Int. J. Production Economics 231 (2021) 107831

Contents lists available at ScienceDirect

International Journal of Production Economics

journal homepage: http://www.elsevier.com/locate/ijpe

Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers

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ARTICLE INFO

Keywords:
Supply chain management
Sustainability
Blockchain
Barrier analysis
DEMATEL
Technology-organization-environment framework

ABSTRACT

Blockchain technology has gained global attention with potential to revolutionize supply chain management and sustainability achievements. The few applied ongoing use cases include blockchain for food, healthcare, and logistics supply chains have emphasized blockchain's untapped potential. Potential support for supply chain and sustainability issues include improving efficiency, transparency, and traceability in addition to billions of dollars in corporate financial savings. Given its promise, the adoption of blockchain technology, although hyped for years, has not seen rapid acceptance. In this study, the technology-organization-environment framework and force field theories are utilized to investigate blockchain adoption barriers. Using various literature streams on technology, organizational practices, and sustainability, a comprehensive overview of barriers for adopting blockchain technology to manage sustainable supply chains is provided. The barriers are explored using technology, organizational, and environmental – supply chain and external – framework followed by inputs from academics and industry experts and then analyzed using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) tool. The results show that supply chain and technological barriers are the most critical barriers among both academics and industry experts. We further determine the similarities and differences among academics and practitioners in perceiving the barriers. This exploratory study reveals interesting relative importance and interrelationships of barriers which are necessary, theoretically and practically for further adoption and dissemination of blockchain technology in a sustainable supply chain environment. It also sets the stage for theoretical observations for understanding blockchain technology implementation in sustainable supply chains. A series of research propositions and research directions culminate from this exploratory study.

1. Introduction

Blockchain technology has recently gained significant attention and hype as a disruptive technology. Its potential benefits have stimulated organizations to consider adopting this technology. Several promising benefits have been posited including cost-savings, enhanced traceability-transparency, and sustainability improvement (Kshetri, 2018). While 82% of Fortune 100 companies have explored blockchain,[1] the investment rate in blockchain has – surprisingly – decreased[2] in 2019. A recent study investigated the influence of blockchain on the circular economy by analyzing various case studies from different industrial sectors and found that none of these cases are in full implementation phase but stuck at demonstration and pilot study stage (Kouhizadeh et al., 2019b). A very basic question is why is this occurring? Are there any barriers that impede organizations from investing and adopting this technology? How are these barriers connected and how do they relate to each other? Should companies address a barrier to mitigate the effect of others? These questions are the main drivers for this study.

Blockchain technology's characteristics such as reliability, traceability, data immutability and smart contracts are giving rise to trustless environments with less need for intermediaries (Iansiti and Lakhani, 2017). There are many blockchain use applications, one of the foremost is supply chain sustainability (Saberi et al., 2019b).

The question arises; 'why supply chains'? And the answer is simple, there is an increase in complexity because of global supply chain networks (Lambert and Enz, 2017). This complexity makes it difficult to make efficient transactions, trace products and data, and assess this

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[1] - https://medium.com/altcoin-magazine/blockchain-to-become-a-commonplace-for-fortune-100-companies-3a302526d8eb.

[2] - https://cointelegraph.com/news/amid-rising-adoption-funding-for-blockchain-startups-dries-up.

https://doi.org/10.1016/j.ijpe.2020.107831
Received 16 September 2019; Received in revised form 27 May 2020; Accepted 8 June 2020
Available online 20 June 2020

information (Ivanov et al., 2019b).

Blockchain is defined as decentralized ledgers that contain transactions as data blocks; with blocks linked to their predecessors by a cryptographic pointer. The chain continues to the originator, first, block. Every time a new block is introduced to the system it gets linked to its predecessor (Dinh et al., 2018). Distributed consensus, secure, traceable, verified, and transparent information are all critical characteristics (Crosby et al., 2016). These characteristics motivated many companies including Walmart[3] and Glencore[4] to integrate blockchain technology into their supply chains to improve the efficiency and performance. A recent survey from Deloitte confirmed that blockchain maturity has increased 18% over the last year in the eyes of many executives and decision makers – representing a major shift in blockchain momentum (Insights, 2019). This fact will be another motivation for this study that prompts us to find important factors (including both barriers and drivers) which expedite blockchain adoption.

Supply chain sustainability has increased in importance over the past three decades and become a major driver for demand and customer loyalty.[5] Sustainability has been defined as a balance of environmental, social and business dimensions, also known as the triple-bottom-line (Seuring et al., 2008). There are social, competitive, and regulatory reasons for championing sustainable supply chain management (SSCM) (Saberi et al., 2018). Consumers seek to verify their products for sustainability and require an accessible information portal for their product information (Nikolakis et al., 2018). This situation has put pressure on suppliers to become sustainable on global and local levels as a prerequisite for participation in some supply chains. Currently there are information and auditing sustainability certification systems in place for supply chains. For example, there is the Business Social Compliance Initiative database that certifies audits of supplier sustainability (Asif et al., 2019). However, these systems are voluntary databases which means that their credibility and validity can be questioned (Kouhizadeh and Sarkis, 2018). Blockchain technology can support these sustainability certifications that flow deep into the supply chain.

Blockchain has the potential to revolutionize supply chain sustainability. Use cases show companies seeking to implement blockchain into their supply chain operations for traceability of products, as in the case of Maersk (Popper and Lohr, 2017), Provenance (Baker and Steiner, 2015), Walmart (Kshetri, 2018), and recently in Mongolia for enhancing the sustainability of cashmere.[6] Some organizations use it for food safety, as in the case of Chipotle Mexican Grill (Casey and Wong, 2017). Minimizing counterfeit products has also been a goal of some blockchain applications (Fernández-Caramés and Fraga-Lamas, 2018; Singh and Singh, 2016). These examples are for safety, security, and environmentally sound supply chain practices, all of which are elements of supply chain sustainability. Despite the many potential blockchain benefits for improving sustainability in a network, the number of use cases applying blockchain for sustainability are very limited while companies continue to struggle with the more holistic aspects of sustainability.[7] As mentioned earlier, the investment in the technology – with some exceptions – is decreasing.

New technology has both advantages and disadvantages. A major sustainability concern of blockchain technology is in its energy consumption. High computational power required for important "proof-of-work" consensus systems consumes many hundreds of megawatts of energy (Fairley, 2017). High energy consumption also means higher carbon emissions. Decentralized ledgers also need higher computational power and resources for maintaining the security of data and entries that are duplicated, which ultimately lead to greater energy consumption.[8] These are only sustainability downsides, but as we shall see in our study there are many other barriers that exist for the adoption of this technology from a SSCM perspective. In addition, switching to a new disruptive technology such as blockchain involves disruptive changes for a company within the context of technical and non-technical practices including internal and external ones (Kurpjuweit et al., 2019; Rugeviciute and Mehrpouya, 2019), that can be difficult to justify.

Even with the promises of blockchain technology, the adoption has been slow. Most of the use cases discussed in the literature are stalled at the pilot and planned use stage. We seek to investigate how this technology with so much economic, social, and environmental promise has stalled. Thus, we need to recognize the possible challenges and obstacles – barriers – that firms might face with implementing this technology.

Using the technology, organization, and environment (TOE) and force field theoretical lenses, we examine the barriers and relationships amongst barriers that have limited implementation of blockchain technology. The barriers derive from a comprehensive literature review of technology and sustainability adoption practices and the organizational adoption barriers they face.

Addressing all barriers simultaneously is practically infeasible. Decision making approaches may be suitable for evaluating the importance and ranking of various barriers. The Decision Making and Trial Evaluation Laboratory (DEMATEL) methodology is chosen because of its ability to identify important barriers while capturing their interdependencies. Other methodologies focusing on decision-making fail to reflect causal relationships and overall influence of factors on each other for empirical theoretical analyses. We use the DEMATEL methodology to identify the critical barriers and their relationships to each other. The study utilizes responses from supply chain, sustainability and blockchain experts to investigate these barriers. This paper is one of the first to broadly investigate blockchain technology and adoption for SSCM barriers based theoretical frameworks and expert perspectives. There are five main research questions that we address in this study as follows:

1. Why has blockchain technology not been considerably implemented in supply chains for sustainability purposes?
2. Can the barriers be examined theoretically and placed within TOE and force field frameworks?
3. What are the levels of importance and relationships amongst the barriers?
4. Is there potential for sequencing and overcoming these barriers to accelerate blockchain implementation?
5. How do two study groups – scholars and practitioners – perceive the importance and relationships among the barriers? What are the similarities and differences in their perspectives?

The contributions of this study include:

- Understanding the barriers that impede blockchain adoption for sustainable supply chain management and evaluating their interrelationships
- Using theory to further explain the barriers of blockchain technology adoption for sustainable supply chain management while extending theoretical underpinning to barriers analysis of organizational innovation adoption

[3] - https://www.forbes.com/sites/biserdimitrov/2019/12/05/how-walmart-and-others-are-riding-a-blockchain-wave-to-supply-chain-paradise/#1ca81b127791.

[4] - https://cointelegraph.com/news/blockchain-supply-chain-platform-gains-metals-giant-glencore-as-member.

[5] - https://www.cgsinc.com/en/infographics/CGS-Survey-Reveals-Sustainability-Is-Driving-Demand-and-Customer-Loyalty.

[6] - https://www.forbes.com/sites/rogerhuang/2019/12/28/un-pilot-in-mongolia-uses-blockchain-to-help-farmers-deliver-sustainable-cashmere/#1e1b48c017d9.

[7] - https://hbr.org/2019/12/the-top-sustainability-stories-of-2019.

[8] - https://www.valuewalk.com/2020/01/progress-of-blockchain-technology:-economic-barriers-investment-tips-and-more/.

- Evaluating differences and similarities of barrier perceptions amongst two research stakeholder communities – academics and practitioners
- Providing insights into how DEMATEL methodology can be used for theory extension and development by informing causal relations for research Proposition development

There are both theoretical and practical implications in guiding organizations, managers and policy makers in prioritizing their effort for resolving barriers to blockchain adoption generally in supply chains and more specifically for sustainability in supply chains. This study is the first that offers a road map for effective blockchain adoption in sustainable supply chain by identifying the critical barriers and assessing their interdependence.

For the remainder of this paper, in Section 2 we review the literature relating to supply chain management, sustainability and blockchain. In this section, we also identify different blockchain and SSCM adoption barriers, borrowing from force field and TOE theoretical perspectives. The methodology is described and sampling is explained in Section 3; study results appear in Section 4. This section is followed by a discussion of the results in section 5 and managerial implications in Section 6, which presents a number theoretical and research propositions. The paper concludes with a summary of findings, study limitations, and future research directions in Section 7.

2. Background

2.1. Blockchain technology: an overview of the current research

Blockchain technology was popularized by Nakamoto (2009) through the cryptocurrency Bitcoin. Although this initial focus was on cryptocurrencies and financial-oriented applications (Crosby et al., 2016), the transformative features of blockchain motivated non-financial sectors to move toward this "game changer" (Johnson, 2018). The literature has introduced blockchain technology applications to address a variety of issues. Exemplary applications include healthcare management (Angraal et al., 2017; Dwivedi et al., 2019; Jayaraman et al., 2019; Mettler, 2016; Yue et al., 2016; Zhang et al., 2018), the energy sector (Ahl et al., 2020; Andoni et al., 2019; Burger et al., 2016; Mengelkamp et al., 2018b), and e-government (Hou, 2017; Navadkar et al., 2018; Ølnes et al., 2017; Pilkington et al., 2017; Sullivan and Burger, 2019). In addition to these applications, there has been growing literature on blockchain technology as an enabler for supply chain management. Table 1 provides an exemplary summary of the current literature on blockchain supply chain management application.

The majority of scientific articles examining blockchain technology potential to support supply chain management represent four main topics-themes (Pournader et al., 2019); trust (Meng et al., 2018), trade (Mengelkamp et al., 2018a), technology (IoT, RFID) (Ben-Daya et al., 2019), and traceability/transparency (Kshetri, 2018).

A study by Chang et al. (2019) presented an overview on how the growing literature addresses how blockchain technology can alleviate global supply chain issues including improving transparency, dispute resolution, compliance, integrity, and stakeholder management. Another recent study by Hughes et al. (2019) delved into the information management literature and delineated the potential for achieving United Nations Sustainability Development Goals. Transparent information that traced origin of materials and products, participating supply chain members, and processes and operations shared on blockchain ledgers can enhance product provenance, chain of custody and authenticity (Montecchi et al., 2019).

The current literature has primarily focused on the potential and benefits of supply chain management blockchain solutions; few studies address blockchain adoption barriers that may play important roles in blockchain's slow adoption rate. Technological challenges of blockchain technology, interoperability, lack of trust and standards, and legal issues are noted as some general challenges preventing the diffusion of blockchain technology across industry (Chang et al., 2019). A comprehensive examination of challenges that limit blockchain adoption for supply chain management is a recognized research gap (Queiroz et al., 2019).

Emergent literature also highlights the role of blockchain technology to support supply chain sustainability (Di Vaio and Varriale, 2019; Kamble et al., 2019b). However, the challenges supply chains face as they seek to integrate blockchain technology for supporting sustainability remain relatively under-investigated. A study by Saberi et al. (2019b) presents an overview of such challenges that stem from intra- and inter-organizational supply chain resources, technological limitations, and external relationships outside supply chains. Our current study utilizes these barriers. We further advance that study by introducing two compelling theories, Force Field Theory and TOE, to theoretically support the identified barriers and the need for barriers analysis. The barriers to adoption research is also extended by evaluating the relative importance and the interdependence of the critical barriers to SSCM blockchain adoption.

Previous barriers analysis studies in blockchain-enabled supply chains have lacked theoretical underpinning. Some studies have utilized theories to examine the intention to adopt and adoption of blockchain technology, rather than seeking to understand the barriers and challenges. Theories include those introduced by Schmidt and Wagner (2019) that examined the influence of blockchain technology on supply chains from a transaction cost theory lens and highlighted the reduction in opportunistic behavior, uncertainty and transaction costs in a blockchain-based supply chain. The technology acceptance model, theory of planned behavior, technology readiness index, and unified theory of acceptance and use of technology, are some example theories that have been used to explain and describe adoption of blockchain technology in supply chains (Kamble et al., 2018; Queiroz and Wamba, 2019). None of these studies have theoretically examined the limitations and barriers in this environment.

Any supply chain innovation adoption will face barriers and require careful planning. Many studies have sought to identify and explore barriers for adopting various supply chain management innovations. Effective supply chain management (Fawcett et al., 2008); sustainable practices (Chkanikova and Mont, 2015; Gold et al., 2017; Gorane and Kant, 2015; Govindan and Hasanagic, 2018; Movahedipour et al., 2017; Sajjad et al., 2015); circular economy (Mangla et al., 2018; Tura et al., 2019); and information systems (Heeks, 2006; Jharkharia and Shankar, 2005; Peng and Nunes, 2010) are some examples of supply chain innovations facing barriers. Many of these studies utilize DEMATEL methodology for investigating supply chain innovation adoption barriers (Dinh et al., 2018; Iansiti and Lakhani, 2017; Kaur et al., 2018). However, these studies have been atheoretical – with deficiencies in theoretical frameworks as a foundation for barrier analyses. Force field theory and TOE provide a substantive theoretical framework that incorporates motivations and barriers for adopting innovations.

In the blockchain technology literature, a recent study utilizing aspects of DEMATEL evaluates the relationship among the enablers of blockchain technology in the agriculture supply chain (Kamble et al., 2019c). Another study applies DEMATEL to determine interrelationships amongst barriers to adopting blockchain technology in industry and service sectors (Biswas and Gupta, 2019). The barriers identified by Biswas and Gupta (2019) did not include blockchain adoption in the supply chain domain or for sustainability. They focused on external and systems issues in a public blockchain setting and cryptocurrencies. Although both studies – Kamble et al. (2019c) and Biswas and Gupta (2019) – can inform our study, their perspective evaluations do not capture private blockchain and especially SSCM concerns. Our study further contributes to the literature by introducing blockchain as a novel technology that requires significant and potentially diverse attention and development from both scholarly and practitioner viewpoints. How these study groups perceive barriers – in addition to group similarities

Table 1
Related literature on blockchain technology for supply chain management.

Stream	Summary	Focus	Theory	Empirical Content-Methodology	Source
Supply chain objectives	Specified the role of blockchain technology in achieving supply chain objectives. Blockchain can help reduce cost and risk and improve quality, flexibility, speed and sustainability	Benefits		Case study	Kshetri (2018)
Blockchain project design	Developed guidelines to design a mindful pilot project for adoption of blockchain technology. Supply chain companies need to select a specific supply chain objective that they seek to achieve through blockchain adoption	Adoption		Case study	Hoek (2019)
Understanding blockchain for supply chain management	Perceived benefits and challenges of blockchain adoption in a general supply chain	Benefits and challenges	Sensemaking Theory	Interviews with supply chain executives	Wang et al. (2019b)
Traceability of food	Introduced and modeled blockchain as a supportive solution for traceability of food and agriculture	Benefits		Case study, simulation	(Behnke and Janssen, 2019; Bumblauskas et al., 2019)
Agriculture supply chain	Determined the interrelationship among enablers of blockchain technology for agriculture supply chain	Benefits		Experts' opinion-DEMATEL	Kamble et al. (2019c)
Adoption behavior	Analyzed the behavioral intention to adopt and the perception of the usefulness of blockchain technology in supply chain management.	Adoption	Technology Acceptance Model (TAM), Technology Readiness Index (TRI) and the Theory of Planned Behavior (TPB)	Empirical data	(Kamble et al., 2018; Karamchandani et al., 2019)
Supply chain operations	Investigated the role of blockchain technology in leveraging variety of supply chain operations such as demand forecasting and inventory management, order management, resilience and risk management and supply chain distribution	Benefits		Conceptual	(Ivanov et al., 2019a); (Martinez et al., 2019); (Min, 2019); (Wu et al., 2017a)
Literature review	Systematically reviewed the papers that address the blockchain technology application in SCM	Adoption, benefits and challenges		Conceptual-review	(Chang et al., 2019; Macrinici et al., 2018; Pournader et al., 2019; Queiroz et al., 2019; Wang et al., 2019a)
Theoretical framework of the literature	Developed a theoretical framework to present relevant topics in supply chain management and logistics for integration of blockchain technology	Adoption	Principal Agent Theory (PAT), Transaction Cost Analysis (TCA), Resource-Based View (RBV) and Network Theory (NT)	Conceptual-review	Treiblmaier (2018)
Adoption guidelines	Examined various blockchain case studies to delineate what supply chain issues can be resolved using blockchain, and developed guidelines to build a blockchain-based supply chain.	Adoption, benefits and challenges		Case studies	Azzi et al. (2019)
Challenges of blockchain technology for industries and services	Determined the interrelationships among the general barriers of blockchain adoption in the industry and service sector	Challenges		Experts' opinion-DEMATEL	Biswas & Gupta (2019)
Blockchain for supporting sustainability in supply chains	The potential of blockchain in enhancing environmental, social, and economic dimensions of sustainability	Benefits and challenges		Conceptual	Saberi et al. (2019b)

and differences – are explored in our study.

The DEMATEL-based analysis in our study is further differentiated from previous studies due to a theoretical focus for barriers analysis – especially by introducing force field theory and TOE as explanatory theoretical lenses, which have never been used in the previous DEMATEL-oriented studies. Theoretical underpinning is lacking in many previous DEMATEL studies that investigate relationships amongst factors (e.g. Bai and Sarkis (2013); Bhatia and Srivastava (2018); Kaur et al. (2018); Lin (2013); Su et al. (2016); Wu and Lee (2007)). Our study fills this gap and aims to examine the barriers that impede blockchain adoption for integrating sustainability in the supply chains; with theoretical observations that form research propositions to advance key theories in the supply chain management context. The present study also seeks to examine how supply chain academics and practitioners perceive the barriers.

2.2. *The case for blockchain within sustainable supply chain management*

Blockchain – a disruptive technology – can enhance SSCM. Blockchain could bolster confidence in product sustainability authenticity by keeping close and accurate track of their flows in supply chains (Saberi et al., 2019b). Blockchain technology can track social and environmental conditions which may be threats to environmental concerns, in addition to social issues such as health and safety of others (Adams et al., 2018). This capability can add to social, environmental and business sustainability.

Public/permissionless and private/permissioned are two popular blockchain technology environments (Ølnes et al., 2017; Pilkington, 2016). In a public blockchain network, any entity can join the network, access the data, and use blockchain ledgers. Bitcoin and other cryptocurrencies are examples of public blockchain. A private blockchain serves only those users that are granted access to the blockchain. A hybrid of public and private blockchain can also exist to address specific business needs. Most practically proposed supply chain use cases adopt a private blockchain environment where known users with restricted access can exchange information (Kshetri, 2018).

Blockchain technology can be instrumental in changing sustainability management as well. There are examples about its application apart from the supply chain. The energy market is always under scrutiny for its sustainability. Blockchain has found its way to make it more sustainable to share energy (Park et al., 2018). There are applications for reduced waste and management of waste in circular fashions (Zhang, 2019). Linkage to the internet of things and geotracking can help in management deep into the supply chain (Heinrich et al., 2019). The technology can also be used for blockchain enabled emissions trading schemes and carbon trading (Fu et al., 2018; Manupati et al., 2019). Blockchain can reduce information asymmetries that may socially and financially deprive small organizations and farmers (Charlebois, 2018). Reduction in unethical, corrupt and counterfeit practices also help blockchain contribute to social supply chain sustainability (O'Dair, 2016).

There are many other examples on how blockchain technology could affect the triple-bottom-line sustainability apart from supply chain applications (e.g. see (Di Vaio and Varriale, 2019; Kouhizadeh and Sarkis, 2018; Kouhizadeh et al., 2019a; Manupati et al., 2019; Nikolakis et al., 2018).

2.3. Force field theory and blockchain adoption

Blockchain technology can have disruptive and revolutionary implications for supply chain processes. Digital technologies and supply chain information systems, e.g. Enterprise Resource Planning (ERP), continue to play important roles in the supply chain. Traditional systems are not able to meet many complex and dynamic issues facing modern supply chains. Many of these systems fail to provide updated, secure, real-time supply chain data (Brody, 2017; Di Vaio and Varriale, 2019). Blockchain technology includes numerous capabilities to support modern supply chains. Full transparency and verifiability, enhanced trust and security of information, and disintermediation are some exemplary drivers for blockchain adoption (Saberi et al., 2019a).

However, blockchain adoption also faces various challenges. The challenges organizations face are defined as resisting forces according to force field theory (Lewin, 1946). These resisting forces freeze the transformation, counteract the driving forces and capabilities of blockchain technology, and impede successful changes within organizations and supply chains.

Force field theory serves as a theoretical framework for this study, in addition to TOE theory. The barriers and challenges that obstruct successful adoption of blockchain within SSCM represent strong forces to stop change.

Although force field theory is a classic framework in change management literature (Sonenshein, 2010), it is an overlooked theory in supply chain management literature. A few studies have found that incorporating force field theory, in addition to other theories, can be valuable in explaining lack of adoption based on various barriers to effective collaboration between supply chain partners in supply chains (Fawcett et al., 2008, 2010). That this theory has not gained additional traction given the innovations and lack of adoption – many examples already given in this section – is surprising.

The present study contributes to adopting force field theory as a significant theory to address barriers research. It can serve as an excellent theoretical backbone for barrier analysis within supply chain literature. This proposed theory can explain the nature and behavior of challenges that organizational entities may face when they adopt any type of innovation; not just blockchain technology.

Force field theory (Lewin, 1951) describes the essence of organizational transformation and change. Lewin's theory of change incorporates three steps: unfreezing, change, and refreezing. The emergence of technologies and innovations unfreezes the organization's present state. These innovations can move organizations toward the change, which happens to be adopting and implementing technology, and refreezes their state with the new technology. This theory is widely used within the change management field and the classic paradigm of change management (Schein, 2010; Waddell et al., 2007). Although some researchers have argued that the three step of change suggested by Lewin is overly simplistic and fails to reflect the today's complex environment (Child, 2015; Clegg et al., 2015), this theory is regarded as a strong tool for building change management among practitioners and academics (Cummings et al., 2016; Hendry, 1996; Levasseur, 2001). However, for this change to occur, overcoming resistant forces, barriers, is necessary.

Resistance forces may stem from variety of internal and external factors at different individual levels and broader organizational levels (Alvesson and Sveningsson, 2015; Lewin, 1946). A number of identified barriers and resisting forces in this study are also relevant to other organizational theories adopted to understand supply chains – for example, the resource-based view theory, relational view, and institutional theory.

There are many blockchain motivations and driving forces we have identified. The role of relationships between barriers derived from this study can help advance these theories for blockchain adoption. We return to this theory, and linking it to TOE, to formulate a number of research propositions that are reinforced by our exploratory study findings.

Force field theory provides an overarching theoretical lens that accounts for the entire resisting forces, rather than a narrow set of resisting forces. These resisting forces and barriers we identify utilize the TOE theoretical framework.

2.4. TOE and blockchain in sustainable supply chains barriers

The popular and research literature are replete with blockchain implementation advantages, and often for SSCM. Blockchain technology can support the supply chain, but significant barriers to adoption exist. New technology adoption is brimming with challenges; blockchain is not exempt. Technology can reap fruits only when various challenges are overcome. The participating parties need to profoundly understand these challenges and plan accordingly.

In this section, we utilize the TOE theoretical lens (Baker, 2012; Oliveira and Martins, 2011; Tornatzky et al., 1990) to identify various challenges and barriers for blockchain technology adoption, especially within the SSCM context. TOE is a theoretical framework that broadly characterizes aspects that relate to adoption of technological innovations (Kuan and Chau, 2001; Zhu et al., 2002). According to TOE, technology adoption by a firm is influenced by three major elements; the technological (T), organizational (O), and environmental (E) contexts (Baker, 2012; Tornatzky et al., 1990). The technological context incorporates the characteristics and availability of a technological innovation. The organizational context refers to the firm's structure, as well as the resources and intra-firm communications. The environmental context presents the characteristics of markets, industries, and the regulatory environment.

Blockchain is a technological innovation and, factors influencing blockchain adoption can follow the TOE framework. The blockchain barriers include technological (T), organizational (O), and environmental (E) barriers. The first two groups of factors are endogenous to the technology or organizations. We expanded the environmental element to include two exogenous dimensions including inter-organizational barriers, and a broad category including barriers external to supply chain and organization barriers.

The technological barriers include basic challenges that are present with blockchain technology like security, accessibility and immaturity of technology. Organizational dimensions include management commitment, policies and culture. The supply chain (inter-organizational) view encapsulates challenges like information disclosure, problems with collaboration and lack of awareness. The final barrier grouping includes government policies, and general normative, and ethical practices.

The barriers – resisting forces – were initially determined using relevant literature in supply chain information systems and technology, SSCM, and blockchain technology. Expert input helped confirm the barriers, definitions, and associated categories. These experts are active in the blockchain-supported supply chain area.

Table 2 summarizes the TOE elements and the underlying barriers. The four barrier dimensions we now present consider both general and SSCM issues that may arise.

2.4.1. Technological barriers

The technological context incorporates technical capability, complexity, difficulty, and availability of the innovation that is considered for adoption (Rogers, 1995). For blockchain adoption this category includes barriers stemming from blockchain technology limitations. Blockchain technology is immature. Thisimmaturity creates technical challenges including scalability, usability, and interoperability (Casino et al., 2018; Swan, 2015; Yli-Huumo et al., 2016). The technology still suffers from latency and throughput issues (Swan, 2015). With lower throughput rate and higher latency, blockchain technology still requires development (Mendling et al., 2018). These issues indicate that implementation of blockchain in supply chain could mean lower transaction numbers, and the transaction times would be higher. When seeking to monitor environmental and social practices, the type, location, and volume of information required make it extremely difficult to manage.

Blockchain technology has been introduced as a secure technology that utilizes a unique decentralized structure with various computational algorithms that make it difficult to hack or crash. Yet, a number of hacks and system attacks, especially in the cryptocurrency environment, have raised questions about the vulnerability of blockchain (Yli-Huumo et al., 2016). Another challenge that raises question on blockchain applications involves disagreements among blockchain communities and actors that leads to "blockchain split". This issue separates blockchain into two or more paths in a public blockchain setting (Islam et al., 2019).

There are also blockchain accessibility concerns; is the IT infrastructure accessible for all blockchain participants (Abeyratne and Monfared, 2016)? To access pertinent information the type of blockchain system in place – open or permissioned – needs consideration (Morabito, 2017). Whether all blockchain participants need access to all supply chain information is an application concern (Gorane and Kant, 2015).

Data immutability is one of the blockchain technology characteristics. Immutability means that data or the information is unchanged. Immutability is a potent feature that ensures reliability and authenticity of information. However, an issue that arises with immutability is that previous data and errors within the records are permanent, as they will continue to live with the blockchain (Palombini, 2017). For example, a poor environmental or social record could exist forever, even though the latest data seeks to correct such information.

The last point is blockchain technology's public image and perceptions. This characteristic is not strictly technological, but image plays a large role in eventual adoption. The public perception may be negative due to the 'dark web' of money-laundering and other illegal activities through blockchain anonymity; although in permissioned block chains this may not be an issue. Over time this perception may change as greater adoption of blockchain occurs (Swan, 2015). The concern is that social and environmental issues need to be at a higher ethical requirement for sustainable supply chains; the unethical perception of the blockchain technology hinders its application where ethical behavior is central to acceptance.

2.4.2. Organizational barriers

The organizational context encompasses factors and issues related to internal focal firm concerns (Tornatzky et al., 1990). Blockchain technology requires hardware and software, with maintenance, to sustain it. The cost associated with additional investments increases with larger implementation (Marsal-Llacuna, 2018). New technology will be costly for the organization and the system partners, not only for the technology but supporting people and process infrastructure (Mougayar, 2016). For sustainability this also means cross-disciplinary participation such as corporate social responsibility, public relationships, and environmental management personnel depending on the sustainability concern to be addressed by the technology.

The lack of commitment from top or middle management creates problems. Their support is essential for blockchain technology implementation (Mangla et al., 2017). This barrier exists for risk-averse companies, where the risks of new technology can affect the organization. In addition, if the supply chain sustainability is the goal for this technology, management may not view the blockchain application as core to its values and mission.

In organizations there is a lack of comprehensive blockchain understanding impeding its implementation (Mougayar, 2016). Adding the need to fully understand and manage sustainability in this context makes it a greater knowledge and expert organizational need. This discomfort with the new technology, applied to a relatively new organizational practice such as sustainability, negatively affects the perceived ease of use (Kamble et al., 2019a).

There are challenges in adoption of blockchain technology in supply chains due to lack of standardization (Morkunas et al., 2019). Internal organizational changes for new standards, both blockchain and in sustainability, would lead to difficulty in establishing connections via blockchain between firms as the systems may vary in architecture.

2.4.3. Environmental barriers – the supply chain inter-organizational view

The environmental elements include factors related to the regulatory environment, industry characteristics, market competition and the linkages among firms (Tornatzky et al., 1990). In a blockchain-based setting, the environmental context may contain two categories: supply chain barriers and broader external barriers – broader external barriers are discussed in the next section. Inter-organizational supply chain barriers refer to external barriers occurring outside the boundaries of the firm; and the technology. Although the environmental context sometimes only focuses on institutional factors, in this study we utilize a broader perspective that incorporates relation-specific issues in the supply chain across organizations.

The most challenging dimension of supply chain concerns arises at the nexus of technical and sustainable practices supply chain integration. Customer lack of awareness about blockchain technology in sustainability may arise, usually due to ineffective communication and collaboration among the partners with different goals and priorities (Mangla et al., 2018; Oliveira and Handfield, 2019). Organizations often lack sustainability knowledge aid fail to adopt sustainable practices across the supply chain; blockchain technology only adds to the complexity and potential confusion (Luthra et al., 2016).

There is often a question about data confidentiality and privacy in inter-organizational systems (Sarkis and Talluri, 2004; Sayogo et al., 2015). Organizations are skeptical about sharing their information as they see information as a competitive edge (Wang et al., 2019b). Blockchain technology makes information transparent and data protection and privacy could be provided via encrypted blockchain (Hughes et al., 2019). There are questions about lack of information sharing policies, which could address how much and what type of information should be shared. The participants are willing to share the information if it adds value towards their customers and their proprietary information is not disclosed (Sayogo et al., 2015). Sustainability information is exceptionally sensitive due to legal and ethical concerns that could not only result in poor public image, but fines and even criminal proceedings. This situation makes the barriers even larger.

It is a challenge to integrate supply chain processes with sustainable practices and blockchain technology. Business process reengineering is required. The processes must be jointly developed and improved to support additional sustainable practices, especially if supply chain members are not well-versed on these issues (Kaur et al., 2018; Sarkis and Zhu, 2018). Organizations are slow to respond to improving sustainable performance due to absence of resources (Govindan et al., 2014). Due to the complex nature of the sustainability the technology needs proper strategic implementation to achieve better quality and processes (Mangla et al., 2017).

Cultural and geographical differences among the supply chain partners can impede the implementation of blockchain technology. These differences often hamper the adoption of uniform performance tools and system across the supply chain (Sajjad et al., 2015) and sustainability, especially social sustainability with its heterogeneous global and cultural definitions making these differences a significant barrier.

2.4.4. Environmental barriers – the external view

Our external barriers are associated with governments, industries, institutions, communities, and non-governmental organizations (NGOs). Lack of governmental policies, market competition and uncertainty, and lack of external stakeholder involvement in adopting sustainability and blockchain are some exemplar external barriers. The category delves into barriers arising from external stakeholders, governments and institutions. Altogether we are focusing on units who are not viewed as direct participants in the supply chain. Organizations and supply chains have faced significant sustainability pressures, driving their need for sustainable practices. Although many pressures exist, a lack of standard policies and frameworks for sustainability and lack of engagement is preventing the advancement of integrated systems, and blockchain standards are even more difficult to pin down (Mangla et al., 2018).

Government regulations are still not fully in support of the blockchain technology given the novelty of the technology (Kamble et al., 2019a) hampering adoption in the supply chain. Gaps in government oversight on what and how to measure further impede the move towards blockchain systems and sustainability. Governmental incentives to support the adoption of sustainable practices (Govindan et al., 2014) may be substantial barriers, organizations seeking to embrace blockchain technology may view the lack of additional supporting incentives barrier especially true for smaller and distributed suppliers in less developed countries.

Governments, acting as public agents that, seek ethical and safe practices (Luthra et al., 2016), have furthered the adoption of sustainable practices and blockchain in the supply chain. Also NGOs working on environmental issues wish involvement (Mangla et al., 2017). There are concerns from supply chain partners due to conflicting or multiple stakeholder requirements, which lead to impediments in sustainable practices with blockchain technology. It is not uncommon to see businesses fearing introduction of new sustainable products in the market due to market demand uncertainty and lack of market information (Mangla et al., 2017, 2018) further impeding the need for blockchain technology. Whether blockchain technology can contribute to economic sustainability and profitability is a concern.

For clearer understanding for successful implementation of the blockchain in SSCM, it is important to search these barriers and interactions. Our exploratory research can support strategic plans including organizational, supply chain, technology developers, and other stakeholder plans to deal with them. It could be possible that some of these factors require less attention, whilst others would need years of involvement. To realize SSCM integration with blockchain technology, exploratory insight is a vital need. We now describe the methodology to explore the barriers and concerns.

3. Research methodology

This section describes the DEMATEL methodology, the sample and participant information.

3.1. DEMATEL methodology

Analyzing a large number of barriers or factors that are interrelated can be overwhelming. Multi-criteria decision-making (MCDM) methodologies and structural modeling approaches provide ways to define relationships and priorities of multiple factors. The analytic hierarchy process (AHP) (Saaty, 1988) and interpretive structural modeling (ISM) (Mandal and Deshmukh, 1994) are two well-established approaches that have been used by SCM scholars to structure and evaluate a number of defined barriers or factors. However, these two methodologies have some limitations. AHP fails to address the interactions amongst the barriers, and ISM is unable to calculate the total influence of each factor. DEMATEL – Decision Making Trial and Evaluation Laboratory (Fontela and Gabus, 1976) – has been recognized as a superior methodology that addresses these issues (Biswas and Gupta, 2019; Tzeng et al., 2007). DEMATEL evaluates the complex interrelationships among variables and factors, classifies them into cause and effect clusters, and provides a hierarchical structure for effective solutions (Yang et al., 2008).

DEMATEL is utilized in numerous research investigations related to sustainability, operations, and supply chain management. Examples include renewable energy resources selection and green supplier selection (Hsu et al., 2013; Su et al., 2016), green supply chain management practice evaluation (Lin, 2013), remanufacturing (Bhatia and Srivastava, 2018), strategic competitive advantage (Wu et al., 2017b), business process management (Bai and Sarkis, 2013), and blockchain adoption in industries and services (Biswas and Gupta, 2019).

DEMATEL explores the causal dependency structure among a set of identified factors and utilizes pairwise comparisons to visualize direct and indirect relationships amongst these factors. DEMATEL is a good methodology for mind-mapping studies. Causal relationships are hard to capture through other methodologies, especially techniques that focus on correlation such as multivariate regression analysis. DEMATEL is valuable when exploring research questions about significance and causation.

The DEMATEL methodology helps to structure the causal relationships among the identified barriers and identifies each barrier's prominence (Fu et al., 2012; Lee et al., 2010). The analysis includes the following steps:

Step 1- Aggregate results (average) and establish pairwise direct-relation matrix
Step 2- Determine the initial influencing matrix (N) by normalizing
Step 3- Calculate the total relation matrix (T)
Step 4- Determine row and column sums from the total relation matrices
Step 5- Determine the overall prominence and net effect values of factors
Step 6- Draw the DEMATEL prominence/effect diagrams – only mapping those relationships above a threshold value

Each step incorporates multiple mathematical evaluations. The prominence and net effect values of each factor are DEMATEL analysis outputs. The final prominence value ranks the factors. Additional details on the DEMATEL methodology and the calculations appear in the Appendix.

3.2. Data collection

The novelty of blockchain technology and a scarcity in actual SSCM blockchain implementation limit a broad-based study. Thus, we selected a convenience sample of respondents that includes academics and practitioners knowledgeable in blockchain and sustainable supply chains to help evaluate the barrier relationships.

We utilized the barriers identified in (Saberi et al., 2019b) and further expanded and integrated them with the most recent literature. The barriers were then grouped based on two theoretical lenses, Force Field theory and TOE; see Table 2. The list of barriers and the underlying categories were further examined, refined, and confirmed by six supply chain management experts involved – for a minimum of three years – in blockchain technology research projects. These experts were mainly university professors conducting and publishing research on the application of blockchain for supply chain management. Further validation occurred during the data acquisition phase for the DEMATEL analyses. We asked each respondent if there were any comments concerning the barriers. There were no direct significant comments concerning the barriers which provided further validation of the barriers selected.

A DEMATEL survey captured respondent inputs using pair-wise comparison matrices. The matrices include barriers at the general – organizational, inter-organizational, technology, and external – and more specific level of categories for each of the general categories. Each matrix includes four to seven barrier factors. This smaller set of factors and multiple matrices helps keep DEMATEL data acquisition more tractable for data gathering. A hierarchical matrix factor set is used; with the general factor groups representing the highest level and the sub-matrices representing elements within each general factor grouping. This process was clearer and results in less respondent fatigue when completing the matrices than if all sub-factors were included in a single matrix. We asked the participants to evaluate the influence of each factor on one another using pair-wise comparisons. Table 3 presents an exemplary pairwise comparison table used in the survey instrument. The table was designed to assess the interrelationships among the barrier categories. The major factors and the sub-factors were each clearly defined for participants. A complementary set of definitions for each pairwise comparison matrix was also provided. Table 4 provides an example definition table for barriers categories for Table 3 factor matrix. A linguistic scale was utilized to convert the strengths of the influence relationships amongst factors to a numerical scale – as shown in Table 5.

3.3. Sample and respondent information

Experts in blockchain and SSCM were invited to participate in this study. 47 responses were obtained. Our respondents were from academia (35) and practice (12).

Academics in the sample were active researchers in blockchain and/or sustainable supply chain management and were mostly university professors. The average work experience of academics were 13.83 years with a standard deviation of 10.08 years. Practitioners were mostly in consulting and leadership positions and involved in sustainability and/or blockchain-oriented projects. Practitioners had 18.55 years of work experience on average with a standard deviation of 9.79 years. Both study groups had an acceptable level of knowledge on blockchain and/or sustainable supply chain management. Table 6 presents the respondent information and profiles.

4. Results

The resulting outputs of the DEMATEL methodology are relationship diagrams. The x-axis presents prominence values and y-axis shows the net influence value. Each barrier has a corresponding prominence (x) and net influence (y) value on the diagram. The arrows connect points and displays the direction of the relative significant influence between two factors. Only significant influences are included.

Two major respondent groups evaluated the barriers; academics and practitioners. To determine if the main categories – barrier groupings – had different perspectives we separated the responses and completed the aggregated DEMATEL for each group. We compared the barrier outcome rankings for the twenty-two barriers that fell over the four major barrier groups. The prominence score for each barrier was calculated by multiplying the prominence score for the barrier group to the prominence score ranks for each barrier. We used a non-parametric rank correlation statistic – Kendall's Tau-b statistic – to determine if the rankings were correlated between the respondent groups. The results revealed that the ordinal ranks are not significantly correlated ($p > .05$) using a two-tailed test. This result further validated our initial conjecture that academics and practitioners may perceive barriers differently. Given these differences, the analysis will compare and contrast the results of DEMATEL analysis between two respondent groups; academics vs practitioners.

4.1. Relationships of main barrier categories

The main barrier categories relationship diagram displays the relationships amongst the main categories between academics and practitioners (see Fig. 1). The connecting arrows only include relationships between the main categories that met the threshold value.

Fig. 1 shows that supply chain barriers (M2) and technological barriers (M3) received the highest prominence values from both academics and practitioners. Both stakeholder groups believe that technological barriers impact supply chain barriers and organizational barriers (M1). Supply chain barriers are affected by external barriers (M4) as well.

Academics highlighted supply chain barriers category as the most prominent; practitioners highlighted technological challenges. The practitioners appear more technology-oriented, who are more concerned about the technology itself, rather than the other general issues.

For practitioners, technological barriers, external barriers, and organizational barriers significantly influence supply chain issues. Academics believe that the effects of organizational barriers on supply chain barriers is not as significant.

Overall, both academics and practitioners agree that addressing technological issues of blockchain technology and obtaining complete support from external sources such as governments, industries, and external stakeholders relate to reducing supply-chain related barriers; a prominent barriers category.

A summary of the results includes:

- Supply chain and technological barriers are the barrier categories with the highest prominence and may require special attention.
- Technological barriers and external barriers need to be initially addressed to harness supply chain obstacles for adopting blockchain in SSCM.
- Technological barriers require initial attention to address organizational obstacles for adopting blockchain in SSCM. This attention is likely to result in decrease of supply chain barriers.

4.2. Technological barriers prominence and relationships

Technological barrier relationship diagrams for academics and practitioners are shown in Fig. 2. Security challenge (T1), the negative perception toward technology (T3), and immaturity of technology (T5) have the highest prominence values for both academics and practitioners. There are also significant relationships across these three barriers that require attention.

Both academics and practitioners view immaturity of technology as the obstacle that impacts security challenge and the negative perception toward technology. Immaturity of technology controls the negative perception toward technology directly and indirectly with an arguably mediating relationship. Security challenge acts as the mediator. To fully address the negative perception toward technology, mediator barrier, security challenge, and immaturity of technology need to be tackled. The practitioners highlight that access to technology (T2) is also relatively important. They consider that this challenge can affect the

Table 2
TOE framework and blockchain barriers in sustainable supply chains (Saberi et al., 2019b).

TOE View	Barrier	Description	Reference
Technological context	T1- Security challenge	There are concerns that data and information may be open to security concerns such as hacking, inaccurate information dispersal and access to sensitive information.	(Biswas and Gupta, 2019; Casino et al., 2018; Hou, 2017; Sayogo et al., 2015; Wang et al., 2019a, 2019b; Yli-Huumo et al., 2016)
	T2- Access to technology	Internet and IT infrastructure are important resources for blockchain adoption. In some cases IT infrastructure of organization is poor or technology access is impractical.	(Abeyratne and Monfared, 2016; Morabito, 2017)
	T3- The negative perception toward technology	Individuals may associate blockchain technology primarily with cryptocurrencies such as Bitcoin. These developments might be perceived as malicious activities. Therefore, organizations may hesitate adoption of general blockchain technology.	Swan (2015)
	T4- Immutability challenge of blockchain technology	Immutability proposes that records cannot be deleted from ledgers. But, if an incorrect record entered in to the blockchain can be updated with additional information, the history of the erroneous record will always be in the blockchain.	(Biswas and Gupta, 2019; Kamble et al., 2019a, 2019c; Palombini, 2017)
	T5- Immaturity of technology	Challenge of scalability of blockchain is an example technical issue that stem from immaturity of blockchain. In fact, blockchain technology would have issue with handling large numbers of transactions. Also, storage of increasing size of blocks is a challenge, encountering big data in real use (called “bloat” problem in Bitcoin). These are some immaturity of technology examples.	(Biswas and Gupta, 2019; Hackius and Petersen, 2017; Lindman et al., 2017; Mendling et al., 2017; Mougayar, 2016; Pilkington, 2015; Swan, 2015; Wang et al., 2016)
Organizational context	O1- Financial constraints	Information collection through supply chain and converting to new systems impose costs on organizations. Also, adopting sustainable practices is costly. Organizations are limited in financial resources to adopt this technology.	(Angraal et al., 2017; Biswas and Gupta, 2019; Hughes et al., 2019; Marsal-Llacuna, 2018; Patel et al., 2017; Sayogo et al., 2015; Wang et al., 2019b)
	O2- Lack of management commitment and support	Some managers fail to have long-term commitment and support of sustainability practices through SCM processes and adopting disruptive technology.	(Crosby et al., 2016; Guo and Liang, 2016; Mangla et al., 2017; Wang et al., 2016)
	O3- Lack of new organizational policies for using blockchain technology	Organizations need to define new policies to adopt blockchain technology (what is the proper usage of the technology, for example where and when).	(Lacity, 2018; Mendling et al., 2017; Wang et al., 2019a)
	O4- Lack of knowledge and expertise	Lack of technical expertise and knowledge about blockchain technology and sustainable supply chains.	(Angelis & da Silva, 2019; Kamble et al., 2019a; Lacity, 2018; Mangla et al., 2017; Mougayar, 2016; Sayogo et al., 2015)
	O5- Difficulty in changing organizational culture	Adopting blockchain technology changes or transforms current organizational culture. Organizational culture consists of guidelines of work culture and appropriate behavior through organizations.	(Gorane and Kant, 2015; Mangla et al., 2017; Mendling et al., 2017)
	O6- Hesitation to convert to new systems	Adopting new systems would require altering or replacing legacy systems. This issue may cause resistance and hesitation from organizations and industries.	(Angelis & da Silva, 2019; Govindan et al., 2014; Michelman, 2017; Saberi et al., 2018)
	O7- Lack of tools for blockchain technology implementation in sustainable supply chains	Lack of standards and appropriate methods, tools, metrics and techniques for blockchain technology implementation and measure sustainability performance within organizations.	(Andoni et al., 2019; Govindan et al., 2014; Mangla et al., 2017; Morkunas et al., 2019)
Environmental context (Supply chain view)	SC1- Lack of customers' awareness and tendency about sustainability and blockchain technology	Lack of understanding by customers about blockchain technology for supply chain sustainability practices.	(Chkanikova and Mont, 2015; Hughes et al., 2019; Luthra et al., 2016; Mangla et al., 2017)
	SC2- Problems in collaboration, communication and coordination in the supply chain	Lack of collaboration, communication, and coordination among supply chain partners with different and sometimes contradictory operational incentives/ objectives and priorities; other reasons that impede collaboration.	(Behnke and Janssen, 2019; Caro et al., 2018; Gorane and Kant, 2015; Kamble et al., 2019c; Kshetri, 2018; Wang et al., 2019b)
	SC3- Challenge of information disclosure policy between partners in the supply chain.	Supply chain participants might have different privacy needs and different policies related to information and data used in sustainable supply chains and for blockchain technology. Confidentiality, privacy and economic value of data may be concerns.	(Hughes et al., 2019; Pournader et al., 2019; Wang et al., 2019b)
	SC4- Challenges in integrating sustainable practices and blockchain technology through SCM	Combining conventional supply chain processes with sustainability practices and blockchain is challenging. Also, technology, materials and processes development are needed to support sustainable practices. For example, facilities and machines need to be updated to be connected to the internet of things or information gathered from them for blockchain technology and sustainability purposes.	(Govindan et al., 2014; Luthra et al., 2016; Mangla et al., 2017; Morkunas et al., 2019)
	SC5- Cultural differences of supply chain partners	Different geographical or organizational culture of supply chain actors and partners that can impede blockchain technology acceptance.	(Caro et al., 2018; Patel et al., 2017; Wang et al., 2019b)
	E1- Lack of governmental policies		(Biswas and Gupta, 2019; Govindan et al., 2014; Hughes et al., 2019; Kamble et al., 2019c; Mangla

(*continued on next page*)

Table 2 (*continued*)

TOE View	Barrier	Description	Reference
Environmental Context (External view)		Governments might be reluctant to direct blockchain technology adoption and sustainable supply chain practices.	et al., 2017; Morkunas et al., 2019; Wang et al., 2019b)
	E2- Market competition and uncertainty	Applying sustainable practices and blockchain technology is time-consuming. It may affect the market competitiveness of the organization and provide competitive risks. Uncertainty about market demands of sustainable products, customers' behavior and future sales are examples.	(Biswas and Gupta, 2019; Mangla et al., 2017; Wang et al., 2019b)
	E3- Lack of external stakeholders' involvement	Lack of involvement and conflicting objectives of related NGOs and communities to support sustainable practices and blockchain technology.	(Mangla et al., 2017; Wang et al., 2019b)
	E4- Lack of industry involvement in blockchain adoption and ethical and safe practices	Lack of industry leadership in ethical and safe practices in sustainability and blockchain technology.	(Hughes et al., 2019; Luthra et al., 2016)
	E5- Lack of rewards and incentives	Problem in promoting sustainable practices and blockchain technology; or lack of reward systems to ensure the integrity of data and incentivize these practices by government and professional organizations.	(Luthra et al., 2016; Wang et al., 2019b)

negative perception toward technology. Alternatively, academics did not consider T2 as an important and influential barrier.

4.3. Organizational barriers prominence and relationships

Net effects and overall prominence of organizational barriers appear in Fig. 3. Although some nuances are discernible, both academics and practitioners have relatively similar opinions on barrier prominence. Lack of management commitment and support (O2), hesitation to convert to new systems (O6), and lack of knowledge and expertise (O4) are the leading prominent barriers for both academics and practitioners. For academics, the next top three prominent barriers are lack of new organizational policies (O3), difficulty in changing organizational culture (O5), and lack of tools for BC and SSCM (O7), respectively. However, practitioners ordered these latter barriers differently – O5, O7, and O3, respectively.

Lack of management commitment and support has the highest overall organizational barrier prominence and is a significant precursor to the other barriers. Although blockchain has gained notice in the business lexicon, managers may still have limited knowledge on the technology. This lack of knowledge makes managers hesitant to adopt the technology. Blockchain is a disruptive technology and integrating with or replacing their legacy systems with blockchain is likely a major concern. Relatedly, financial constraints, lack of management support, and lack of knowledge and expertise influence hesitation to convert to new systems. A mediated relationship among lack of management commitment and support, lack of knowledge and expertise, and hesitation to convert to new systems is represented in the academic relationship diagram.

Both study groups provide relatively similar pictures for causation relationships. A careful comparison reveals that practitioners highlight that lack of knowledge and expertise may prevent the development of tools and instruments for integrating blockchain and SSCM. In addition, practitioners do not observe a significant relationship between lack of management commitment and support and lack of knowledge and expertise.

Surprisingly, financial constraints, a typical resource barrier in adopting new information systems, has a low relative prominence compared with the other barriers; but this may due to lack of influences on this barrier. It may also suppose that blockchain is perceived to be an inexpensive technology that does not require significant financial resources due to availability of public platforms. However, financial resources still need to be addressed to mitigate other challenges. The other potential relationship that did not appear is the influence of blockchain technology adoption in generating financial returns, but this result is only likely to occur after implementation, when barriers mitigation occurs.

4.4. Supply chain barriers prominence and relationships

Supply chain barriers relationships appear in Fig. 4. Academics suggest that cultural differences of supply chain partners (SC5) affects the other issues in the supply chain category. Alternatively, practitioners posit that lack of customer awareness and tendency (SC1) for adopting blockchain and sustainability significantly influences the other hurdles.

For academics, mediation is observed amongst cultural differences of supply chain partners, challenge of information disclosure policy between partners (SC3), and challenges in integrating SSCM and blockchain technology (SC4). SC5 influences SC3 and SC3 influences SC4. There is also a direct relationship between SC5 and SC4. This mediation effect shows that value systems will drive practices that can impede adoption; whether such mediation exists in blockchain and SSCM calls for further research.

Both academics and practitioners attest that problems in collaboration, communication and coordination in the SCs (SC2), SC3 and SC4 are prominent and important barriers to consider. Practitioners also propose that SC1 is very prominent, even more than SC3.

Overall, problems in collaboration, communication and coordination in the SCs, challenge of information disclosure policy between partners in the SCs and challenges in integrating SSCM and blockchain technology are three barriers with the highest prominence values. Supply chain integration, which can be addressed with blockchain technology and some SSCM practices, can occur only after adoption. This paradox is a major concern.

The prominent barriers are largely influenced by cultural differences of supply chain partners, according to the academics, and lack of customer awareness and tendency, according to practitioners. Cultural differences and lack of customer awareness about the blockchain and SSCM point to the fact that customers and supply chain partners may have different mindsets that impede blockchain integration and transparency in the supply chain. These barriers affect the most important and critical barriers in this category and require significant attention.

4.5. External barriers prominence and relationships

Net effects and overall prominence of external barriers appear in Fig. 5. Academic expert results reveal lack of industry involvement (E4), lack of external stakeholder involvement (E3), and lack of rewards and

Table 3
DEMATEL influence table/matrix for barriers categories.

	Organizational Barriers	Supply Chain Inter-Organizational Barriers	Technological Barriers	External Barriers
Organizational Barriers	0			
Supply Chain Inter-Organizational Barriers		0		
Technological Barriers			0	
External Barriers				0

Table 4
Barriers categories definitions.

Organizational Barriers	Organizational barriers are internal to the organizational boundaries, such as financial constraints, lack of management commitment and support, lack of new organizational policies for using technology, and lack of knowledge and expertise.
Supply Chain Inter-Organizational Barriers	This category mainly includes supply chain partners' relationship barriers. Lack of customers' awareness and tendency about sustainability and blockchain technology, problems in collaboration, communication and coordination in the supply chain, and challenge of information disclosure policy between partners in the supply chain are some examples.
Technological Barriers	This category incorporates technical issues of blockchain technology that impede its application for business purposes, such as security challenge, access to technology, and immaturity of blockchain technology.
External Barriers	External barriers are challenges stemming from governments, industries, institutions, communities, and NGOs, such as lack of governmental policies, market competition and uncertainty, and lack of external stakeholders' involvement.

incentives (E5) as the most prominent external barriers. Practitioners propose that lack of industry involvement (E4), lack of external stakeholder involvement (E3), and lack of governmental policies (E1) are the most prominent barriers. There is some similarity in opinion on these factors.

Both academics and practitioners agree that lack of governmental policies and lack of external stakeholders' involvement influence lack of industry involvement. Academics also propose that lack of rewards and incentives mediates the relationship between E1 and E4.

Overall, lack of external stakeholder involvement and lack of governmental policies for adopting blockchain are the major external barriers requiring adopting blockchain technology for SSCM. Lack of governmental regulations and external stakeholder involvement make industries unwilling to use blockchain technology for sustainability purposes. Stakeholder roles are especially pertinent for many corporate sustainability programs.

5. Discussion and analysis

In this section, we parlay the initial results and findings from our exploratory study into a series of general and specific research propositions. These results not only provide some insights into specific blockchain and SSCM adoption concerns, but also may inform general theoretical perspectives. We attempt to identify consensus patterns, although many nuances do exist throughout these results, in most cases we only present select consensus and harmonious observations.

In our evaluation of the barriers to blockchain adoption for SSCM, we separated the respondents into two major stakeholder groups. We found some significant differences based on initial DEMATEL results. Thus, we were motivated not only to determine absolute relationships amongst the barriers, but to determine why such a divergence occurs. This issue may also relate to the potential disconnect between academic and practitioner world views and how these differences may take research in directions that practitioners may not find useful. The results also portend that different stakeholder groups may view various practical questions, especially, in this case technology adoption, from differing perspectives.

Table 5
Linguistic term and equivalent numerical value for pair-wised comparisons.

Linguistic Term	Numerical Value
None	0
Very Little	1
Moderate	2
High	3
Very High	4

The overall results show academics feel supply chain barriers are most important, while technological issues are prominent for practitioners; although supply chain barriers are not too far behind. The practitioners seem to have a bias toward the technology side of expertise; with lesser supply chain and sustainability experience. Their practical concern is driven by the blockchain technology itself. Alternatively, academics provide a more holistic view that takes into account both blockchain technology, sustainability, and supply chain contexts. Given these divergent perspectives, many instances of similarities remain. Scholars view blockchain as a disruptive technology that can address SSCM complexities and relationships.

Stakeholder theory posits that any entity who is affected by an organization can be a stakeholder (Donaldson and Preston, 1995). According to this theory, the long-term success of a company relies on how well the company would reflect and satisfy the needs of their stakeholders. Stakeholder theory indicates that evaluation of barriers may vary between the groups of decision makers, given heterogeneous perspectives, background, and experience concerning a situation (Zhang et al., 2005). In the present study, academics and practitioners are different stakeholders that have variations in perceived barriers to blockchain technology. Their institutional fields are not completely aligned yet in terms of blockchain and SSCM adoption considerations and barriers. The complexity of concerns increases as SSCM is also incorporated.

Given the TOE framework for barrier categorization in this study; implications arise for this theoretical perspective to understanding technological change and adoption in organizations. Various stakeholder perspectives and expectations do create nuances in TOE and affect the relative relationships of these factors. This relative importance may not only be evident in stakeholder experts but stakeholder users of the technology. Thus, we arrive at a general theoretical Proposition.

Proposition 1. *Stakeholder theory can expand the usability and*

Table 6
Respondent information.

Number	Academic/ Practitioner	Position	Type of Organization/Department	Years of Work Experience/ Research
1	Practitioner	Supply Chain Management Consultant		32
2	Practitioner	Research Fellow	Energy and Climate Policy Institute	13
3	Practitioner	Supply Chain Management Consultant	Food Supply Chain	4
4	Practitioner	Vice President Development Programs and Business Support Services	Financial Institution	12
5	Practitioner	Senior Operations Consultant - CEO	Manufacturing For Heavy Equipment - Blockchain Startup For Supply Chain and Logistics	10
6	Practitioner	Researcher	Sustainable Operations Projects	25
7	Practitioner	Senior Vice President	Sustainability of Forests	30
8	Practitioner	CEO		29
9	Practitioner			
10	Practitioner	Senior Business Control	Strategic Finance	7
11	Practitioner	Consultant	Federal/State Government	24
12	Practitioner	Marketing Director	Container Shipping and Logistics	18
13	Academic	Assistant Professor	Operations Management and Supply Chain Management	3
14	Academic	Assistant Professor		5
15	Academic	Professor		5
16	Academic	Associate Professor		
17	Academic	Assistant Professor with Prior Experience		19
18	Academic	Junior Scholar		
19	Academic	Full Professor		29
20	Academic	Professor	Supply Chain Management	20+
21	Academic	Research Associate	Supply Chain Management	
22	Academic	Junior Scholar		1
23	Academic	Chair Professor	Purchasing and Supply Chain Management	9
24	Academic	Professor and Associate Head	Industrial and Systems Engineering	6
25	Academic	Professor		25
26	Academic	Professor		20
27	Academic	Junior Scholar + practical experience	Environmental Management and Policy	4
28	Academic	Lecturer	Operations Management	1.5
29	Academic	Senior Researcher		5
30	Academic	Junior Scholar		2
31	Academic	Professor	Logistics and Supply Chain Management	20
32	Academic	Senior Lecturer	Operations Management	6
33	Academic	Professor	Business and Management	25
34	Academic	Professor		20
35	Academic	Junior Scholar		4
36	Academic	Assistant Professor with Prior Experience		17
37	Academic	Junior Scholar		10
38	Academic	Professor		22
39	Academic	Professor		15
40	Academic	Professor	Business School	20+
41	Academic	Professor	Freight and Logistics Systems	30
42	Academic	Professor and Director		30+
43	Academic	Professor		20+
44	Academic	Lecturer and Researcher	Supply Chain Management and Logistics	31
45	Academic	Professor and Chair	Logistics	20+
46	Academic	Chair Professor	Operations Management	25
47	Academic	Senior Lecturer		

understanding of the TOE framework. Different stakeholders will perceive underlying factors differently especially in emergent and complex technological and organizational relationships.

The results of this study indicate technological barriers affect the supply chain challenges for adopting blockchain technology for SSCM. Practitioners suggest that technological issues might affect the organizational challenges, which also result in influencing supply chain barriers. There is a mediating effect of organizational barriers between the relationship between technological and supply chain barriers. For example, the immaturity of blockchain technology, which is a technological issue, can be a concern for managers and affect their commitment and support of blockchain technology for their supply chains. Thus, there is a broader technological concern affecting a specific organizational concern, which in turn has implications for the broader inter-organizational acceptance.

Addressing blockchain in SSCM immaturity and characteristic concerns may enhance management organizational support. Management – organizational – support drives inter-organizational collaboration and coordination, especially in the case of internal and external relationships in SSCM environments (Zhu et al., 2012). Therefore, the organizational barriers can have an intervening effect and clarify the relationship between technological and supply chain challenges (Soroor et al., 2009); initial results also point this is especially true in blockchain and supply chain environments (Francisco and Swanson, 2018). We now posit our second Proposition:

Proposition 2. *Organizational barriers mediate the relationship between technological barriers and supply chain barriers in blockchain adoption for sustainable supply chain management.*

The TOE framework argues that accessibility and availability characteristics are important for innovation acceptance (Tornatzky et al., 1990). The results of our analysis show that accessibility to blockchain technology is important. Blockchain accessibility affects the negative perception toward using blockchain, especially in complex SSCM environments. Immaturity and security challenges influence the negative perception toward blockchain technology; especially given the sensitive nature of SSCM information (Hofmann et al., 2014). Technology immaturity and the negative perception toward technology is mediated

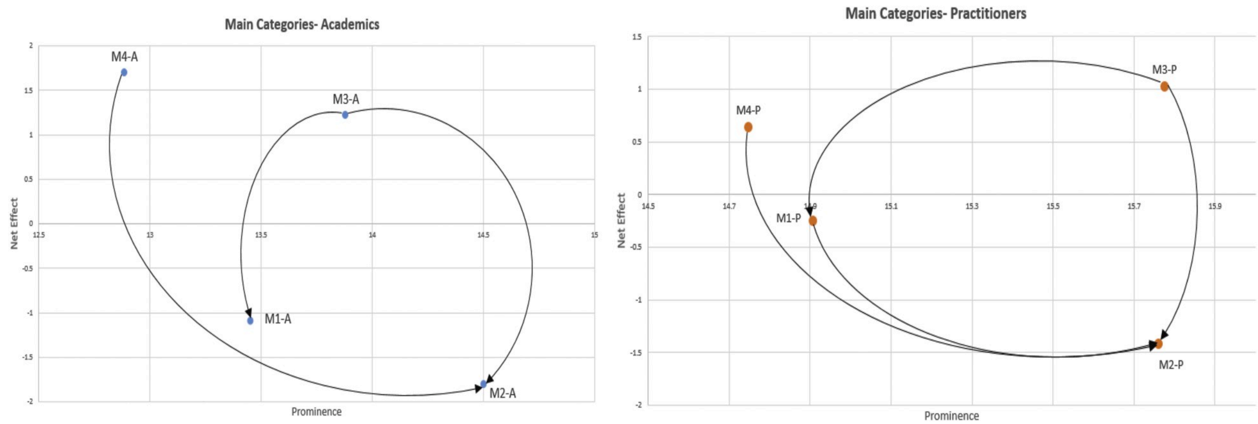

Fig. 1. DEMATEL main barriers categories relationships for academics and practitioners.

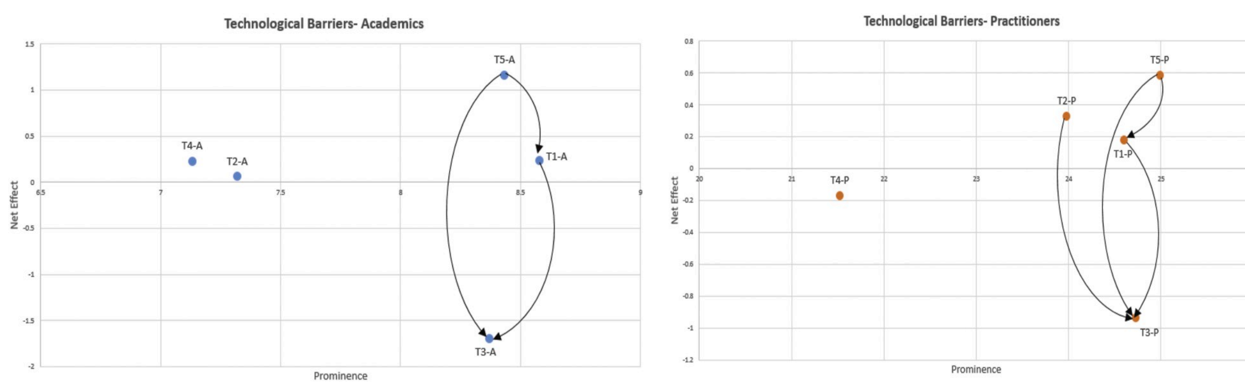

Fig. 2. DEMATEL technological barriers relationships for academics and practitioners.

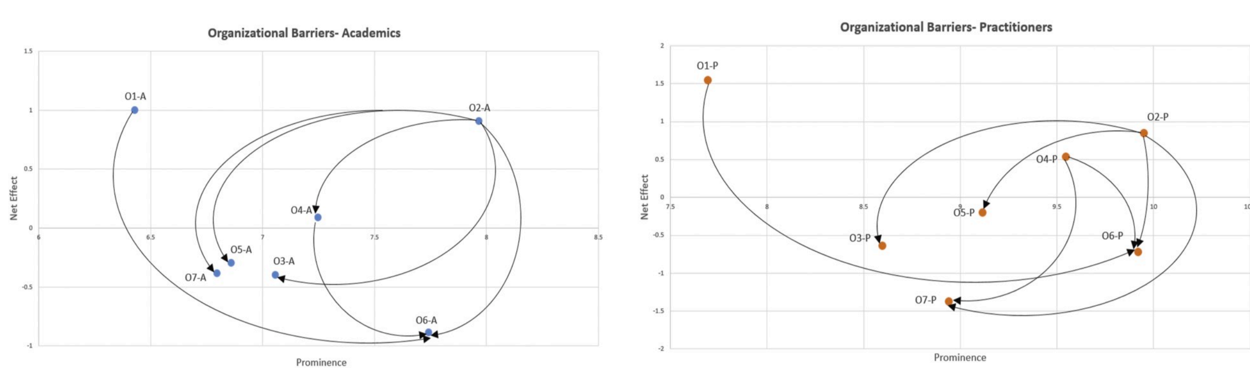

Fig. 3. DEMATEL organizational barriers relationships for academics and practitioners.

by blockchain technology security challenges. Thus, information sharing risk avoidance plays an important aspect in managing adoption barriers. Information sharing risk, given the environment of supportive information sharing for supply chain coordination and collaboration, still requires detailed investigation (Colicchia et al., 2019).

Therefore, to fully address negative blockchain perception, immaturity and security challenges of blockchain both need to be addressed. The technological barriers analysis highlights the presence of interrelationships among the constructs of technological dimension within the TOE framework, including technology accessibility and characteristics. Here we arrive at the third Proposition:

Proposition 3. *- Blockchain and SSCM accessibility is reduced through maturity and security concerns within the technology TOE dimension. Lack of accessibility reduces blockchain in SSCM adoption.*

Lack of management commitment and support, hesitation to convert to new systems, and lack of knowledge and expertise are top three prominenet barriers for both study groups. Companies initially need to address lack of management commitment and support and financial constraints, according to practitioner and academic opinions. These two organizational barriers largely influence the majority of other organizational barriers.

Organizational challenges relate to the resource-based view (RBV) of the organization. RBV proposes that a firm's capabilities stem from its valuable, rare, inimitable, and non-substitutable resources (Barney, 1991). Firms can build competitive advantages through developing their organizational resources and following a path of capabilities development (Dierickx and Cool, 1989). Building organizational knowledge is a central factor in dynamic capabilities. This can help firms survive in a competitive environment (Wu, 2010) and successfully embed new

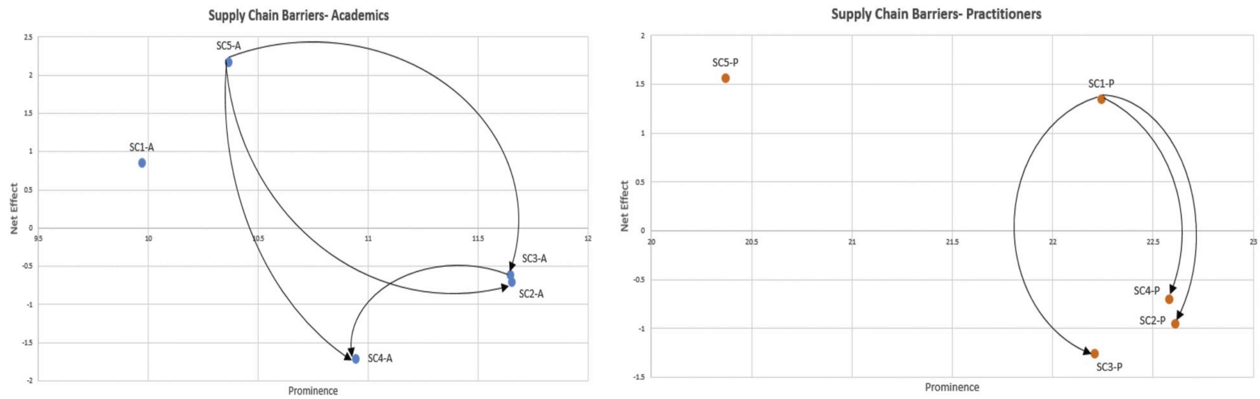

Fig. 4. DEMATEL supply chain barriers relationships for academics and practitioners.

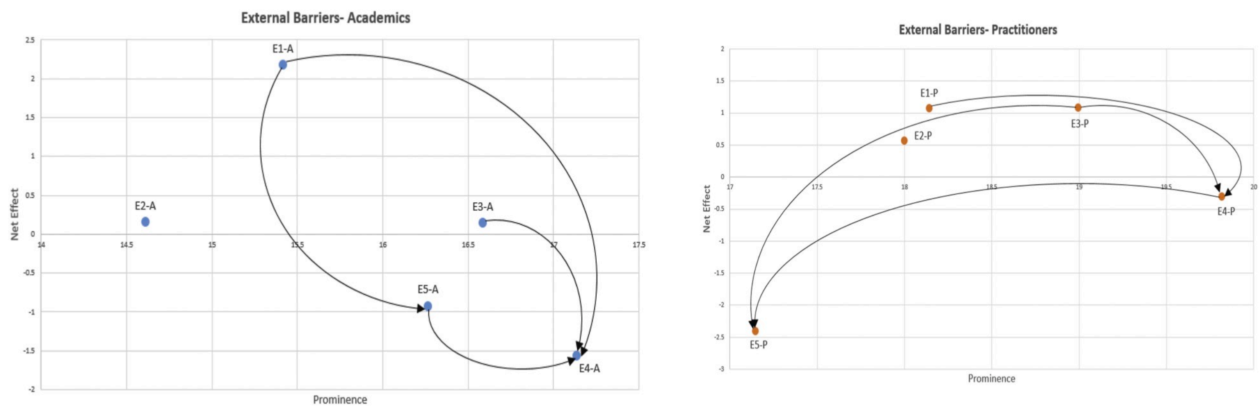

Fig. 5. DEMATEL external barriers relationships for academics and practitioners.

technology.

Financial resources, was seen as less prominent by both academics and practitioners. Financial resources are typically viewed as tangible resources within RBV. Management support and the need for knowledge and expertise are considered intangible resources effecting adoption of blockchain technology for SSCM. These latter resources are important in this context. The results of our analysis show that blockchain and SSCM adoption appears to need more focus on the intangible resources, rather than tangible resource requirements. This focus on the need for intangible resources for building stronger competitive advantages has also been supported by the recent literature e.g. (Kamasak, 2017; Khan et al., 2019; Molloy and Barney, 2015). Here we arrive at the fourth Proposition.

Proposition 4. *- Blockchain adoption in supply chains requires tangible and intangible resources. However, intangible resources play a more important role in successful adoption.*

Supply chain issues include problems in collaboration, communication and coordination and the challenge of information disclosure policy between partners in the supply chains. These elements have the highest prominence values amongst the other supply chain related barriers. Academics suggest that cultural differences of supply chain partners – related to values differences –influences the most prominent barriers in this category. Practitioners highlighted customer perspective as the most influencing factor.

The relational view theory can help explain these supply chain relationship complexities (Borgatti and Cross, 2003; Dyer and Singh, 1998). The relational view suggests that critical resources may extend firm boundaries. Critical resources may be a combination of resources existing in different supply chain partners (Takeishi, 2001). As firms operate within a network of interdependent relationships, the competitive capabilities shift from a firm level to an inter-firm relationship level. The relational view stipulates that a firm's competitive advantages are often inter-linked to the competitive capabilities of the network of relationships. The strength of the links are relational rents.

Information sharing, collaboration, and coordination among supply chain partners for implementing blockchain technology in SSCM are critical factors that can strengthen network organizational capabilities and improve supply chain relational rents. Incorporating customer, and other stakeholder concerns can also help build relational rents. These aspects may be used to build necessary motivations and pressures that can help disconfirm current security and accessibility risk barriers – which, as posited by Lewin's force field theory and theory of change (Lewin, 1947, 1951), can encourage adoption of technology and change. Here we arrive at the fifth Proposition:

Proposition 5. *- Blockchain adoption for sustainable supply chains will positively relate to relational rents and serve as motivation to decrease supply chain barriers. Relational rents are influenced by building sustainability-based relation-specific assets, improved knowledge sharing routines, building complementary sustainable supply chain resources, and embedding effective sustainability governance structures.*

External pressures cause firms to adopt socially responsible practices to gain social legitimacy (Hirsch, 1975). Firms respond to isomorphic institutional pressures by transforming their processes and aligning them with social expectations. Institutional theory can inform how companies address an innovation, e.g. sustainability, from external pressures (Jennings and Zandbergen, 1995).

Three types of isomorphic drivers exist: coercive, normative, and mimetic (DiMaggio and Powell, 1983). First, *coercive isomorphic drivers stem from powerful sources*. Governmental regulations, requirements, and policies for preserving the environment, taxing the environmental damages, and imposing fines are coercive pressure examples. Normative market, consumer, and community pressures drive companies to implement sustainability practices to form legitimization (Ball and Craig, 2010). Mimetic pressures cause companies to imitate competitor success paths and practices (Zhu and Liu, 2010).

External barriers to blockchain technology adoption for sustainability in supply chains can be viewed from an institutional lens; but also represent important pressures based on Lewin's force field theory (Lewin, 1947). Lack of industry involvement in adopting blockchain technology is a critical barrier. Industry involvement in blockchain adoption can be a mimetic pressure that affects successful adoption of blockchain especially for SSCM. For blockchain and sustainability standards to be effective, a critical mass of organizations need to favor adoption (Economides, 1996).

A number of industries have formed consortiums to link companies that seek to adopt blockchain technology. In the automobile industry, BMW, Ford, General Motors, Renault are example companies that have already formed consortiums to apply blockchain technology (Allison, 2018). BiTA[9] is another consortium for blockchain adoption in transportation in which FedEx, UPS, BANSF, and other transportation companies participate. These consortiums have been developed to define the models, standards, and reliable governance structures for utilizing blockchain technology. They also include ethical and sustainability aspects and may be the first motivational pressure to overcome the resistance pressures.

Governmental regulations and pressures are an example of a coercive force, while external stakeholders' involvement like NGOs can be seen as a normative pressure. Lack of governmental regulations and external stakeholders' involvement make industries unwilling to involve in using blockchain. Therefore, in order to increase industry involvement in using blockchain, governments and external stockholders need to support blockchain adoption. Here we arrive at the final Proposition:

Proposition 6. - *In the blockchain technology setting, when companies integrate blockchain in their supply chains, coercive and normative pressures can affect mimetic forces; to overcome resistant forces to adoption of blockchain in SSCM.*

6. Implications and managerial insights

The four different barrier categories investigated in this study for blockchain adoption in sustainable supply chains are initial and exploratory; but, they do provide supply chain managers and decision and policy makers with timely information to initiate addressing obstacles and organizing plans to resolve obstructions related to blockchain technology adoption.

Overall, we found supply chain and technological barriers had the greatest prominence. Our findings are compatible with the latest global blockchain survey from Deloitte (Insights, 2019) in which joining consortia or networks and forming blockchain-based supply chains were identified as the biggest challenges for adopting blockchain technology for supply chains. The result informs managers that they need to recruit partners in their supply chains to have greater and more effective blockchain adoption. Convincing, incentivizing, and finding creative approaches to encouraging partners – both upstream and downstream – to join consortia or co-operate, is necessary. Contractual, preferred selection, and supporting blockchain learning and partner development could be ways to support these adoption efforts.

Both academics and practitioners found that security challenges, a negative perception toward technology, and immaturity of the technology have the highest prominence values and share a mediating relationship. It is evident that risk and acceptance are critical initial concerns for this emergent technology and its application to SSCM. These findings suggest preparing the organization and its partners and employees for blockchain implementation. Blockchain technology application in supply chains typically relies on other technologies – such as the Internet of Things (Kim and Laskowski, 2018) – to track, trace and integrate the information of goods and products flow in the supply chain. This reliance requires aligning internal – legacy – information technology processes, simplifying, and digitizing the processes. It also requires building internal technical expertise before blockchain adoption can occur. Blockchain technology is very immature and needs time for development; for organizations to prepare themselves for security as well. Given the lack of expertise and immature technology, organizations are likely to rely on external technical developers to advance blockchain technology development and solve many of these barriers.

For organizational barriers lack of management commitment and support acts as an important antecedent for other barriers. Defining the blockchain technology value propositions for a supply chain would alleviate the hindrance from upper level management. Overcoming this barrier calls for revisiting the business model and integrating the blockchain values into the current business value Proposition (Morkunas et al., 2019; Nowiński and Kozma, 2017).

For specific supply chain barriers, problems in supply chain collaboration, communication and coordination, information disclosure policy between supply chain partners challenges, and challenges in integrating SSCM and blockchain technology have the highest prominence. These obstacles can be alleviated by developing corporate cultures toward a collaborative ecosystem for technological advancement. Finding the right collaborators to build effective governance structures (Korpela et al., 2017) is necessary for successful adoption of blockchain. Clear disclosure policies, that allow for protection of some proprietary and sensitive information will be necessary. The initial stages of adoption, to enhance greater acceptance, should be sharing less sensitive information, such as good sustainability practices – rather than information on poor or critical sustainability practices. Another approach might be information sharing and collaboration on developmental, continuous improvement, information for better environmental and social practices. These more positive practices and collaborations with this type of information sharing may help more companies gain competitive advantage; building a positive improvement experience from SSCM information sharing using blockchain.

For the external barriers, lack of industry involvement is the most prominent barrier while lack of governmental policies is also a major concern. The result implies that governments can be involved early on in blockchain implementation by encouraging innovations around and investments in blockchain via regulations and flexible policies. Through government support businesses may test markets for new blockchain solutions inside regulatory frameworks for the sake of all user safety (Ølnes et al., 2017). Setting up a blockchain sandbox controlled and managed by governments will create a safe harbor for supply chains to inexpensively demonstrate this technology and provide the opportunity for governments to support change, rather than to react and match to systems established by others. Standards can be cooperatively developed by both industry and government to advance blockchain technology. These areas are currently occurring through groups such as ISO and IEEE; but both are at relatively early stages of setting these blockchain technology standards, many having SSCM implications.

7. Conclusion and future research directions

In this study, we examined blockchain technology application in a sustainable supply chain environment. Blockchain technology enables transparent, secure, decentralized ledgers, smart contracts and reliable networks for sustainable supply chain management. It can improve efficiencies by replacing some intermediaries. Given these potential benefits, the adoption rate of these technologies has not been overwhelming.

We investigated the barriers adoption of blockchain technology for

[9] https://www.bita.studio/.

SSCM. A comprehensive set of barriers were identified based on two theories including TOE and Force Field theories and literature on disruptive technologies and organizational practices such as green and sustainable supply chains. The TOE framework helped inform the categories to include – technological, organizational, and environmental barriers – the latter barrier included supply chain and external barriers. One of main objectives of this study is to understand the relationships and prominence of barriers. To do this we utilized DEMATEL to explore the relationships using inputs from academic and professional experts.

The findings can facilitate decision-making process for policy makers and policy planners involved in this process. The first fundamental outcome of this exploratory study is that we investigated the barriers via causality and prominence. Our study results allow organizations to prioritize effort helping to manage both time and resources.

Secondly, this research develops several propositions suggesting important links between organizational, technological, and external concepts for blockchain adoption. Many of these propositions are informed by various organizational theories including force field, stakeholder, resource-based view, relational and institutional theories. We interpret and extend these theories for organizational change and adoption of blockchain that not only influence an organization, but supply chains as well. The research propositions suggest a number of promising areas for further research inquiry. Thirdly, this is the first work that attempts to systematically investigate and prioritize the barriers to blockchain technology adoption in sustainable supply chains from the lens of two groups of stakeholders.

The limitations commonly associated with exploratory research also apply to our study. We only looked at a snapshot of a convenient sample of respondents. Given the relative novelty of blockchain technology and sustainable supply chains, a broad based study is not feasible when seeking to delve into the level of detail needed for these complex relationships. The differing complementary opinions of academics and practitioners might be related to this nascent technology status, subject to personal opinions of respondents, and/or the characteristics of our respondents. Thus, further and broader longitudinal studies are needed to determine the evolution of these barriers and how much they shift in terms of prominence and relationships. Additional external stakeholders such as governmental regulators and NGOs may provide different valuations and relationships. Longitudinal studies trace the level of blockchain adoption effect on enhancing efficiency, transparency and traceability of sustainable supply chains.

Another future research direction is to consider these factors together rather than as a hierarchy. Exploratory and confirmatory factor analyses can help further validate the identified barrier categories. Comparing the interdependencies of the sub-factors is necessary to further identify more nuances and barriers evaluation. Assigning different weights to the respondent groups and analyzing the sensitivity of the results is another approach that captures the nuances in the results. Lastly, each Proposition suggests promising areas of inquiry for researchers; therefore, empirically investigating the propositions would disclose the hidden projected links between blockchain implementation and four categories of barriers and factors inside each category.

Overall, blockchain technology as an application to SSCM shows promise. However, both these organizational practices are in their infancy. Understanding their roles and management is critical not only for organizational and supply chain competitive advantages, but also for social and environmental benefits overall. There is much more to investigate in this emergent field.

Acknowledgement

This research was funded by grant #227940 from the Association of Supply Chain Management and by grant #19020005 from the Alfred P. Sloan Foundation and the Environmental Law Institute.

Appendix A

This section provides additional detail on the DEMATEL methodology and results.

DEMATEL (Fontela and Gabus, 1976) is an exploratory methodology that aims to develop a structured network that portrays and simplifies the interrelationships and the prominence or strengths of factors under investigation.

DEMATEL methodology forms pairwise comparisons matrices to assess the relationships between the factors. Then, a measurement scale is established to convert the linguistic terms to the numerical values. In this study our measurement scale that was utilized to assess the strength of the relationship between two given factors was divided into 0, 1, 2, 3, and 4, which respectively represented none, very little, little, high, and very high relationship. The following steps form the DEMATEL analysis (Lee et al., 2010):

Step 1- Aggregate results (average) and establish a pairwise direct-relation matrix

A survey instrument composed of matrices and containing pairwise comparisons of the barriers is completed by experts. We aggregated the expert evaluation by calculating the average scores and form aggregate direct relation matrices.

When the number of factors is n, the pairwise comparisons matrix, X, is $n \times n$. Each element within this matrix, x_{ij}, represents the level of the influence of the factor i on a factor j. The influence of each factor on itself that forms the diagonal of the direct-relation matrix is set to zero. A general pairwise direct-relation matrix is presented in expression (E1).

$$X = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & & x_{2n} \\ \vdots & & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \tag{E1}$$

Step 2- Determine the initial influencing matrix (N) by normalizing

The aggregate direct-relation matrix ($\boldsymbol{X}$) is normalized to calculate the initial normalized influence matrix ($\boldsymbol{N}$) using expressions (E2) and (E3) (Wu and Lee, 2007):

$$N = k^{*}X \tag{E2}$$

$$k = \frac{1}{\max\limits_{1 \le i \le n}\left(\sum_{j=1}^{n} x_{ij}\right)} \tag{E3}$$

Step 3- Calculate the total relation matrix (T)

The total relation matrix that determines the relationship between factors can be calculated from expression (E4):

$$T = N + N^2 + N^3 \ldots = \sum_{i=1}^{\infty} N^i = N(I - N)^{-1} \tag{E4}$$

where I is the identity matrix.

The total relation matrices for the academics and practitioners' assessments of the main barriers categories is summarized in Table A-1. The total relation matrices for the academics and practitioners' evaluations of technological barriers, organizational barriers, supply chain barriers, and external barriers are presented in Tables A-2, A-3, A-4, and A-5, respectively.

Step 4- Determine row and column sums from the total relation matrices

Given t_{ij} is the comparison variable of the factor i on the factor j in the total relation matrix, $\boldsymbol{T}$, where $i,j = 1, 2, \ldots$, n, the row (D_i) and column (R_j) sum for each row i and column j can be obtained using expressions (E5) and (E6).

$$D_i = \sum_{j=1}^{n} t_{ij} \quad \forall i \tag{E5}$$

$$R_j = \sum_{i=1}^{n} t_{ij} \quad \forall j \tag{E6}$$

Step 5- Determine the overall prominence and net effect value of factors

The overall prominence (P_i) denotes the overall value that a factor is being influenced by and the influence on other factors. The net effect value (E_i) indicates the difference between the impact that a factor has on others and received by others. P_i and E_i can be calculated, respectively by expressions (E7) and (E8).

$$P_i = \{D_i + R_j | i = j\} \tag{E7}$$

$$E_i = \{D_i - R_j | i = j\} \tag{E8}$$

The overall prominence and net effect values of the main, technological, organizational, supply chain, and external barriers for the two respondent groups are summarized in Table A-6.

Step 6- Draw the DEMATEL prominence/effect diagrams – only mapping those relationships above a threshold value

The last step is the graphical representation for each factor of the calculated prominence and net effect values on a two-dimensional axis. The x-axis represents the prominence value and the y-axis is the net effect value of factors.

The inter-relationships between barriers can be captured by directed arrows. To clarify the visualization, we defined a threshold that sets the cut-off point for relationships between factors. Therefore, those values in the total relation matrix that are greater than the threshold would depict the arrows in the final DEMATEL diagrams. The threshold value θ (Fu et al., 2012) is defined by expression (E9).

$$\theta = mean(T) + SD_T \tag{E9}$$

where average of all t_{ij} values within the total relationship matrix is ($mean(T)$) and the standard deviation of all t_{ij} values is (SD_T). The t_{ij} values that are greater than the θ indicate a significant relationship between the two factors and correspond to arrows on DEMATEL diagrams. Those values that are above the thresholds are highlighted in each of the total relation matrices.

Table A-1
The total-relation matrix for main barriers categories among academics and practitioners

Academics					Practitioners				
	M1-A	M2-A	M3-A	M4-A		M1-P	M2-P	M3-P	M4-P
M1-A	1.478	1.935	1.476	1.289	M1-P	1.653	**2.134**	1.812	1.727
M2-A	1.745	1.705	1.537	1.359	M2-P	1.847	1.834	1.802	1.692
M3-A	**2.066**	**2.302**	1.574	1.606	M3-P	**2.134**	**2.402**	1.844	2.020
M4-A	1.984	**2.213**	1.748	1.343	M4-P	1.945	**2.216**	1.917	1.615

Table A-2
The total-relation matrix for technological barriers among academics and practitioners

Academics						Practitioners					
	T1-A	T2-A	T3-A	T4-A	T5-A		T1-P	T2-P	T3-P	T4-P	T5-P
T1-A	0.766	0.810	**1.168**	0.819	0.844	T1-P	2.367	2.497	**2.681**	2.279	2.564
T2-A	0.795	0.562	0.956	0.654	0.725	T2-P	2.521	2.251	**2.640**	2.223	2.520
T3-A	0.717	0.657	0.702	0.605	0.656	T3-P	2.472	2.402	2.389	2.173	2.459

(continued on next page)

Table A-2 (*continued*)

Academics						Practitioners					
	T1-A	T2-A	T3-A	T4-A	T5-A		T1-P	T2-P	T3-P	T4-P	T5-P
T4-A	0.824	0.676	0.966	0.537	0.677	T4-P	2.216	2.119	2.315	1.813	2.215
T5-A	**1.068**	0.923	**1.240**	0.837	0.732	T5-P	**2.631**	2.555	**2.803**	2.357	2.441

Table A-3
The total-relation matrix for organizational barriers among academics and practitioners

Academics								Practitioners							
	O1-A	O2-A	O3-A	O4-A	O5-A	O6-A	O7-A		O1–P	O2–P	O3–P	O4–P	O5–P	O6–P	O7–P
O1-A	0.326	0.560	0.553	0.543	0.521	**0.654**	0.557	O1–P	0.376	0.675	0.652	0.683	0.658	**0.796**	0.778
O2-A	0.523	0.504	**0.685**	**0.649**	**0.662**	**0.775**	**0.636**	O2–P	0.542	0.649	**0.815**	0.779	**0.820**	**0.922**	**0.874**
O3-A	0.365	0.471	0.400	0.501	0.501	0.596	0.496	O3–P	0.385	0.565	0.486	0.587	0.606	0.687	0.664
O4-A	0.393	0.540	0.566	0.423	0.542	**0.651**	0.551	O4–P	0.483	0.735	0.756	0.598	0.758	**0.857**	**0.854**
O5-A	0.365	0.484	0.510	0.482	0.380	0.591	0.470	O5–P	0.429	0.676	0.676	0.642	0.551	0.759	0.725
O6-A	0.384	0.505	0.526	0.508	0.515	0.476	0.512	O6–P	0.463	0.694	0.686	0.666	0.698	0.646	0.749
O7-A	0.361	0.470	0.491	0.477	0.462	0.573	0.371	O7–P	0.397	0.556	0.548	0.551	0.567	0.650	0.515

Table A-4
The total-relation matrix for supply chain barriers among academics and practitioners

Academics						Practitioners					
	SC1-A	SC2-A	SC3-A	SC4-A	SC5-A		SC1–P	SC2–P	SC3–P	SC4–P	SC5–P
SC1-A	0.787	1.241	1.245	1.290	0.845	SC1–P	2.089	**2.556**	**2.556**	**2.539**	2.053
SC2-A	0.948	1.080	1.285	1.311	0.851	SC2–P	2.093	2.162	2.356	2.340	1.881
SC3-A	0.954	1.305	1.080	**1.327**	0.853	SC3–P	2.011	2.293	2.083	2.265	1.824
SC4-A	0.800	1.083	1.074	0.934	0.728	SC4–P	2.145	2.372	2.364	2.160	1.899
SC5-A	1.072	**1.469**	**1.444**	**1.462**	0.821	SC5–P	2.111	2.396	2.373	2.338	1.747

Table A-5
The total-relation matrix for external barriers among academics and practitioners

Academics						Practitioners					
	E1-A	E2-A	E3-A	E4-A	E5-A		E1-P	E2-P	E3-P	E4-P	E5-P
E1-A	1.323	1.613	1.824	**2.091**	**1.947**	E1-P	1.637	1.857	1.899	**2.131**	2.082
E2-A	1.237	1.212	1.559	1.768	1.607	E2-P	1.759	1.616	1.842	2.072	1.994
E3-A	1.439	1.548	1.563	**1.983**	1.831	E3-P	1.918	1.949	1.797	**2.223**	**2.152**
E4-A	1.338	1.443	1.641	1.654	1.712	E4-P	1.863	1.869	1.950	1.961	**2.111**
E5-A	1.280	1.410	1.635	**1.849**	1.497	E5-P	1.359	1.426	1.469	1.677	1.440

Table A-6
Prominence and net effect values for barriers as evaluated by academics and practitioners

	Academics			Practitioners		
	Barriers	Prominence (Pi)	Net Effect (Ei)	Barriers	Prominence (Pi)	Net Effect (Ei)
Main Barriers Categories	M1-A	13.452	−1.094	M1-P	14.906	−0.252
	M2-A	14.502	−1.808	M2-P	15.761	−1.412
	M3-A	13.882	1.214	M3-P	15.775	1.025
	M4-A	12.886	1.689	M4-P	14.748	0.640
Technological Barriers	T1-A	8.577	0.236	T1-P	24.596	0.181
	T2-A	7.319	0.066	T2-P	23.979	0.330
	T3-A	8.370	−1.697	T3-P	24.723	−0.934
	T4-A	7.131	0.229	T4-P	21.522	−0.166
	T5-A	8.433	1.166	T5-P	24.987	0.588
Organizational Barriers	O1-A	6.432	0.996	O1–P	7.692	1.544
	O2-A	7.969	0.901	O2–P	9.949	0.850
	O3-A	7.059	−0.401	O3–P	8.597	−0.640
	O4-A	7.250	0.084	O4–P	9.546	0.535
	O5-A	6.863	−0.301	O5–P	9.115	−0.197
	O6-A	7.743	−0.890	O6–P	9.920	−0.717
	O7-A	6.798	−0.388	O7–P	8.941	−1.375
Supply Chain Barriers	SC1-A	9.970	0.848	SC1–P	22.243	1.344
	SC2-A	11.653	−0.703	SC2–P	22.609	−0.949
	SC3-A	11.648	−0.609	SC3–P	22.208	−1.257
	SC4-A	10.942	−1.706	SC4–P	22.581	−0.700
	SC5-A	10.366	2.170	SC5–P	20.370	1.561
External Barriers	E1-A	15.415	2.179	E1-P	18.142	1.071

(*continued on next page*)

Table A-6 (*continued*)

	Academics			Practitioners		
	Barriers	Prominence (Pi)	Net Effect (Ei)	Barriers	Prominence (Pi)	Net Effect (Ei)
	E2-A	14.609	0.157	E2-P	18.000	0.568
	E3-A	16.585	0.143	E3-P	18.996	1.081
	E4-A	17.134	−1.557	E4-P	19.818	−0.310
	E5-A	16.264	−0.922	E5-P	17.148	−2.410

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