things (IoT), Artificial Intelligence, and Machine Learning to manage big data and link organisations in the supply chain more effectively to support industry 4.0 policies, carbon reduction, and green assessments[4]. Blockchain technology also has the potential to transform carbon assets trading. As an example, IBM and Energy Blockchain Labs Inc. in China are developing a green assets blockchain-based platform that helps organisations to track and measure their carbon footprint, meet the Carbon Emission Reduction (CER) quotas, and facilitate carbon asset development and trading. Transparent, secure and real-time information on the blockchain gives organisations the opportunity to cooperate and trade their carbon assets in a more efficient way in the green assets markets[5].

Third, blockchain can improve the recycling. People and organisations may not be motivated to participate in recycling programmes. Blockchain technology has been used to motivate people in Northern Europe through financial rewards in the form of cryptographic tokens in exchange for depositing recyclables like plastic containers, cans, or bottles. Meanwhile, it is difficult to track and compare the impact of various recycling programmes. Blockchain makes it possible to track data for evaluating the impact of various programmes. For example, Social Plastic is a project based on blockchain technology to turn plastic into money and aims to reduce the plastic waste. RecycleToCoin is another blockchain application that enables people to return plastic containers (futurethinkers 2017). The possibilities for this type of effort for closed-loop supply chains make blockchain amenable to emerging concepts such as the circular economy.

Fourth, blockchain benefits the emission trading process by improve emission trading schemes (ETS) efficacy. With the application of blockchain technology, fraud can be avoided due to the fidelity and transparency of blockchain. Thus, a reputation-based system is created which solves the inefficiency of ETS and it encourages all the participant to figure out a long-term solution to the emission reduction, because the participants are encouraged by the economic benefits of good reputation (Khaqqi et al. 2018).

The use of Blockchain technology as a supply chain governance and information management mechanism will be challenging specially in a sustainable network. Disruptive technologies typically face challenges, whether in the short-term or long-term (Mendling et al. 2017). Therefore, participants of supply chain need to be prepared for it to have it as an opportunity, rather than a threat, as it might challenge the relationships through supply chain. These examples show the potential for economic, social, and environmental (sustainability) influences that can be managed in a blockchain-enabled supply chain.

5. Preparing for blockchain technology adoption in the supply chain – understanding the barriers

Thus far in this paper, we have defined how blockchain technology can change and disrupt supply chain design, activities, and product flows. Benefits and innovations have been presented. Now we consider some of the concerns related to implementation in this environment; especially with respect to supply chains, blockchain technology, and sustainability.

Successful implementation of blockchain technology to trace sustainable practices and managing supply chain processes and products through the supply chain begins with the identification of challenges and barriers to be managed. Supply chain partners need to understand and plan for these obstacles for blockchain technology adoption and implementation.

In this section, relevant literature including books, journals, conference papers, review papers, and online database were reviewed to identify various barriers hindering blockchain technology adoption in general and for sustainable supply chains in particular. The barriers were determined based on the literature related to supply chain information systems, sustainabile supply chains, and blockchain technology. The references that formed the list of barriers are from these three major areas. Experts' feedback was also acquired to further validate the list of barriers. The barriers are summarised and grouped into four main categories of intra-organisational barriers, inter-organisational barriers, system-related barriers, and external barriers considering the internal and external limitation of organisation in adopting a new technology (Figure 3).

5.1. Intra-organisational barriers

These set of barriers stem from internal activities of organisations. Top management support is a key factor to the successful implementation of any supply chain practices. However, some managers fail to have long-term commitment and support to adopt a new technology and stick to sustainability values. Lack of management commitment impedes integrity of sustainability practices through supply chain processes (Govindan and Hasanagic 2018). Lack of awareness and commitment of management in the supply chain would challenge resource allocations (Fawcett et al. 2006) and financial decisions.

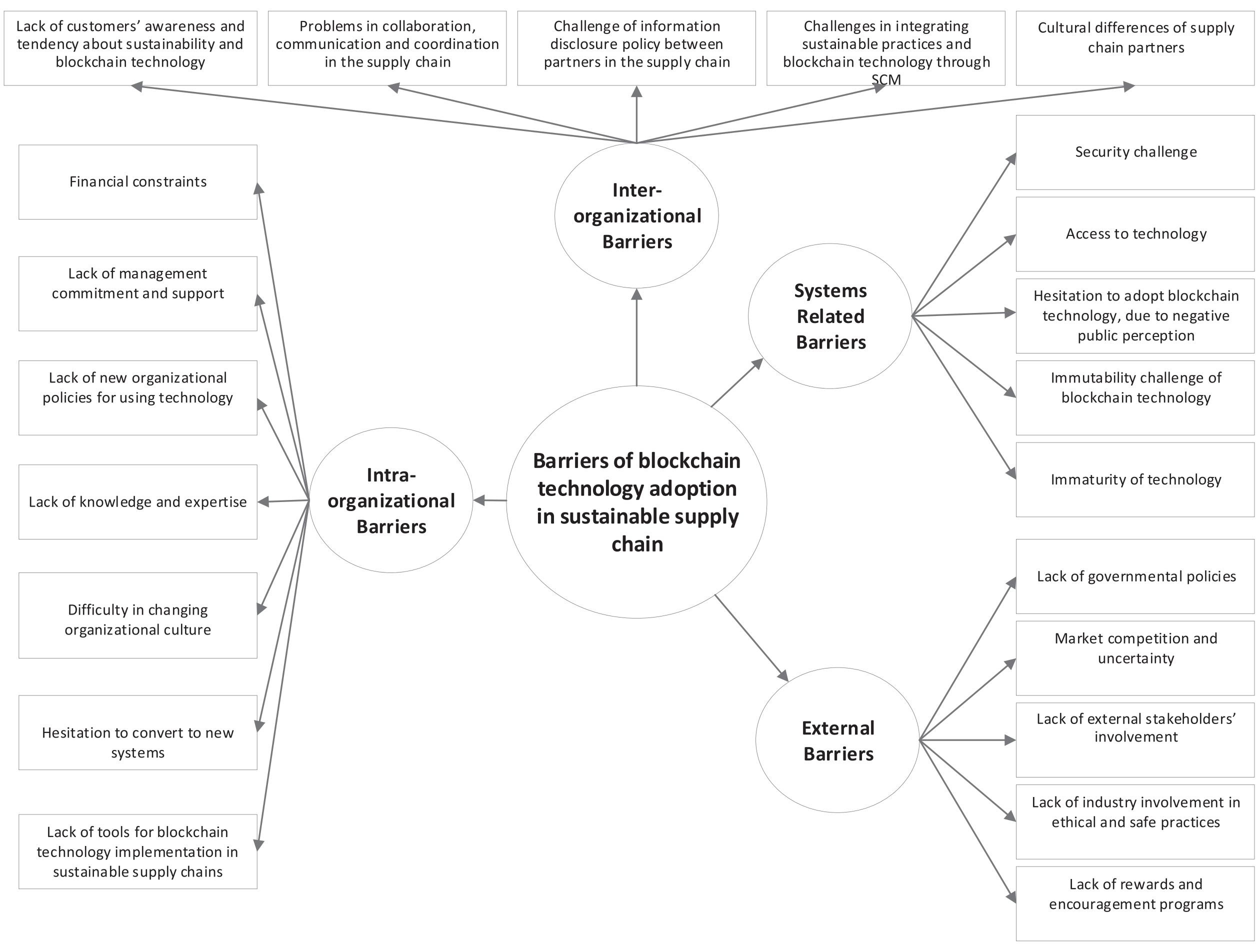

Figure 3. Barriers of blockchain technology adoption in sustainable supply chain.

Blockchain technology acceptance requires investing in new hardware and software for information collection, which is costly for organisations and network partners (Mougayar 2016).

Lack of the required new organisational policies to clarify the usage of blockchain technology could be a challenge. Blockchain technology adoption may change or transform current organisational cultures (Mendling et al. 2017). Organisational culture outlines the guidelines of the work cultures, values, and appropriate behaviour within organisations (Gorane and Kant 2015). Also, adopting blockchain technology in supply chain processes requires new roles, responsibilities, and expertise to support different facets of adopting technology (Mendling et al. 2017).

Limited technical expertise and knowledge of using blockchain technology act as a barrier of adopting this new technology into the supply chain. Although there is growing interest about blockchain in the technical market, the limited number of applications and technical developers of blockchain is an issue (Mougayar 2016). Blockchain technology is an information technology (Swan 2015), which can be disruptive and requires altering or replacing legacy systems (Mougayar 2016). Converting to new systems may change organisational culture or hierarchy and lead to resistance and hesitation from individuals and organisations (Jharkharia and Shankar 2005). Theoretically, using the Technology Acceptance Model (TAM), the level of applicability of a new information technology in terms of its usefulness and ease of use for individuals and organisations can be predicted and evaluated (Venkatesh et al. 2003; Wallace and Sheetz 2014). Blockchain application can be evaluated from TAM angle.

If organisations wish to have sustainable supply chains with supporting a new information technology that is adopted by all the supply chain network, they need to embed sustainability practices into their organisational vision and mission (Mathiyazhagan et al. 2013). Proactive plans to implement sustainability at all organisational levels and throughout the supply chain are also needed (Tseng, Lim, and Wong 2015). Lack of standard tools, methods, and indicators hinder successful implementation and measurement of sustainability practices (Mangla, Govindan, and Luthra 2017) within a blockchain environment, for a given organisation. Blockchain technology is in its early stages and supply chains that successfully implemented this technology to track their sustainable practices are difficult to find. Lack of business models and best practices in implementing blockchain technology is a challenge (Mougayar 2016).

One of the main drivers of adopting sustainable practices in organisations is environmental regulations and rules. Organisations are investing and seeking to meet minimal sustainability criteria, which can simultaneously impede their creativity and innovativeness in implementing sustainable methods (Sajjad, Eweje, and Tappin 2015). A driver that can improve creativity in implementing sustainability is customers' demands for sustainable products and processes. Lack of customers' awareness and willingness to contribute in sustainable development is a barrier of sustainability implementation. In this case, customers do not understand the green certification schemes and are unwilling to contribute in recycling processes or pay more for sustainable products (Chkanikova and Mont 2015; Mangla, Govindan, and Luthra 2017).

5.2. Inter-organisational barriers

This category mainly identifies and introduces supply chain partners' relationship barriers. Principally, supply chain management is about managing relationships among partners to create value for stakeholders (Lambert and Enz 2017). However, relationships between partners could be challenging, especially when it comes to integrating information technology and sustainability practices. Blockchain technology would facilitate information sharing through a supply chain. Although information transparency and verifiability is a need for evaluating sustainability performance of a supply chain (Sarkis and Zhu 2018), some organisations may assume information as a competitive advantage which makes them unwilling to share valuable and critical information (Fawcett et al. 2009; Sayogo et al. 2015). The hesitation to reveal information from some partners may limit the full benefits of adopting blockchain technology and hinder successful implementation of this technology.

Different privacy policies related to information and data usage and release in supply chains might lead to new challenges for data sharing between partners (Sayogo et al. 2015). Because of transparency of information in blockchain technology information sharing rules and policies should be defined and managed within supply chain network. Lack of solid rules for information sharing eventually affects collaboration among supply chain partners (Gorane and Kant 2015). Lack of collaboration and effective communication among supply chain partners with different and even contradictory operational objectives and priorities (Mangla, Govindan, and Luthra 2017) disturb sustainability (Oliveira and Handfield 2018) and supply chain operations and implementation of blockchain to create sustainable values. Communication challenges would be worse where supply chain partners are geographically dispersed with different cultures (Sajjad, Eweje, and Tappin 2015).

Finally, combining conventional supply chain processes with sustainability practices is not an easy process. Current technologies, designs, materials, and processes need to be improved to support sustainable practices (Kaur et al. 2018; Sarkis and Zhu 2018). For example, reduction in greenhouse gas emissions, carbon footprints, water pollution, energy consumption, and waste requires an update in materials, machines, and facilities. This imposed cost on the supply chain.

Similarly, information collection for blockchain technology purposes mostly needs its own facilities and devices. RFID and the Internet of Things are two potential solutions to such an issue.

5.3. System-related barriers

In order to implement blockchain technology and gather information for supply chain management purposes (e.g. Internet of Things), new IT tools are needed. This can be a challenge for some supply chain participants (Abeyratne and Monfared 2016). All of the participants of a chain need to access the required information to take advantage of the opportunities for value savings in an integrated supply chain (Fawcett et al. 2009; Gorane and Kant 2015). Therefore, technology access limitation to get real-time information in a supply chain is a barrier to implementing blockchain technology.

Blockchain technology is in its early development stages and considered an immature technology in terms of scalability and handling a large number of transactions (Yli-Huumo et al. 2016). Apparently, increasing size and number of blocks is a storage dilemma for handling big data in real-time usage, this is called a 'bloat' problem in Bitcoin (Swan 2015). For supply chain networks it is expected that there are even larger data requirements, that go beyond financial data, and include data related to processes and practices. Therefore, improvement in storage management and advanced cloud computing infrastructure will be required.

Data manipulation in supply chain networks can be a major concern (Mishra, Raghunathan, and Yue 2007). While adopting blockchain technology gives every participant of supply chain networks an opportunity to verify transactions, collusion is still possible by obtaining consensus of participants (Swan 2015). Data security and privacy concerns are also challenges of using blockchain technology (Mougayar 2016). Security challenge of blockchain technology in the Bitcoin network including hacks and attacks has been addressed in some research (Lim et al. 2014; Vasek and Moore 2015). While some solutions have been suggested to mitigate blockchain security challenges, the effectivity of these solutions has not been evaluated (Yli-Huumo et al. 2016). Still, blockchain technology is associated primarily with cryptocurrencies such as Bitcoin and with its malicious activities (Swan 2015), the 'dark web' reputation, which slows down blockchain technology adoption in general.

Immutability of information is another important feature of blockchain technology. It means that information cannot be changed and removed in blockchain without consensus. That prevents falsifying and adulteration of data (Tian 2016). However, humans are still involved in applying this technology with the possibility of having erroneous recorded data. Even if the key owners can edit the data and update it with additional information, the scar of erroneous record will always be in the blockchain (Palombini 2017).

5.4. External barriers

This category introduces challenges stemming from external stakeholders, industries, institutions, and governments; those entities not directly economically benefiting from supply chain activities. External pressures and support for implementing sustainability and technological practices can drive organisations to integrate them into their processes. Lack of appropriate governmental and industry policy and willingness to direct and support sustainable and safe practice is a hurdle for achieving sustainability and advanced technological supporting mechanisms (Mangla et al. 2018). Governmental regulations and laws are still unclear about the usage of blockchain technology. In fact, the adverse policies issued by several governments about Bitcoin is a concern for markets and organisations that can affect broader usage of blockchain for business objectives (Mougayar 2016). Hence, governments, NGOs, industries, communities, and professional organisations should promote blockchain technology to create sustainability value. In addition, demand uncertainty for sustainable products and customers' behaviour ambiguity may affect market competition (Kaur et al. 2018) and impede the integration of sustainability and blockchain technology. Organisations need to ensure that their investment on green products, sustainable processes, and a new technology like blockchain would be compensated by their customers.

Reviewing and clustering blockchain technology adoption obstacles will pave the way in effectively understanding new technology in supply chain networks and building sustainability aspects of supply chain. These factors are not empirically tested or verified, nevertheless, this framework and factors provide a starting point for future research studies. More in-depth works are likely to bring to the additional wider contextual factors that go beyond the inter/intra-organisational environment, technical and external outlooks such as political developments to globalise supply chain networks.

Building on some of the basic understandings, benefits, and barriers to adopting blockchain technology in a supply chain setting, we now consider some of the theoretical and research implications. To help advance the research agenda into blockchain technology adoption for supply chains, we propose a number of research propositions based on outcomes from the adoption of blockchain technology in the supply chain context.

6. A research agenda and propositions – post adoption

A number of general research propositions related to blockchain technology adoption for supply chain management set the stage for a research agenda. Although research questions pertaining to early stages of adoption and barriers, do exist, and a research agenda on adoption and diffusion is also needed, we focus on concerns and issues relating to post-adoption aspects. That is, we identify a number of research propositions focusing on identifying potential outcomes from the implementation of this disruptive technology; and primarily focused on the supply chain, its relationships, and performance. This section is based on background from the previous background sections and foundational theories within the supply chain management literature.

We shall begin with one of the most basic theories and assumptions in supply chain management theory that we believe will be greatly influenced by blockchain technology. This area is related to long-term agreements and collaboration. Specifically, we begin by considering the construct of opportunism; which is typically assumed to be lessened in successful strategic and collaborative supply chains (Ketchen and Hult 2007).

Opportunism is an important construct within transaction cost economics (TCE). Opportunism refers to self-interest of parties who are involved in trades and exchanges (Williamson 1985). An example of the opportunistic behaviour of companies in supply chain management context can be their effort to make suppliers highly dependent on them, and take advantage of this power to make pressure on them (Ketchen and Hult 2007). The existence of intermediaries and agencies in supply chains increases the potential for abusing power and intentional taking advantage, such as cheating and untruthful activities. (Grover and Malhotra 2003; Ketchen and Hult 2007). Opportunism, which is assumed as the effect of environmental uncertainty and specific asset, is also an important issue for strategic decisions of firms in supply chain context (Handley and Benton 2012; Wang, Ye, and Tan 2014). The presence of opportunism compels companies to keep track of inappropriate and opportunistic behaviour of their parties. This imposes transaction cost on the companies in terms of costly auditing and monitoring activities, such as contracts, regulations, and reporting requirements (Carter and Rogers 2008).

Blockchain technology provides transparency and cuts intermediaries from transactions (Crosby et al. 2016). Disintermediation, which is a crucial effect of applying blockchain technology, can mitigate the potential opportunistic behaviour. Also, information is shared among supply chain participants and distortion of information is much less likely through a blockchain technology foundation (Tian 2016). In a transparent supply chain, where information is accessible to the related participants, opportunistic behaviour like subtle violation of agreements and concealing critical information is more difficult in compare with traditional supply chain management systems. The resultant transparency, security, and auditability reduce the potential for the opportunistic behaviour of participants of supply chains. This leads to the first research proposition:

> P1: Implementing blockchain technology in supply chains decreases opportunistic behaviour.

Related to power and opportunism, is the construct of trust in supplier-buyer (Ireland and Webb 2007). Trust is an organisations' belief that their partners will take positive actions to benefit them, and will not negatively affect them (Anderson and Narus 1990). Based on the literature, trust is a crucial element of a successful supply chain implementation, especially for long-term strategic collaborations (La Londe 2002; Kwon and Suh 2005). Many studies have examined the outcomes of trust between supply chain participants and the trust role in improving commitment and better performance of supply chains (Kwon and Suh 2005; Cao, Schniederjans, and Schniederjans 2017; Schorsch, Wallenburg, and Wieland 2017). Much of this improved performance arises from firms becoming more fully committed in strategic partnerships to increase efficiency and effectiveness (Ireland and Webb 2007).

The blockchain technology context facilitates trading in a trust-free environment. Transactions are verified by the majority of supply chain participants, who define the consensus rules, and there is less need for building trust between supply chain partners (Crosby et al. 2016; English, Auer, and Domingue 2016). This trust-free environment portends that supply chain partner trust needs to be reconsidered within supply chain management theories. The trust-free relationship could dramatically change buyer–supplier relationships and challenge the related trust theories. Social capital theory, resource dependency theory, social exchange theory, and transaction costs theory each incorporate constructs of trust in the supplier-buyer relationship (Kwon and Suh 2004; Ireland and Webb 2007). Taking a trustless environment into consideration, current supply chain theories need to be reevaluated for use of blockchain technology. Thus, our second research proposition is defined as:

> P2: Blockchain technology facilitates trading in a trustless environment. This concept is likely to transform the current trust-based theories in supply chain management.

Governance mechanisms and structures are key constructs within transaction cost theory (Rindfleisch and Heide 1997). Organising transactions in supply chains lie in five governance structure types including market, modular, relational, captive, and hierarchy.

Three key dimensions are used as the basis to classify supply chain governance structures. First, transactions complexity refers to the required complexity of the shared supply chain information. The second is the ability to standardise and codify the complex information to be shared among partners without additional investment. Supply base capabilities are the third dimension and refer to supplier competence level, which is the ease associated with finding the capable supplier (Gereffi, Humphrey, and Sturgeon 2005; Ashenbaum 2018). In blockchain-based supply chains, where no central authority is responsible for information management and validation (Crosby et al. 2016), the question of who and what governs transactions, rules, and policies is unclear, and yet very important. These characteristics, based on the three dimensions may bring into question current supply chain governance structures, its assumptions and many previous theoretical paradigms. Will it be likely that for all blockchain supply chains to be more market governance, or captive? That is, will all governance structures exist in a blockchain or will some dominate? If so, which structures will be the best? Will there need to be a hybrid structure or new structure that needs to be developed and studied? Therefore, supply chain governance structures will require more scholarly research to further understand blockchain implementation. Here, we arrive at the third proposition:

> P3: Supply chain governance structures characteristics need to be further evaluated for effectiveness in understanding blockchain-based supply chains.

Blockchain technology is foremost an information technology. Thus, information theory can provide substantial insights into further understanding the supply chain and blockchain nexus. Information processing theory (IPT) is one such perspective. IPT focuses on the link between environmental uncertainty, information processing and adaptation needs of organisations. Needs are defined by the difference between the amount of information required and the amount already possessed by the organisation (Galbraith 1973, 1977). High levels of environmental uncertainty that challenges collaboration and information sharing in supply chains are driven from internal organisational factors (i.e. organisational flexibility) and market conditions (i.e. market volatility) (Galbraith 1977; Flynn, Koufteros, and Lu 2016; Fan et al. 2017; Srinivasan and Swink 2017).

Several studies have contributed to advancing IPT from the supply chain perspective. Various supply chain phenomena are explained using IPT (Busse, Meinlschmidt, and Foerstl 2017). IPT is linked to operational performance, where the analytics capability of an organisation is complemented with organisational flexibility. The source of analytics capability is supply chain transparency, measured by supply, and demand visibility (Srinivasan and Swink 2017; Zhu et al. 2018). Blockchain technology provides significant visibility (Swan 2015). Information sharing amongst supply chain partners is likely to be dramatically altered with the implementation of blockchain technology. This change intensifies the importance of advancing IPT to evaluate the information processing needs after blockchain implementation. Researchers and theorists we may need to turn to information theory to help evaluate and understand supply chain phenomena. For example, the competitiveness of private versus public supply chains in a blockchain setting may be evaluated using IPT. Greater transparency may be needed in public settings to manage the environmental uncertainty, private blockchain models may enhance private supply chain competitiveness. Hence, we arrive at the fourth proposition:

> P4: Information processing theory play a more important role in understanding the blockchain-based supply chain. Information processing theory needs further advancement to help evaluate and understand blockchain-based supply chain phenomena and nuances.

The four previous propositions have some relationship to supply chain coordination, integration, and collaboration characteristics (Flynn, Huo, and Zhao 2010). One of the more important contingencies posited in supply chain integration and coordination research and related to IPT is environmental uncertainty (Wong, Boon-Itt, and Wong 2011). The argument is that performance will be affected by the level of integration and environmental uncertainty. It may be that environmental uncertainties will be mitigated with blockchain technology, and with less need for further integration and coordination for strategic relationships. That is, whether or not blockchain technology exists in the supply chain may be a contingency. In this environment there is less need to build trust to reduce opportunism, no matter the governance structure; even market structures. Performance outcomes may not require the type of formal coordination that strategic relationships require. The basic foundations and definitions of supply chain management include a definition by (Mentzer et al. 2001) where supply chain management is

> the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain (that consists of multiple firms), for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.

The implication is that formal strategic coordination is needed to achieve advantageous performance. This definition also implies that strategic partnering is necessary for long-term supply chain benefits.

Blockchain technology, with transparent systems that are distributed, may be more conducive to operational partnering rather than strategic partnering. The visibility of information, which may include cost, materials, capabilities, and performance measures, may cause organisations to seek out short-term relationships. Finding the best relationship will be dynamic. These shorter term pressures may increase environmental uncertainty by providing greater information on what other potential relationships may benefit organisations. This information visible environment also provides incentives for promiscuity between partners to allow each organisation to find the best deal, in what might be a very dynamic and open performance system. This situation may be especially true in public blockchain supply chains. It will also be dependent on who is involved in private supply chains, and potentially the characteristics of smart contracts. For example, if multiple sources exist for a material, and these sources are allowed in a private supply chain, whoever can execute the smart contract most effectively, maybe through a bidding process, can form the partnership. The smart contract may decide how often a bid goes out and how it is met. Given these situations, it is foreseen that operational relationships, rather than strategic, will become the norm in blockchain-enabled supply chain. Overall, new managerial decision making and governance models will be needed (Oliveira and Handfield 2018) which results in our fifth proposition:

> P5: Operational relationships, due to transparency, visibility, smart contracts, and distributed relationships of blockchain technology will have improved performance outcomes and not necessarily require strategic formal coordination and supply chain integration.

As we have seen in the other propositions, some of the traditional constructs and relationships in existing theory may have to be revisited to determine their applicability. Thus, blockchain technology may require new theoretical perspectives for more complete understanding. Grounded theory approaches can be used to build upon blockchain's features and practical implementation observations. A new theory can practically advance knowledge of the field, guide the research and clarify research directions (Van de Ven 1989). Since blockchain technology is nascent, more scholarly research is essential to develop new theories and advance theories and designs for integrating blockchain technology (Saberi, Kouhizadeh, and Sarkis 2018). Borrowing theories from other academic fields such as sociology, economics, psychology, or political science can also be a useful approach to conceptualise blockchain technology as an academic discipline.

For example, normalisation process theory (May and Finch 2009), originating in the sociology literature, concerns the implementation process by which practices become routinely embedded in everyday life and sustained in the social context. The extended argument from this theory is that operational routines may exist across organisations, can also strongly relate and influence performance outcomes. Given the more operational relationship tendencies that emerge from a blockchain-enabled supply chain, this theoretical perspective may be more appropriate, then say the more established and strategically focused resource-based view (Barney 1991) of the organisation and supply chains. Therefore, we arrive at a general sixth research proposition:

> P6: In order to support the development and understanding of blockchain technology in the supply chain, interdisciplinary investigations are needed to build theories and designs for blockchain technology.

In our review of potential applications of blockchain technology and the supply chain, we made an especial focus on sustainability issues. Sustainability in supply chains is given a little more attention here since it covers a comprehensive influence and relationship of supply chains going beyond economics and business to include society and the environment. Economic, environmental and social performance are three key aspects of sustainability that can be measured by comprehensive sustainability metrics (de Sousa Jabbour et al. 2018b). There is a large body of literature on sustainability metrics that have been used to measure performance and majority of them address the environmental aspects (Ahi and Searcy 2015). As indicated earlier in this paper, blockchain technology has the potential to improve economic, social, and environmental performance. However, the amount of improvements may not be equal. Blockchain technology, based on current and developing applications in the supply chain, seems to have more opportunities to boost environmental performance than social performance. GHG emissions, water usage, energy consumption, waste generation, and the use of hazardous and toxic substances are some examples of environmental metrics (Varsei et al. 2014) that can be more easily measured and monitored in blockchain platform transactions. The 'Internet of Things' enriches environmental performance by providing the more accurate and secure data from machines and devices in production, logistics, and other inter-functional inter-firm processes; blockchain technology has similar capabilities.

An application of blockchain technology in improving social performance is building a proper incentivising system that inspires companies to contribute in improving social values on blockchain infrastructure. The Backfeed, which is an interesting conceptual model that is developed on blockchain backbone, facilitates cooperation among participants, and allows them to be rewarded for their contribution in the value system. The rewards can be formed as cryptocurrencies tokens and reputation scores (Pazaitis, De Filippi, and Kostakis 2017). However, social performance is difficult to measure and maintain (Seuring 2013), even after blockchain implementation. Social performance is culturally contextual, with broader ranges of subjectivity; whereas it is easier to find scientific measurements and performance on environmental factors. In addition, social measures may be more politically sensitive. Although blockchain technology promises greater transparency improvement in equity, labour practices and decent work, human rights, and other social metrics, it may cause companies to take efforts to hide and not to share critical, personal, or nefarious information. Also, the definition of social aspects of sustainability has not been well-defined on the literature and is less mature overall in sustainable supply chain research (Hutchins and Sutherland 2008; Seuring and Müller 2008; Fahimnia, Sarkis, and Davarzani 2015) which makes the social performance measurement more challenging. Overall, from a sustainability perspective we arrive at the seventh and final research proposition:

> P7: Blockchain technology in the supply chain will more effectively manage economic and environmental (ecological) sustainability rather than social sustainability in the supply chain.

Disruption and uncertainty in supply chains have inspired the emergent use of risk management in supply chains. Natural and man-made disasters threaten the performance of supply chains and solution techniques are required to control and mitigate supply chain risks (Heckmann, Comes, and Nickel 2015; Fahimnia et al. 2015). Digital technologies have transformed supply chain management risks. Blockchain technology has the potential to improve efficiency through the use of smart contracts. Regulations, contracts, and policies, that can delay supply chain and logistic activities, can automatically be executed by smart contracts. This innovative application helps save time and reduce risk in supply chains (Ivanov, Dolgui, and Sokolov 2018).

Blockchain technology provides information transparency in the supply chain. For example, in the food industry, traceability of information and provenance improves food safety and quality. As a use case, IBM and Walmart collaborated to trace products from their origin on a blockchain infrastructure (Carter and Koh 2018). Supply chain participants can monitor materials, goods and information flow in the blockchain. This would facilitate predicting hazardous events and emergency management. In addition, real-time information circulation in supply chains, especially by removing intermediaries and multiple middle layers on a blockchain platform, facilitate supply chain risk management. Therefore, the issue that blockchain technology can improve supply chain risk and resiliency requires further investigation.

7. Conclusion

In this paper, we proposed and discussed the adoption of blockchain technology in supply chain networks. The evolution of blockchain-based supply chain management is presented which enables the creation of shared, secure, decentralised ledgers, autonomous digital contracts (smart contracts), and trustworthy and secure networks. In addition, it supports transaction between partners (peer-to-peer) by reducing the role of middlemen/intermediaries in the network.

In addition to an overview of blockchain technology and its applicability in the supply chain, obstacles facing organisations for blockchain technology adoption are summarised in this paper. Many of these barriers utilise theories and literature that considered similar disruptive technologies. This is the first papers to clearly identify and categorise blockchain barriers in general, and those specific to the adoption of the technology for supply chain purposes. The barriers of blockchain adoption in supply chain are reviewed as multi-faceted issues which affect not only the relationship between supply chain partners but also partners' employees and their stakeholders. In addition, the technological barriers pertaining to blockchain adoption are included and many stem from blockchain technology immaturity. System-related issues of blockchain technology, which can limit its adoption, requires more focus in future research and effective technical solutions to address the scalability issues need to be more studied. More empirical research is required to explore the significance of the various barriers and identify the causal relationships among them. This research would establish fundamentals to effectively manage blockchain implementation.

Furthermore, the majority of the reviewed literature studied blockchain technology in the Bitcoin and other cryptocurrencies' environment. However, other applications of blockchain technology, especially business applications, rarely have been addressed in the past scholarly research. Hence, more research is required to evaluate the adoption of blockchain technology for different business purposes. In order to motivate basic research, we introduced some general research propositions that focus on post-adoption issues facing blockchain-enabled supply chains.

In addition to the future research on the theoretical propositions, technical and engineering research related to various supply chain themes is also needed. For example, distributed supply chain coordination (Chan and Chan 2010; Ivanov et al. 2016), material and information flow coordination (Ivanov, Sokolov, and Raguinia 2014), virtual enterprises (Sarkis, Talluri, and Gunasekaran 2007; Crispim and de Sousa 2010), agile supply chain management (Sarkis and Talluri 2001; Cabral, Grilo, and Cruz-Machado 2012), flexibility in supply chains (Ivanov, Das, and Choi 2018), performance measurement of supply chains (Arzu Akyuz and Erman Erkan 2010), supply chain resiliency, risk and ripple effect (Dolgui, Ivanov, and Sokolov 2018; Ivanov 2018), real-time control and service oriented supply chains (Xu 2011) are all potential technical topics that can relate to advancing blockchains and supply chain research.

Practically, given that the broader use of blockchain technology for business purposes has already started and supported by some leading companies, such as IBM, Boeing, Microsoft, and SAP. Investigations are needed to evaluate the case studies and pilot programmes and provide valuable practical information to enhance blockchain implementation. Post-implementation success and failure factors of this technology can also be addressed in the future research.

We also identified the relative importance of blockchain technology for sustainability in supply chains. Future research can also go in this direction where the environmental and social/humanity dimension of sustainability, including the U.N.'s sustainable development goals (SDGs), as an example, can be used to study blockchain-enable supply chain effectiveness.

Considerable opportunities exist for a better understanding of this technology and its application to go beyond traditional information systems and web-based integration in supply chains. We encourage academia to examine and build on the identified research propositions and the emergent digitisation and supply chain research (e.g. Ivanov, Das, and Choi 2018; Oliveira and Handfield 2018). Understanding the full implications of blockchain technology in the supply chain will require transdisciplinary efforts. Professional organisations need to be involved and work with academia to develop standards and provide practical performance measurement on blockchain technology implementation. Undoubtedly, there is a substantial amount of work in this area for future research direction.

Acknowledgement

We wish to acknowledge the APICS Research, Innovation, & Strategy Committee for supporting our research on Blockchain Technology and Sustainable Supply Chains.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the APICS Research, Innovation, & Strategy Committee, grant number 227940.

Notes

1. https://www.cdc.gov/salmonella/kiambu-07-17/index.html
2. https://www.cdc.gov/ecoli/2015/o26-11-15/index.html
3. https://www.weforum.org/agenda/2017/09/carbon-currency-blockchain-poseidon-ecosphere/
4. https://www.sheffield.ac.uk/polopoly_fs/1.782537!/file/SCEnAT4.0forIndustry4.0.pdf
5. https://www.ibm.com/case-studies/energy-blockchain-labs-inc

References

Abeyratne, S. A., and R. P. Monfared. 2016. "Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger." *International Journal of Research in Engineering and Technology* 5 (9): 1–10.

Adams, R., B. Kewell, and G. Parry. 2018. "Blockchain for Good? Digital Ledger Technology and Sustainable Development Goals." In *Handbook of Sustainability and Social Science Research*, 127–140. Cham: Springer.

Ahi, P., and C. Searcy. 2015. "An Analysis of Metrics Used to Measure Performance in Green and Sustainable Supply Chains." *Journal of Cleaner Production* 86: 360–377.

Anderson, J. C., and J. A. Narus. 1990. "A Model of Distributor Firm and Manufacturer Firm Working Partnerships." *Journal of Marketing* 54 (1): 42–58.

Arzu Akyuz, G., and T. Erman Erkan. 2010. "Supply Chain Performance Measurement: A Literature Review." *International Journal of Production Research* 48 (17): 5137–5155.

Ashenbaum, B. 2018. "From Market to Hierarchy: An Empirical Assessment of a Supply Chain Governance Typology." *Journal of Purchasing and Supply Management* 24 (1): 59–67.

Barney, J. 1991. "Firm Resources and Sustained Competitive Advantage." *Journal of Management* 17 (1): 99–120.

Busse, C., J. Meinlschmidt, and K. Foerstl. 2017. "Managing Information Processing Needs in Global Supply Chains: A Prerequisite to Sustainable Supply Chain Management." *Journal of Supply Chain Management* 53 (1): 87–113.

Cabral, I., A. Grilo, and V. Cruz-Machado. 2012. "A Decision-Making Model for Lean, Agile, Resilient and Green Supply Chain Management." *International Journal of Production Research* 50 (17): 4830–4845.

Cao, Q., D. G. Schniederjans, and M. Schniederjans. 2017. "Establishing the Use of Cloud Computing in Supply Chain Management." *Operations Management Research* 10 (1-2): 47–63.

Carter, C., and L. Koh. 2018. *Blockchain Disruption in Transport: Are You Decentralised Yet?* Milton Keynes: T. S. Catapult. https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2018/06/06105742/Blockchain-Disruption-in-Transport-Concept-Paper.pdf.

Carter, C. R., and D. S. Rogers. 2008. "A Framework of Sustainable Supply Chain Management: Moving Toward new Theory." *International Journal of Physical Distribution & Logistics Management* 38 (5): 360–387.

Chan, H. K., and F. T. Chan. 2010. “A Review of Coordination Studies in the Context of Supply Chain Dynamics.” *International Journal of Production Research* 48 (10): 2793–2819.

Chkanikova, O., and O. Mont. 2015. “Corporate Supply Chain Responsibility: Drivers and Barriers for Sustainable Food Retailing.” *Corporate Social Responsibility and Environmental Management* 22 (2): 65–82.

Costa, C., F. Antonucci, F. Pallottino, J. Aguzzi, D. Sarriá, and P. Menesatti. 2013. “A Review on Agri-Food Supply Chain Traceability by Means of RFID Technology.” *Food and Bioprocess Technology* 6 (2): 353–366.

Crispim, J. A., and J. P. de Sousa. 2010. “Partner Selection in Virtual Enterprises.” *International Journal of Production Research* 48 (3): 683–707.

Crosby, M., P. Pattanayak, S. Verma, and V. Kalyanaraman. 2016. “Blockchain Technology: Beyond Bitcoin.” *Applied Innovation* 2: 6–9.

Delmolino, K., M. Arnett, A. Kosba, A. Miller, and E. Shi. 2016. *Step by Step Towards Creating a Safe Smart Contract: Lessons and Insights from a Cryptocurrency Lab International Conference on Financial Cryptography and Data Security*.

de Sousa Jabbour, A. B. L., C. J. Chiappetta Jabbour, J. Sarkis, A. Gunasekaran, M. W. Furlan Matos Alves, and D. A. Ribeiro. 2018a. “Decarbonisation of Operations Management – Looking Back, Moving Forward: A Review and Implications for the Production Research Community.” *International Journal of Production Research* 1–23. doi:10.1080/00207543.2017.1421790.

de Sousa Jabbour, A. B. L., C. J. C. Jabbour, C. Foropon, and M. Godinho Filho. 2018b. “When Titans Meet – Can Industry 4.0 Revolutionise the Environmentally-Sustainable Manufacturing Wave? The Role of Critical Success Factors.” *Technological Forecasting and Social Change* 132: 18–25.

Dolgui, A., D. Ivanov, and B. Sokolov. 2018. “Ripple Effect in the Supply Chain: An Analysis and Recent Literature.” *International Journal of Production Research* 56 (1–2): 414–430.

Dong, F., P. Zhou, Z. Liu, D. Shen, Z. Xu, and J. Luo. 2017. “Towards a Fast and Secure Design for Enterprise-Oriented Cloud Storage Systems.” *Concurrency and Computation: Practice and Experience* 29 (19): e4177.

English, M., S. Auer, and J. Domingue. 2016. “Block Chain Technologies & The Semantic Web: A Framework for Symbiotic Development.” Computer Science Conference for University of Bonn Students, J. Lehmann, H. Thakkar, L. Halilaj, and R. Asmat, Eds.

Eyal, I. 2017. “Blockchain Technology: Transforming Libertarian Cryptocurrency Dreams to Finance and Banking Realities.” *Computer* 50 (9): 38–49.

Fahimnia, B., J. Sarkis, and H. Davarzani. 2015. “Green Supply Chain Management: A Review and Bibliometric Analysis.” *International Journal of Production Economics* 162: 101–114.

Fahimnia, B., C. S. Tang, H. Davarzani, and J. Sarkis. 2015. “Quantitative Models for Managing Supply Chain Risks: A Review.” *European Journal of Operational Research* 247 (1): 1–15.

Fan, H., G. Li, H. Sun, and T. Cheng. 2017. “An Information Processing Perspective on Supply Chain Risk Management: Antecedents, Mechanism, and Consequences.” *International Journal of Production Economics* 185: 63–75.

Fanning, K., and D. P. Centers. 2016. “Blockchain and Its Coming Impact on Financial Services.” *Journal of Corporate Accounting & Finance* 27 (5): 53–57.

Fawcett, S. E., J. A. Ogden, G. M. Magnan, and M. Bixby Cooper. 2006. “Organizational Commitment and Governance for Supply Chain Success.” *International Journal of Physical Distribution & Logistics Management* 36 (1): 22–35.

Fawcett, S. E., C. Wallin, C. Allred, and G. Magnan. 2009. “Supply Chain Information-Sharing: Benchmarking a Proven Path.” *Benchmarking: An International Journal* 16 (2): 222–246.

Flynn, B. B., B. Huo, and X. Zhao. 2010. “The Impact of Supply Chain Integration on Performance: A Contingency and Configuration Approach.” *Journal of Operations Management* 28 (1): 58–71.

Flynn, B. B., X. Koufteros, and G. Lu. 2016. “On Theory in Supply Chain Uncertainty and Its Implications for Supply Chain Integration.” *Journal of Supply Chain Management* 52 (3): 3–27.

futurethinkers. 2017. “7 Ways The Blockchain Can Save The Environment and Stop Climate Change.” http://futurethinkers.org/blockchain-environment-climate-change/.

Galbraith, J. R. 1973. *Designing Complex Organizations*. New York: Addison-Wesley.

Galbraith, J. R. 1977. *Organization Design*. Boston: Addison Wesley.

Gereffi, G., J. Humphrey, and T. Sturgeon. 2005. “The Governance of Global Value Chains.” *Review of International Political Economy* 12 (1): 78–104.

Gorane, S., and R. Kant. 2015. “Modelling the SCM Implementation Barriers.” *Journal of Modelling in Management* 10 (2): 158–178.

Govindan, K., and M. Hasanagic. 2018. “A Systematic Review on Drivers, Barriers, and Practices Towards Circular Economy: A Supply Chain Perspective.” *International Journal of Production Research* 56 (1–2): 278–311.

Grimm, J. H., J. S. Hofstetter, and J. Sarkis. 2016. “Exploring Sub-Suppliers’ Compliance with Corporate Sustainability Standards.” *Journal of Cleaner Production* 112: 1971–1984.

Groenfeldt, T. 2017. *IBM and Maersk Apply Blockchain to Container Shipping*.

Grover, V., and M. K. Malhotra. 2003. “Transaction Cost Framework in Operations and Supply Chain Management Research: Theory and Measurement.” *Journal of Operations Management* 21 (4): 457–473.

Handley, S. M., and W. Benton Jr. 2012. “The Influence of Exchange Hazards and Power on Opportunism in Outsourcing Relationships.” *Journal of Operations Management* 30 (1-2): 55–68.

Heckmann, I., T. Comes, and S. Nickel. 2015. "A Critical Review on Supply Chain Risk – Definition, Measure and Modeling." *Omega* 52: 119–132.

Hofmann, E., U. M. Strewe, and N. Bosia. 2017. *Supply Chain Finance and Blockchain Technology: The Case of Reverse Securitisation*. Cham: Springer.

Hofmann, E., U. M. Strewe, and N. Bosia. 2018. "Discussion – How Does the Full Potential of Blockchain Technology in Supply Chain Finance Look Like?" In *Supply Chain Finance and Blockchain Technology*, 77–87. Cham: Springer.

Hutchins, M. J., and J. W. Sutherland. 2008. "An Exploration of Measures of Social Sustainability and Their Application to Supply Chain Decisions." *Journal of Cleaner Production* 16 (15): 1688–1698.

Ireland, R. D., and J. W. Webb. 2007. "A Multi-Theoretic Perspective on Trust and Power in Strategic Supply Chains." *Journal of Operations Management* 25 (2): 482–497.

Ivanov, D. 2018. "Revealing Interfaces of Supply Chain Resilience and Sustainability: A Simulation Study." *International Journal of Production Research* 56 (10): 3507–3523.

Ivanov, D., A. Das, and T.-M. Choi. 2018. "New Flexibility Drivers for Manufacturing, Supply Chain and Service Operations." *International Journal of Production Research* 56 (10): 3359–3368.

Ivanov, D., A. Dolgui, and B. Sokolov. 2018. "The Impact of Digital Technology and Industry 4.0 on the Ripple Effect and Supply Chain Risk Analytics." *International Journal of Production Research*, 1–18.

Ivanov, D., A. Dolgui, B. Sokolov, F. Werner, and M. Ivanova. 2016. "A Dynamic Model and an Algorithm for Short-Term Supply Chain Scheduling in the Smart Factory Industry 4.0." *International Journal of Production Research* 54 (2): 386–402.

Ivanov, D., B. Sokolov, and E. A. D. Raguinia. 2014. "Integrated Dynamic Scheduling of Material Flows and Distributed Information Services in Collaborative Cyber-Physical Supply Networks." *International Journal of Systems Science: Operations & Logistics* 1 (1): 18–26.

Jharkharia, S., and R. Shankar. 2005. "IT-enablement of Supply Chains: Understanding the Barriers." *Journal of Enterprise Information Management* 18 (1): 11–27.

Johnson, M. E. 2006. "Supply Chain Management: Technology, Globalization, and Policy at a Crossroads." *Interfaces* 36 (3): 191–193. http://www.jstor.org.ezproxy.wpi.edu/stable/20141388.

Kaur, J., R. Sidhu, A. Awasthi, S. Chauhan, and S. Goyal. 2018. "A DEMATEL Based Approach for Investigating Barriers in Green Supply Chain Management in Canadian Manufacturing Firms." *International Journal of Production Research* 56 (1–2): 312–332.

Ketchen Jr, D. J., and G. T. M. Hult. 2007. "Bridging Organization Theory and Supply Chain Management: The Case of Best Value Supply Chains." *Journal of Operations Management* 25 (2): 573–580.

Ketchen Jr, D. J., and G. T. M. Hult. 2007. "Toward Greater Integration of Insights from Organization Theory and Supply Chain Management." *Journal of Operations Management* 25 (2): 455–458.

Khaqqi, K. N., J. J. Sikorski, K. Hadinoto, and M. Kraft. 2018. "Incorporating Seller/Buyer Reputation-Based System in Blockchain-Enabled Emission Trading Application." *Applied Energy* 209: 8–19. doi:10.1016/j.apenergy.2017.10.070.

Koh, S. L., A. Genovese, A. A. Acquaye, P. Barratt, N. Rana, J. Kuylenstierna, and D. Gibbs. 2013. "Decarbonising Product Supply Chains: Design and Development of an Integrated Evidence-Based Decision Support System – the Supply Chain Environmental Analysis Tool (SCEnAT)." *International Journal of Production Research* 51 (7): 2092–2109.

Kwon, I. W. G., and T. Suh. 2004. "Factors Affecting the Level of Trust and Commitment in Supply Chain Relationships." *The Journal of Supply Chain Management* 40 (1): 4–14.

Kwon, I.-W. G., and T. Suh. 2005. "Trust, Commitment and Relationships in Supply Chain Management: A Path Analysis." *Supply Chain Management: an International Journal* 10 (1): 26–33.

La Londe, B. 2002. "Insights: Who Can You Trust These Days?" *Supply Chain Management Review* 6 (3): 9–12.

Lambert, D. M., and M. G. Enz. 2017. "Issues in Supply Chain Management: Progress and Potential." *Industrial Marketing Management* 62 (Supplement C): 1–16. doi:10.1016/j.indmarman.2016.12.002.

Lemieux, V. L., and V. L. Lemieux. 2016. "Trusting Records: Is Blockchain Technology the Answer?" *Records Management Journal* 26 (2): 110–139.

Lim, I.-K., Y.-H. Kim, J.-G. Lee, J.-P. Lee, H. Nam-Gung, and J.-K. Lee. 2014. "The Analysis and Countermeasures on Security Breach of Bitcoin." International Conference on Computational Science and Its Applications.

Mangla, S. K., K. Govindan, and S. Luthra. 2017. "Prioritizing the Barriers to Achieve Sustainable Consumption and Production Trends in Supply Chains Using Fuzzy Analytical Hierarchy Process." *Journal of Cleaner Production* 151: 509–525.

Mangla, S. K., S. Luthra, N. Mishra, A. Singh, N. P. Rana, M. Dora, and Y. Dwivedi. 2018. "Barriers to Effective Circular Supply Chain Management in a Developing Country Context." *Production Planning & Control* 29 (6): 551–569.

Mathiyazhagan, K., K. Govindan, A. NoorulHaq, and Y. Geng. 2013. "An ISM Approach for the Barrier Analysis in Implementing Green Supply Chain Management." *Journal of Cleaner Production* 47: 283–297.

Maurer, B. 2017. "Blockchains Are a Diamond's Best Friend: Zelizer for the Bitcoinmoment." In *Money Talks: Explaining How Money Really Works*, edited by F. F. W. Nina Bandelj and Viviana A. Zelizer, 215–230. Princeton: Princeton University Press.

May, C., and T. Finch. 2009. "Implementing, Embedding, and Integrating Practices: An Outline of Normalization Process Theory." *Sociology* 43 (3): 535–554.

Mendling, J., I. Weber, W. van der Aalst, J. V. Brocke, C. Cabanillas, F. Daniel, and S. Dustdar. 2017. "Blockchains for Business Process Management-Challenges and Opportunities." *ACM Transactions on Management Information Systems (TMIS)* 9 (1): 1–16. *arXiv Preprint ArXiv:1704.03610*.

Mentzer, J. T., W. DeWitt, J. S. Keebler, S. Min, N. W. Nix, C. D. Smith, and Z. G. Zacharia. 2001. "Defining Supply Chain Management." *Journal of Business Logistics* 22 (2): 1–25.

Mishra, B. K., S. Raghunathan, and X. Yue. 2007. "Information Sharing in Supply Chains: Incentives for Information Distortion." *IIE Transactions* 39 (9): 863–877.

Mougayar, W. 2016. *The Business Blockchain: Promise, Practice, and Application of the Next Internet Technology*. Hoboken: John Wiley & Sons.

Nakamoto, S. 2008. Bitcoin: A Peer to Peer Electronic Cash System. Accessed 20 March 2018. https://bitcoin.org/bitcoin.pdf

Nofer, M., P. Gomber, O. Hinz, and D. Schiereck. 2017. "Blockchain." *Business & Information Systems Engineering* 59 (3): 183–187.

Oliveira, Marcos Paulo Valadares de, and Robert Handfield. 2018. "Analytical Foundations for Development of Real-Time Supply Chain Capabilities." *International Journal of Production Research* 1–19. doi:10.1080/00207543.2018.1493240.

Ølnes, S., J. Ubacht, and M. Janssen. 2017. "Blockchain in Government: Benefits and Implications of Distributed Ledger Technology for Information Sharing." *Government Information Quarterly* 34 (3): 355–364.

Palombini, M. 2017. *The Other Side of Blockchain: We Choose What We Want to See* Blockchain, General News, Tech Ethics.

Pazaitis, A., P. De Filippi, and V. Kostakis. 2017. "Blockchain and Value Systems in the Sharing Economy: The Illustrative Case of Backfeed." *Technological Forecasting and Social Change* 125: 105–115.

Peters, G. W., and E. Panayi. 2016. "Understanding Modern Banking Ledgers Through Blockchain Technologies: Future of Transaction Processing and Smart Contracts on the Internet of Money." In *Banking Beyond Banks and Money*, 239–278. Cham: Springer.

Pilkington, M. 2015. "Blockchain technology: principles and applications." Browser Download This Paper.

Popa, V. 2013. "The Financial Supply Chain Management: A New Solution for Supply Chain Resilience." *Amfiteatru Economic Journal* 15 (33): 140–153.

Rindfleisch, A., and J. B. Heide. 1997. "Transaction Cost Analysis: Past, Present, and Future Applications." *Journal of Marketing* 61 (4): 30–54.

Rosencrance, L. 2017. Blockchain Technology Will Help The World Go Green. *Bitcoin Magazine*.

Rotunno, R., V. Cesarotti, A. Bellman, V. Introna, and M. Benedetti. 2014. "Impact of Track and Trace Integration on Pharmaceutical Production Systems." *International Journal of Engineering Business Management* 6: 25. doi:10.5772/58934.

Saberi, S., M. Kouhizadeh, and J. Sarkis. 2018. "Blockchain Technology: A Panacea or Pariah for Resources Conservation and Recycling?" *Resources, Conservation and Recycling* 130: 80–81.

Sajjad, A., G. Eweje, and D. Tappin. 2015. "Sustainable Supply Chain Management: Motivators and Barriers." *Business Strategy and the Environment* 24 (7): 643–655.

Sarkis, J., and S. Talluri. 2001. "Agile Supply Chain Management." In *Agile Manufacturing: The 21st Century Competitive Strategy*, edited by A. Gunasekaran, 359–376. Oxford: Elsevier Science Ltd.

Sarkis, J., S. Talluri, and A. Gunasekaran. 2007. "A Strategic Model for Agile Virtual Enterprise Partner Selection." *International Journal of Operations & Production Management* 27 (11): 1213–1234.

Sarkis, J., and Q. Zhu. 2018. "Environmental Sustainability and Production: Taking the Road Less Travelled." *International Journal of Production Research* 56 (1–2): 743–759.

Sarpong, S. 2014. "Traceability and Supply Chain Complexity: Confronting the Issues and Concerns." *European Business Review* 26 (3): 271–284.

Sayogo, D. S., J. Zhang, L. Luna-Reyes, H. Jarman, G. Tayi, D. L. Andersen, and D. F. Andersen. 2015. "Challenges and Requirements for Developing Data Architecture Supporting Integration of Sustainable Supply Chains." *Information Technology and Management* 16 (1): 5–18.

Schorsch, T., C. M. Wallenburg, and A. Wieland. 2017. "The Human Factor in SCM." *International Journal of Physical Distribution & Logistics Management* 47 (4): 238–262.

Seifert, R. W., and D. Seifert. 2011. "Financing the Chain." *International Commerce Review* 10 (1): 32–44.

Seuring, S. 2013. "A Review of Modeling Approaches for Sustainable Supply Chain Management." *Decision Support Systems* 54 (4): 1513–1520.

Seuring, S., and M. Müller. 2008. "From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management." *Journal of Cleaner Production* 16 (15): 1699–1710.

Seuring, S., J. Sarkis, M. Müller, and P. Rao. 2008. "Sustainability and Supply Chain Management – An Introduction to the Special Issue." *Journal of Cleaner Production* 16 (15): 1545–1551.

Srinivasan, R., and M. Swink. 2017. "An Investigation of Visibility and Flexibility as Complements to Supply Chain Analytics: An Organizational Information Processing Theory Perspective." *Production and Operations Management*, 1–19.

Staples, M., S. Chen, S. Falamaki, A. Ponomarev, P. Rimba, A. B. Tran, and J. Zhu. 2017. "Risks and Opportunities for Systems Using Blockchain and Smartcontracts." *Data61*. https://research.csiro.au/data61/wp-content/uploads/sites/85/2016/08/Blockchain-RisksandOpps-PDF.pdf.

Steiner, J., and J. Baker. 2015. "Blockchain: The Solution for Transparency in Product Supply Chains." https://www.provenance.org/whitepaper.

Swan, M. 2015. "Blockchain: Blueprint for a new economy." O'Reilly Media, Inc.

Tapscott, D., and A. Tapscott. 2017. "How Blockchain Will Change Organizations." *MIT Sloan Management Review* 58 (2): 10.

Tian, F. 2016. "An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology." 13th International Conference on Service Systems and Service Management (ICSSSM), 2016.

Tian, F. 2017. "A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things." 2017 International Conference on Service Systems and Service Management (ICSSSM).

Tseng, M., M. Lim, and W. P. Wong. 2015. "Sustainable Supply Chain Management." *Industrial Management & Data Systems* 115 (3): 436–461.

Van de Ven, A. H. 1989. "Nothing Is Quite So Practical as a Good Theory." *Academy of Management Review* 14 (4): 486–489.

Varsei, M., C. Soosay, B. Fahimnia, and J. Sarkis. 2014. "Framing Sustainability Performance of Supply Chains with Multidimensional Indicators." *Supply Chain Management: An International Journal* 19 (3): 242–257.

Vasek, M., and T. Moore. 2015. "There's No Free Lunch, Even Using Bitcoin: Tracking the Popularity and Profits of Virtual Currency Scams." International Conference on Financial Cryptography and Data Security.

Venkatesh, V., M. G. Morris, G. B. Davis, and F. D. Davis. 2003. "User Acceptance of Information Technology: Toward a Unified View." *MIS Quarterly* 27 (3): 425–478.

Wallace, L. G., and S. D. Sheetz. 2014. "The Adoption of Software Measures: A Technology Acceptance Model (TAM) Perspective." *Information & Management* 51 (2): 249–259.

Wang, Z., F. Ye, and K. H. Tan. 2014. "Effects of Managerial Ties and Trust on Supply Chain Information Sharing and Supplier Opportunism." *International Journal of Production Research* 52 (23): 7046–7061.

Ward, T. 2017. "Blockchain Could Help Us Save the Environment. Here's How." https://futurism.com/blockchain-could-help-save-environment-heres-how/.

Williamson, O. E. 1985. *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*, 61–75. Wiesbaden: Gabler.

Wong, C. Y., S. Boon-Itt, and C. W. Wong. 2011. "The Contingency Effects of Environmental Uncertainty on the Relationship Between Supply Chain Integration and Operational Performance." *Journal of Operations Management* 29 (6): 604–615.

Xu, L. D. 2011. "Information Architecture for Supply Chain Quality Management." *International Journal of Production Research* 49 (1): 183–198.

Yli-Huumo, J., D. Ko, S. Choi, S. Park, and K. Smolander. 2016. "Where Is Current Research on Blockchain Technology? A Systematic Review" *PLOS ONE* 11 (10): e0163477.

Zhu, Q., J. Sarkis, and K.-H. Lai. 2018. "Regulatory Policy Awareness and Environmental Supply Chain Cooperation in China: A Regulatory-Exchange-Theoretic Perspective." *IEEE Transactions on Engineering Management* 65 (1): 46–58.

Zhu, S., J. Song, B. T. Hazen, K. Lee, and C. Cegielski. 2018. "How Supply Chain Analytics Enables Operational Supply Chain Transparency: An Organizational Information Processing Theory Perspective." *International Journal of Physical Distribution & Logistics Management* 48 (1): 47–68.