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Blockchain Technology and the Sustainable Supply Chain: Theoretically Exploring Adoption Barriers

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Abstract

Blockchain technology has gained global interest. Its application to supply chain management has achieved some of the most interest. Sustainability is also an important use case. Overall, the fit, with some necessary improvements, seem quite feasible and can contribute greatly to the application of blockchain technology to sustainable supply chain management. Additionally, the application of this technology holds the promise for billions of dollars in corporate financial savings. Given its promise, the adoption of blockchain technology, although hyped for years, has not seen rapid acceptance. We utilize the technology-organization-environment framework and force field theories to investigate these adoption barriers. Using various literature streams on technology, organizational practices, and sustainability, we provide a comprehensive overview of barriers for adopting blockchain technology to manage sustainable supply chains. We explore the barriers using technology, organizational, and environmental – supply chain and external – framework. This exploratory study includes relative importance and interrelationships of barriers. Understanding these aspects may parlay what is necessary, theoretically and practically, for further adoption and dissemination of blockchain technology in a sustainable supply chain environment. This paper builds a deeper foundation for blockchain technology research. 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; analyzing inputs from a variety of respondents familiar with supply chains and/or blockchain technology.

Keyword: Supply Chain Management, Sustainability, Blockchain, Barrier Analysis, DEMATEL, Technology-Organization-Environment framework

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1. Introduction

Blockchain has emerged as a potentially disruptive technology. 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 & Lakhani, 2017). There are many blockchain use applications, one of the foremost is sustainability of supply chains (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 & Enz, 2017). This complexity makes it difficult to make efficient transactions, trace products and data, and assess this information (Ivanov et al., 2019).

Blockchain is a decentralized ledger of transactions also known as a peer-to-peer system. It is comprised of a network of nodes maintaining a set of shared historical transactions. The transactions within the system are each agreed upon on – the transactions are all verified by participant consensus. The information is secure, traceable and auditable (Swan, 2015). Blockchains are compose of 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). Globally, organizations seek to take advantage of these characteristics. Distributed consensus, secure, traceable, verified, and transparent information are all critical characteristics (Crosby et al., 2016).

Supply chain sustainability has increased in importance over the past three decades. 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 chain. For example, there is the Business Social Compliance Initiative database that certifies audits of supplier sustainability. But these systems are voluntary databases which means that their credibility and validity can be questioned (Kouhizadeh & 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 case of Maersk (Popper & Lohr, 2017), Provenance (Baker & Steiner, 2015), and Walmart (Kshetri, 2018). Some organizations use it for food safety, as in the case of Chipotle Mexican Grill (Casey & Wong, 2017). Minimizing counterfeit products has also been a goal of some blockchain applications (Fernández-Caramés & Fraga-Lamas, 2018; Singh & Singh, 2016). These examples are for safety, security, and environmentally sound supply chain practices, all of which are elements of supply chain sustainability.

New technology has both upsides and downsides. 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. These are only sustainability downsides, but as we shall see in our article there are many other barriers that exist for the adoption of this technology from a SSCM perspective.

Even with the promises of blockchain technology, the adoption has been slow. Most of the use cases discussed in the literature is 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.

This paper is one of the first to broadly investigate blockchain technology and adoption for SSCM barriers. Addressing all barriers simultaneously is practically infeasible, 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. A series of research propositions from this exploratory research is developed. 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.

For the remainder of this paper, in Section 2 we review the literature relating to 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, which presents a number of theoretical and research propositions. The paper concludes with a summary of findings, study limitations, and future research directions in Section 6.

2. Background

2.1. The Case for Blockchains 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 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 types of blockchain technology (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 blockchains. 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 can be instrumental in changing how we see sustainability 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). They can also be used for blockchain enabled emissions trading schemes and carbon trading (Fu et al., 2018). Blockchains can reduce information assymetries 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 could affect the triple-bottom-line sustainability apart from supply chain applications (e.g. see Kouhizadeh & Sarkis, 2018; Kouhizadeh et al., 2019).

2.2. 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).

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 the second theoretical framework for this study, in addition to TOE theory. The barriers and challenges that obstruct successful adoption of blockchains within SSCM represent strong forces to stop change.

The literature identifies and explores barriers for adopting various supply chain management innovations. Effective supply chain management (Fawcett et al., 2008); sustainable practices (Chkanikova & Mont, 2015; Gold et al., 2017; Gorane & Kant, 2015; Govindan & Hasanagic, 2018; Movahedipour et al., 2017; Sajjad et al., 2015); circular economy (Mangla et al., 2018; Tura et al., 2019); and information systems (Jharkharia & Shankar, 2005; Peng & Nunes, 2010) practices are examples of supply chain innovations facing barriers.

Many of these studies utilized DEMATEL methodology for investigating supply chain innovation adoption barriers (Dinh et al., 2018; Iansiti & Lakhani, 2017; Kaur et al., 2018). However, these studies were atheoretical – with deficiencies in theoretical frameworks as a foundation for barrier analyses. Force field theory provides a clear organizational barriers theoretical framework that incorporates motivations and barriers for adopting innovations.

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., 2010; Fawcett et al., 2008). 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 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 being used as the fundamentals of 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). But 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 & 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.

2.3. 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 understand these challenges and plan accordingly.

In this section, we utilize the TOE theoretical lens (Baker, 2012; Oliveira & Martins, 2011; Tornatzky et al., 1990) to identify various challenges and barriers for blockchain technology adoption, especially within the SSCM context. The blockchain barriers are technological (T), organizational (O), and environmental (E) barriers. The first two groups of factors are endogenous to the technology or organizations. The latter includes two environmentally exogenous dimensions including inter-organizational barriers, and a broad category of external to supply chain and organization barriers.

The technological barriers will include basic challenges that are present with blockchain technology like security, accessibility and immaturity of technology. Organizational dimensions will 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 and definitions. These experts are active in the blockchain-supported supply chain area.

Table 1 summarize the TOE elements and the underlying barriers. The four barrier dimensions we now present consider both general and SSCM issues that may arise.

2.3.1. 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. Their immaturity creates technical challenges including scalability, usability, interoperability (Casino et al., 2018; Swan, 2015; Yli-Huumo et al., 2016). Blockchain has been initially 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 blockchains (Yli-Huumo et al., 2016).

There are also blockchain accessibility concerns; is the IT infrastructure accessible for all blockchain participants (Abeyratne & 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 & Kant, 2015).

The blockchain technology has an inherent characteristic of security (Saberi et al., 2019b). Particularly the security and distribution characteristics of blockchain technology contributes to its 'trustless' environment (Crosby et al., 2016). But, the security issue is still a concern. The technology is still vulnerable to insider attacks potentially hampering network security (Meng et al., 2018). Blockchain is vulnerable to a 51% attack allowing a single entity to have command over majority of the network (Yli-Huumo et al., 2016). In terms of the supply chain involving multitudes of participants, these attacks could easily bring down the system.

The blockchain technology is an immature technology (Mougayar, 2016). Speed of transaction is currently slower than some traditional systems. For example, for cryptocurrency exchanges, it takes 10 minutes to sufficiently secure a transaction -- for Bitcoin – when compared to traditional credit card systems that take a few seconds. The technology suffers from the issues like scalability and handling of large number of transactions which could put a limit on the data storage and bandwidth (Yli-Huumo et al., 2016).

Alongside these scalability limitations 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 mean that implementation of blockchains 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 makes it extremely difficult to manage.

Data immutability is one of the characteristics of the blockchain technology. Immutability means the data or the information is unchanged. The issue is even with the ability to change and update the data and errors within the records are permanent, as they will continue to live with the blockchain (Palombini, 2017). Thus, even 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 views also has a perception, 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.

2.3.2. Organizational Barriers

The organizational context encompasses factors and issues related to internal focal firm concerns. Example organizational barriers may include financial constraints, lack of management support, lack of new organizational technology policies, and lack of knowledge and expertise.

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 impact the organization. Also, 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 organization there is a lack of comprehensive blockchain understanding impeding its implementation (Mougayar, 2016). Adding the need to more 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 chain due to lack of standardization (Morkunas et al., 2019). Internal organizational changes for new standards, both blockchain and in sustainability, leads to difficulty in establishing connections via blockchain between firms as the systems vary in architecture from each other. These barriers are further evaluated in the next section.

2.3.3. Environmental Barriers – The Supply Chain Inter-Organizational View

The environmental context contains 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 focusses on institutional factors, in this study we utilize a broader perspective that incorporates relation-specific issues in the supply chain across organizations.

Supply chain barriers include supply chain entity relationship challenges. Lack of customer awareness and tendencies concerning sustainability and blockchain technology, problems in collaboration, communication and coordination in the supply chain, and conflict of information disclosure policy between partners in the supply chain, are some examples.

The most challenging dimension of supply chain concerns arises at the nexus of technical and sustainable practices supply chain integration. Customers' lack of awareness and tendency 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 & Handfield, 2019). Organizations often lack the knowledge on sustainability and in turn 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 & Talluri, 2004; Sayogo et al., 2015). Organizations are skeptical about sharing their information as they see information as a competitive edge (Wang et al., 2019). 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 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 & Zhu, 2018). Organizations are slow to respond to improving sustainable performance due to absence of resources (Govindan et al., 2014).

Due to 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.

2.3.4. 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 stakeholders' involvement in adopting sustainability and blockchains 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 which further impedes the move towards blockchain systems and sustainability. Governmental incentives to support the adoption of sustainable practices (Govindan et al., 2014) may be substantial barrier, organizations seeking to embrace blockchain technology may see the lack of additional supporting incentives barrier especially true for smaller and distributed suppliers in less developed countries.

Governments, acting as public agents, seek ethical and safe practices (Luthra et al., 2016), which have furthered the adoption of sustainable practices and blockchains 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; Mangla et al., 2018) further impeding the need for blockchain technology. Whether the blockchain technology can contribute to economic sustainability, profitability, is a concern.

For clearer understanding for successful implementation of the blockchain in SSCM, it is important to search these barriers and interactions. The research here 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. Methodology

An initial list of barriers from the academic literature appears in Table 1. The TOE framework was used to group the factors; as described in the previous section. The list of barriers and the identified categories were further examined, refined, and confirmed by six experts from the supply chain management field who were also involved in blockchain technology research projects. A DEMATEL – Decision Making Trial and Evaluation Laboratory (Fontela & Gabus, 1976) – survey captures inputs using pair-wise comparison matrices composed of barriers at the general and more specific level. Each matrix includes between four to seven factors. This smaller set of factors and multiple matrices helps keeps DEMATEL data acquisition more tractable for data gathering. In this way a hierarchical matrix factor set was used; with the general factor groups representing the highest level and the sub-matrices representing each general factor grouping. This process allowed for a clearer approach, with less fatigue, for respondents to fill out the surveys. The major factors and the sub-factors were each clearly defined for participants.

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 DEMATEL methodology and the calculations appear in the Appendix.

DEMATEL appears in numerous research investigations related to sustainability 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), strategic competitive advantage (Wu et al., 2017), and business process management (Bai & Sarkis, 2013).

A recent study, utilizing some aspects of DEMATEL, evaluates the relationship among the enablers of blockchain technology in the agriculture supply chain (Kamble et al., 2019b). Another study applies DEMATEL to find the interrelationships among the barriers to adopting blockchain technology in industry and service sectors (Biswas & Gupta, 2019). The barriers identified in this study did not include blockchain adoption in the supply chain domain. This study focused more on external and system issues in a public blockchain setting and cryptocurrencies. Although both studies can inform our study, their perspective evaluations do not capture private blockchains 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 scholars and practitioners. How these study groups perceive the barriers, similarities and differences in their observations and evaluations are explored in our study.

The DEMATEL-based analysis in our study further differentiates from previous studies due to a theoretical focus for barriers analysis and introducing force field theory as an explanatory theoretical lens. Adding theoretical underpinnings is lacking in many previous DEMATEL studies that look for practical relationships amongst factors. The present 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 for further study as a goal.

3.1. Sample and Participant Information

Experts in blockchain and SSCN were invited to participate in this study. 47 responses were obtained. Our major respondents were represented from academia (35) and practice (12). A linguistic scale was utilized to convert the strengths of the influence relationships amongst factors to a numerical scale (see Table 2).

Table 2- 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

4. DEMATEL Results

The resulting outputs of the DEMATEL methodology are relationship diagrams. The x-axis presents prominence values and y-axis shows the net influencing 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.

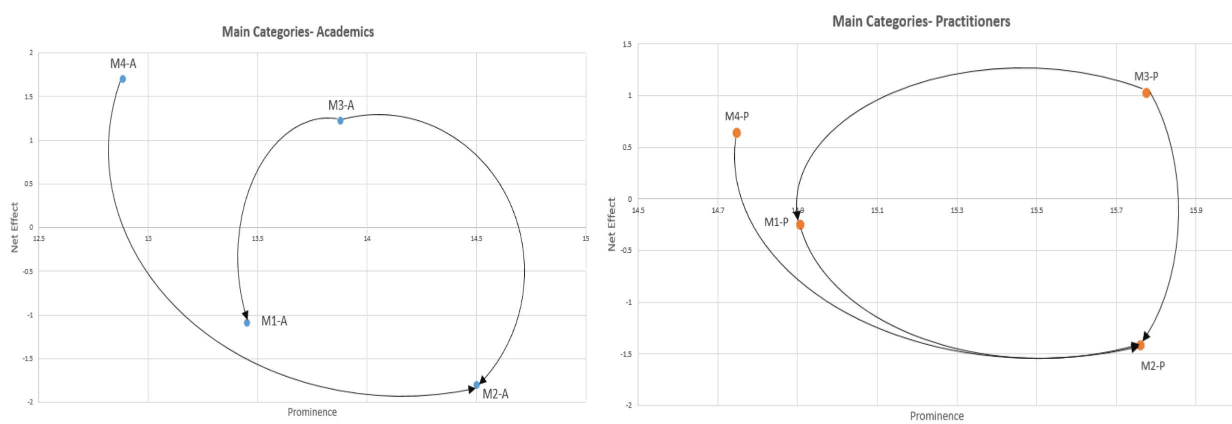
Two major respondent groups evaluated the barriers; academics and practitioners. To determine if the main categories -- barrier groupings -- had different perspectives we separated the responses and completed the aggregated DEMATEL for each group. We compared the barrier outcome rankings for the twenty-two barriers that fell over the four groups. The prominence score for each barrier, 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. 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. 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 Figure 1). The connecting arrows only include relationships between the main categories that met the threshold value.

Figure 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 impacts supply chain barriers and organizational barriers (M1). Supply chain barriers are affected by external barriers (M4) as well.

Figure 1- DEMATEL main barriers categories relationships for academics and practitioners



M1: Organizational barriers; M2: Supply chain barriers; M3: Technological barriers; M4: External barriers;

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:

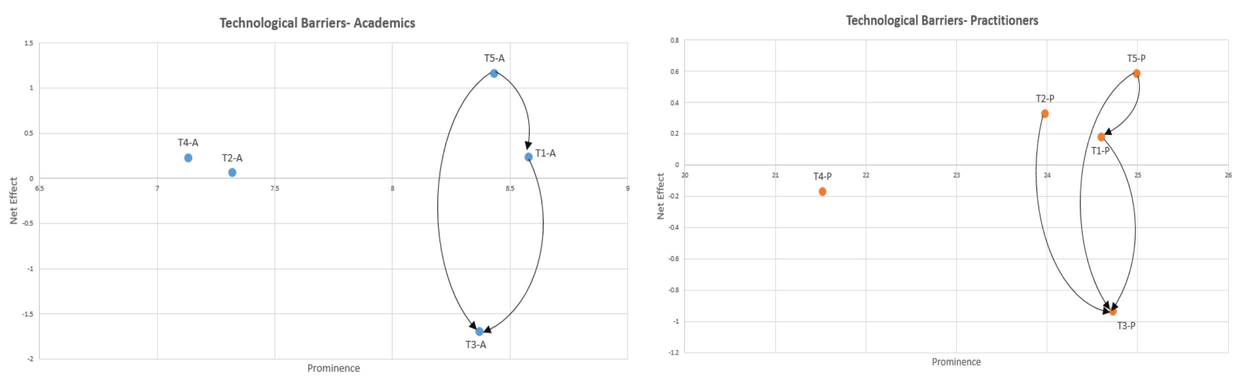
- Supply chain and technological barriers are the barrier categories with highest prominence and may require special attention.
- Technological barriers and external barriers need to be initially addressed to harness supply chain obstacles for adopting blockchain in SSCM.
- Technological barriers require 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 Figure 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 negative perception toward technology. Alternatively, academics did not consider T2 as an important and influential barrier.

Figure 2- DEMATEL technological barriers relationships for academics and practitioners



T1: Security challenge; T2: Access to technology; T3: The negative perception toward technology; T4: Immutability challenge of technology; T5: Immaturity of technology;

4.3. Organizational Barriers Prominence and Relationships

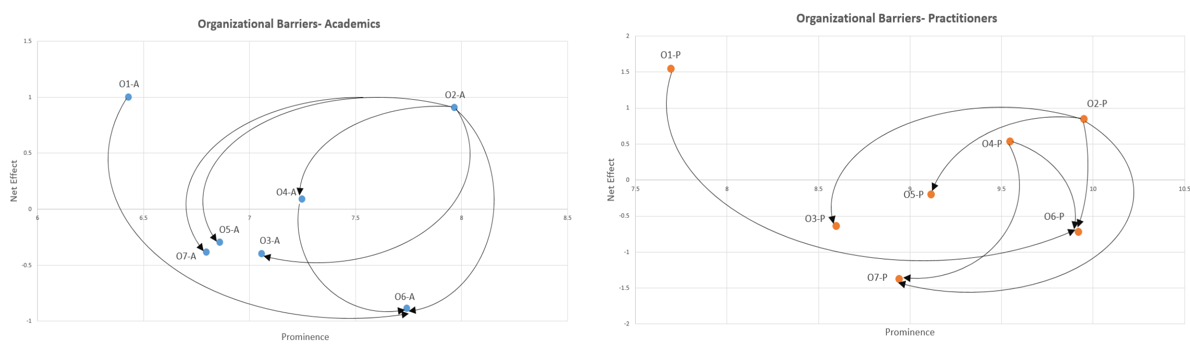
Net effects and overall prominence of organizational barriers appear in Figure 3. Although some nuances are discernable, both academics and practitioners have relatively similar opinions on barrier prominence. Lack of management commitment and support (O2), hesitation to convert to new systems (O6), 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 on the technology. This lack of knowledge makes managers hesitant to adopt the technology. Blockchain is a disruptive technology and integrating with or replace 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. Also, 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 in 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.

Figure 3- DEMATEL organizational barriers relationships for academics and practitioners



O1: Financial constraints; O2: Lack of management commitment and support; O3: Lack of new organizational policies; O4: Lack of knowledge and expertise; O5: Difficulty in changing organizational culture; O6: Hesitation to convert to new systems; O7: Lack of tools for BC and SSCM;

4.4. Supply Chain Barriers Prominence and Relationships

Supply chain barriers relationships appear in Figure 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

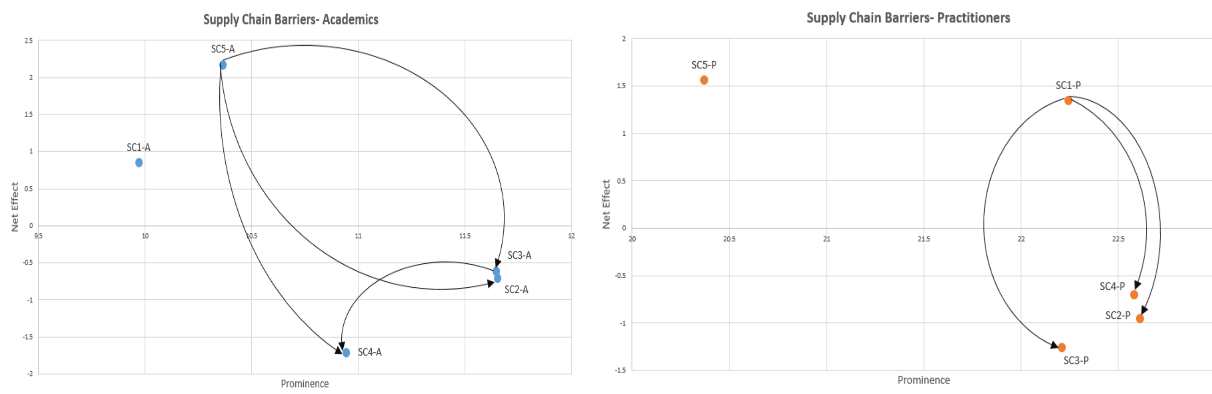
SSCM and blockchain technology (SC4). SC5 influences SC3 and SC3 influences SC4. There is also a direct relationship between SC5 and SC4. This mediation effect shows that value systems will drive practices that can impede adoption; whether such mediation in blockchain and SSCM calls for further research.

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 customers' awareness and tendency, according to practitioners. Cultural differences and lack of customers' awareness about the blockchain and SSCM point out to the fact that customers and supply chain partners may have different mindsets that impede blockchain integration and transparency in the supply chains. These barriers affect the most important and critical barriers in this category and require significant attention.

Figure 4- DEMATEL supply chain barriers relationships for academics and practitioners



SC1: Lack of customers' awareness and tendency; SC2: Problems in collaboration, communication and coordination in the supply chains; SC3: Challenge of information disclosure policy between partners in the supply chains; SC4: Challenges in integrating SSCM and blockchain technology; SC5: Cultural differences of supply chain partners;

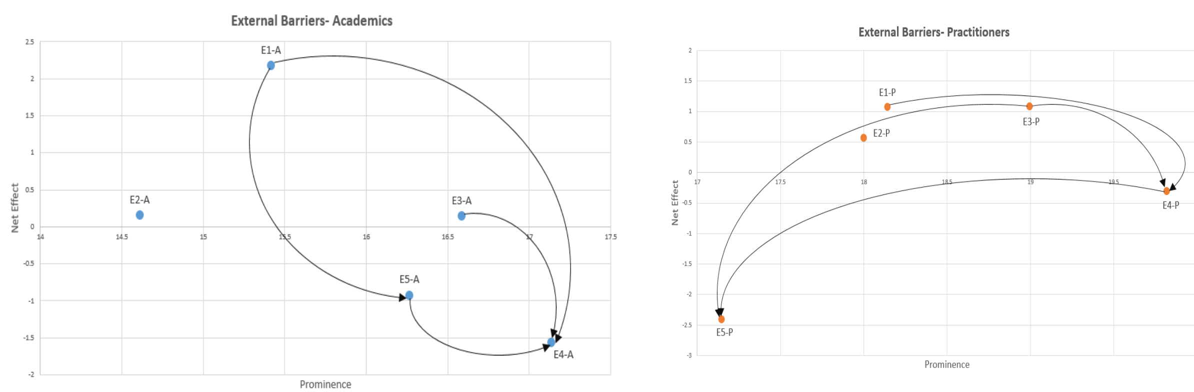
4.5. External Barriers Prominence and Relationships

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

Figure 5- DEMATEL external barriers relationships for academics and practitioners



E1: Lack of governmental policies; E2: Market competition and uncertainty; E3: Lack of external stakeholders' involvement; E4: Lack of industry involvement; E5: Lack of rewards and incentives;

5. Discussion and Analysis

In this section we parlay the initial results and findings from our 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 potential disconnects 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.

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, there still were many instances of similarities. Scholars view blockchain as a disruptive technology that can address SSCM complexities and relationships.

Stakeholder theory posits that any entity who is affected by a company can be a stakeholder (Donaldson & 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 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 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 utilizing in 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 & 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 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 inter-relationships 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 practitioners and academics' 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 & 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 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 & 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 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 & Cross, 2003; Dyer & 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 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 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 & Zandbergen, 1995).

Three types of isomorphic drivers exist: coercive, normative, and mimetic (DiMaggio & 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 & Craig, 2010). Mimetic pressures cause companies to imitate competitor success paths and practices (Zhu & 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[4] 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:

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

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 blockchains in SSCM.

6. Conclusion and Future Research Directions

In this study we examined blockchain technology application in a sustainable supply chain environment. Blockchain technology enable 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.

Thus we investigated the barriers adoption of blockchain technology for SSCM. A comprehensive set of barriers were identified based on various theories and literature whose focus was on disruptive technologies and organizational practices such as green and sustainable supply chains. The Technology-Organization-Environment framework helped inform the categories to include: technological, organizational, and environmental barriers – this latter barrier included supply chain and external barriers.

We wanted 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.

These findings can facilitate decision-making process for policy makers and policy planners involved in this process. The fundamental outcome of this exploratory study is that we investigated the barriers via causality and prominence. Organizations can prioritize efforts on specific barriers both in terms of time and resources. There are a number of managerial implications on which of the prominent general and specific barriers to focus on.

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 theory. We interpret and extend these theories to organizational change and adoption of technologies 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.

Overall, we found that both the supply chain view and technological barriers had the highest prominence. Within the technological barriers for both academics and practitioners, we found that security challenge, the negative perception toward technology, and immaturity of technology have the highest prominence values and share a mediating relationship. It is evident that risk and acceptance are critical initial concerns in this emergent technology and its application to SSCM.

For organizational barriers lack of management commitment and support acts as an important antecedent for other barriers. For supply chain barriers, problems in collaboration, communication and coordination in the supply chains, along with challenge in information disclosure policy between supply chain partners, and challenges in integrating SSCM and blockchain technology have the highest prominence.

For the external barriers, it was found that lack of industry involvement is the most prominent barrier while lack of governmental policies is also a major effective one. Overall, the implications of these barriers are pretty evident. Governmental and industry standardization is needed to take advantage of the potential blockchain benefits for SSCM.

This study is exploratory and thus has numerous limitations. These limitations set the foundation for additional research that can extend this 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.

Another future research direction is to consider these factors together rather than as a hierarchy. Comparing the interdependencies of the sub-factors is necessary to further identify more nuances and barriers evaluation.

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. But, 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.

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Table 1- TOE framework and blockchain barriers in sustainable supply chains

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.	(Casino et al., 2018; Hou, 2017; Sayogo et al., 2015; 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 & 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.	(Kamble et al., 2019a; Kamble et al., 2019b; Palombini, 2017)
	T5- Immaturity of technology	Challenge of scalability of blockchain is an example technical issue that stem from immaturity of blockchains. 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.	(Hackius & 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; Govindan et al., 2014; Hughes et al., 2019; Marsal-Llacuna, 2018; Sayogo et al., 2015)
	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 & 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)
	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 & 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.	(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 & 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.	(Caro et al., 2018; Gorane & Kant, 2015; Kamble et al., 2019b; Kshetri, 2018; Mangla et al., 2017)
	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; Sayogo et al., 2015; Wang et al., 2019)
	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	(Govindan et al., 2014; Luthra et al., 2016; Mangla et al., 2017; Morkunas et al., 2019)

		things or information gathered from them for blockchain technology and sustainability purposes.	
	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; Sajjad et al., 2015; Wang et al., 2019)
Environmental Context (External view)	E1- Lack of governmental policies	Governments might be reluctant to direct blockchain technology adoption and sustainable supply chain practices.	(Govindan et al., 2014; Hughes et al., 2019; Kamble et al., 2019b; Mangla et al., 2017; Morkunas et al., 2019)
	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.	(Govindan et al., 2014; Mangla et al., 2017; Wang et al., 2019)
	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., 2019)
	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., 2019)

APPENDIX

Additional Detail on the DEMATEL Methodology and Results

DEMATEL methodology was initially introduced at the Battelle Memorial Institute of Geneva Research Center (Gabus & Fontela, 1973). DEMATEL is a methodology that explores the causal dependency structure among a set of identified factors. DEMATEL methodology utilizes pairwise comparisons to visualize direct and indirect relationships among factors/variables.

DEMATEL 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. Given the novelty of blockchain technology and the scarcity in actual blockchain implementation for sustainable supply chain management that limit a broad based study, we selected a convenience sample of respondents that includes academics and practitioners knowledgeable in blockchain and sustainable supply chains.

Similar to the many other decision-making methods, the factors should be defined, either through the literature or brain-storming and expert insights. We Identified barriers through a comprehensive literature review and further confirmation from the experts.

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).

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

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

The aggregate direct-relation matrix (***X***) is normalized to calculate the initial normalized influence matrix (***N***) using expressions (E2) and (E3) (Wu & Lee, 2007):

$$N = k * X \quad \text{(E2)}$$

$$k = \frac{1}{\max_{1 \le i \le n}\left(\sum_{j=1}^{n} x_{ij}\right)} \quad \text{(E3)}$$

Step 3- Calculate the total relation matrix (T)

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

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

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, ***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).

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

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

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
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
	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