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Blockchain technology in the supply chain: An integrated theoretical perspective of organizational adoption

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A R T I C L E I N F O

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A B S T R A C T

Blockchain technology has been growing in importance and acceptability over the past few years. Yet, there is limited empirical research on the organizational and technology specific factors that play a critical role in driving its adoption in the supply chain. The purpose of this paper is to develop a comprehensive framework for blockchain adoption in the supply chain by identifying the enablers and empirically evaluating their interdependencies and impact on adoption. 20 enablers of blockchain adoption in the supply chain are identified using an extensive literature review and theoretical lenses from the Diffusion of Innovation (DOI) theory and the business technology adoption model developed by Iacovou, Benbassat and Dexter (1995). In the confirmatory phase, we employ the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to extract logic from data collected from 37 French experts about the impact of the enablers and their interdependencies. Our paper extends the multi-theoretic empirical studies to blockchain technology and identifies the enablers of blockchain adoption from technological, organizational, supply chain and external environment perspectives. Regarding the importance of the categories of enablers, we find that the relative advantage of the technology and the external pressure are the most prominent categories of enablers that impact blockchain adoption in the supply chain. Our analysis also shows the important causal role on adoption of the potential of blockchain to reduce transaction cost, the consumer interest in traceability data and the establishment of a regulatory framework for blockchain usage.

1. Introduction

Blockchain technology has recently gained importance as a promising technology in the area of supply chain management. For instance, Maersk used an IBM blockchain solution to efficiently track its containers around the world (Popper and Lohr, 2017). Catina Volpone vineyard (www.cantinavolpone.it) in Puglia, Italy and Ernst and Young's EZ Lab (www.ezlab.it) developed a blockchain-based solution that enables full transparency through the wine supply chain and allows customers to access information about the harvesting, pressing, and bottling dates and conditions, among many other details for each bottle or case of wine (Montecchi et al., 2019). Similarly, Walmart and IBM have successfully implemented a blockchain-based solution for tracking pork products in China with a farm-to-table approach, providing transparency and full information about the supply chain stages every individual product went through (Yiannas, 2017). Blockchain solutions providers such as Everledger (everledger.io), Provenance (provenance.org), Bext360 (bext360.com) conducted pilot projects and offered typical use cases that demonstrate blockchain potential in verifying and certifying the origin, authenticity and integrity of products such as diamond, wine buttles, luxury fashion, coffee beans, and medicines (Kshetri, 2018; Montecchi et al., 2019; Lacity, 2018; Tönnissen and Teuteberg, 2020). Enabling traceability, enhancing transparency and establishing product provenance as shown in the above examples are not the only benefits of using blockchain technology. Indeed, blockchain is a distributed ledger (database) through which supply chain partners can interact and create, verify, validate, and securely store various kinds of records such as product information, certificates, localization data, transaction records, data acquired from sensors and other connected devices (Crosby et al., 2016; Iansiti and Lakhani, 2017). Thus, in addition to providing traceability and making the whole history of products digitally available, blockchain promises to improve supply chain coordination and process efficiency (Kshetri, 2018; Babich and Hilary, 2020; Queiroz et al., 2020; Wamba et al., 2020) and to achieve

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supply chain sustainability goals (Casey and Wong, 2017; Kouhizadeh and Sarkis, 2018; Kshetri, 2018; Babich and Hilary, 2020).

Despite the promises and the enormous potential of blockchain technology, its adoption in supply chains is still underexplored. Few studies address this question, offering a fragmented view of adoption's enablers. Our objective in this research is to further investigate blockchain adoption in supply chains, develop a comprehensive framework for adoption enablers, measure their level of influence and understand their mutual relationships. Our work answers the following questions:

RQ1: What are the enablers of blockchain technology adoption in the supply chain?
RQ2: What are the levels of influence of the identified enablers on the adoption decision?
RQ3: How do the enablers interact and influence each other?

We base our study on an integrative theoretical approach that combines the Diffusion of Innovation (DoI) theory (Rogers, 2010) and the business technology adoption model developed in Iacovou, Benbasat and Dexter (1995). The choice of these theoretical lenses allows us to extend the technology adoption framework to include factors related to the technology itself, the organization at both the firm and the supply chain levels, and the environment. As for the empirical investigation, we use the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology (Gabus and Fontela, 1972) to analyze data collected from experts in supply chain or IT management working in France. DEMATEL is very appropriate for our purpose because it is designed for modeling relationships and interdependencies between a large number of factors and evaluating their impact.

Our paper provides both theoretical and practical contributions that improve our understanding of the enablers of blockchain adoption in supply chains and offer guidance to managers and policymakers on how they can best direct their efforts to enhance adoption. From the theory perspective, our work is the first effort to provide an extensive list of enabling factors of blockchain adoption in supply chains, evaluate their effects and map their interdependencies. It also adds contribution to the very limited body of research that uses a multi-theoretic framework to establish the theoretical context of blockchain technology adoption for the supply chain management. Our study also contributes to the practice by providing an evaluation of the importance of the enablers of blockchain adoption in the supply chain and by analyzing their interdependencies. Managers and policymakers may use the results and insights from this study to inform their decisions and action plans for blockchain adoption in their supply chains.

The remainder of this paper is structured as follows. In Section 2, we provide an overview of the literature on blockchain technology applications in supply chain management and its adoption. In Section 3, we develop a theoretical framework for considering blockchain adoption in supply chains and identify the enablers of adoption from the literature. Research methodology and data collection are presented in Section 4. The results obtained are presented and discussed in Section 5. Then, Section 6 presents implications and managerial insights from our study, and Section 7 conclude the paper.

2. Background

2.1. Blockchain technology

Blockchain technology can be defined as a peer-to-peer network technology that is used to build and maintain distributed ledgers or databases of records (Crosby et al., 2016; Iansiti and Lakhani, 2017). Parties participating in a blockchain (firms, institutions, individuals, etc.) can interact with each other and create all kinds of records (product information, certificates, localization data, transaction records, data acquired from sensors, etc.). Before being stored on the blockchain, records are verified and validated using specific *consensus* mechanisms (Crosby et al., 2016). Then, records are combined to form a block of data that is linked with previous blocks to form a chain of blocks or a "blockchain". Data in a blockchain is ordered chronologically, every block of the chain contains a hash of the previous blocks, and the whole database is replicated and stored on different nodes of the system (Crosby et al., 2016). There exist public (permissionless) and private (permissioned) blockchains (Casey and Wong, 2017). A public blockchain is generally open and allows everyone to have access to the data. A typical example of an open blockchain is the one used to develop Bitcoin. On the opposite, a private blockchain is restrained to a given number of predefined participants who may have different levels of permission to record and access data. Both public and private blockchains are characterized by the implementation of consensus mechanisms to validate data, the use of cryptographic links between the blocks of the chain and the creation of replicates of the whole database in multiple nodes of the network (Crosby et al., 2016; Casey and Wong, 2017). These characteristics offer the guarantee that data recorded on a blockchain is valid, immune against any alteration and protected against the failure of some of the nodes of the system (Crosby et al., 2016; Casey and Wong, 2017; Babich and Hilary, 2020).

Though blockchain technology was first created and implemented to support cryptocurrency transactions (Nakamoto, 2008), it found application in various domains and business sectors (Carson et al., 2018; Lacity, 2018). Across sectors, multiple use cases demonstrate the high potential of blockchain technology in achieving operations and supply chain management goals (Hackius and Petersen, 2017; Kshetri, 2018; Queiroz et al., 2020).

2.2. Use of blockchain technology in supply chain management

A supply chain is typically composed of independent organizations which are directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Mentzer et al., 2001). Effective management of a supply chain requires members to cooperate and mutually share information (Gunasekaran et al., 2001; Tan et al., 2002; Carr and Kaynak, 2007; Fawcett et al., 2011). In this regard, blockchain technology promises to drastically improve supply chain management and achieve supply chain performance objectives by providing a platform for direct interaction between supply chain members to exchange credible and tamper-proof data (Casey and Wong, 2017; Kshetri, 2018; Babich and Hilary, 2020; Queiroz et al., 2020; Wamba et al., 2020). One of the main benefits of this technology is that it enables full product traceability and enhances visibility through the different supply chain stages (Casey and Wong, 2017; Babich and Hilary, 2020). For instance, using smart tagging and blockchain technology, the UK-based blockchain solutions provider Provenance was able to successfully track fish caught by fishermen in Indonesia, and provide robust proof of compliance to standards from the origin and along the chain to consumers (https://www.provenance.org). Another example of blockchain-enabled product tracking is the pilot project conducted by Walmart in collaboration with IBM to digitally track pork products in China from the farm to the customer table. The technology enabled timely digital access to full individual pork product data, including the farm it comes from, factory it went through, the batch number, the storage temperature and shipping details (Yiannas, 2017). In addition to product tracking, blockchain offers powerful solutions for acquiring and aggregating detailed product information that may be used to authenticate products and certify their origin, as well as to assure product quality and integrity (Montecchi et al., 2019). For instance, the startup Everledger (https://www.everledger.io) has developed blockchain-based solutions to create and maintain unique identifying data for individual units of products in various sectors. The solutions are used for tracking and authenticating wine bottles (Kshetri, 2018), as well as for providing quality assurance and helping jewelers comply with regulations in diamond industry (Casey and Wong, 2017). Blockchain may also be used by Supply chain members to share demand, inventory, and capacity-related data. This data may then be selectively aggregated through the different tiers of the supply chain and used to improve supply chain coordination and operational efficiency (Babich and Hilary, 2020). A higher degree of coordination and operational efficiency may also be obtained through the implementation of blockchain enabled smart contracts to automate transactions among supply chain members (Babich and Hilary, 2020; Wang et` al., 2019). Blockchain technology is instrumental in achieving supply chain sustainability goals (Kouhizadeh and Sarkis, 2018; Kshetri, 2018; Babich and Hilary, 2020). Indeed, product provenance knowledge helps in fighting against product counterfeiting (Alzahrani, N., and Bulusu, N., 2018; Montecchi et` al., 2019), while product tracking capabilities help in better planning and implementing reverse logistics operations, such as product takeback, product reuse, remanufacturing, and recycling (Kouhizadeh and Sarkis, 2018; Babich and Hilary, 2020). The technology may also be used by supply chain members to share sustainability-related data from the different processing and transportation stages the product went through. Then, by aggregating this data, the overall product carbon footprint can be efficiently evaluated, as it has been demonstrated by Shakhbulatov et` al. (2019) for transportation operations in the food industry. Blockchain technology may also be used by Supply chain members to upload certificates of compliance with different sustainability standards, which may then be compiled to ascertain claims of product and supply chain sustainability (Kouhizadeh and Sarkis, 2018; Babich and Hilary, 2020). Furthermore, using blockchain technology is believed to improve supply chain risk management (Kouhizadeh and Sarkis, 2018; Kshetri, 2018; Babich and Hilary, 2020) and supply chain resilience (Dubey et` al., 2020) in addition to lowering transaction costs between the supply chain members (Kshetri, 2018; Schmidt and Wagner, 2019; Wamba et` al., 2020).

2.3. Adoption of blockchain technology in the supply chain

The innovative nature of blockchain technology and its potential for improving supply chain management has woken the interest in investigating the challenges and enablers of its adoption in supply chain context. In a pioneering work, Casey and Wong (2017) discussed the obstacles related to blockchain technology adoption in global supply chains and highlighted the challenges related to the interoperability between different blockchains and the complexity of the rules and regulations that govern contracting and commercial exchange, especially across national borders. Thus, to further encourage blockchain adoption in global supply chains, the authors advocate agreeing on standards and rules for interoperability between blockchains, as well as adapting current regulations and industry practices to the new dematerialized, automated and global nature of blockchains (Casey and Wong, 2017). Drawing on in-depth interviews with supply chain experts, Wang et` al. (2019) reported on the perceived challenging nature of the complexity of the technology and its high cost of implementation. They also highlighted the need for establishing clear governance rules for blockchains and providing interoperability between two or more different blockchains and between blockchains and other existing systems, in addition to resolving the problematic question of data ownership. Leveraging lessons from RFID implementation research by using a multi-approach methodology based on focus group, survey and cases, van Hoek (2019) highlighted the importance of multiple internal and external drivers in addition to management commitment for blockchain implementation. In a study involving four supply chains in the dairy food sector, Behnke and Janssen (2020) identified 18 boundary conditions for using blockchain solutions to provide product traceability. These conditions were then aggregated in 5 categories which are: firm's internal business processes and information system-related conditions such as the technical capacity and ability of different supply chain members to maintain traceability; supply chain process conditions that involve the interface and consistency between internal and external supply chain-related processes; traceability conditions that comprise consensus between supply chain members on the type, level of details and granularity of traceability data; quality-related conditions that involve consistency between supply chain members with regards to quality data; and regulatory conditions in relation with compliance to different product, country or customer-specific regulations. Using an integrative framework composed of institutional, market and technical factors Janssen et` al. (2020) suggest that blockchain adoption may be negatively impacted by the resistance of organizations to change, the lack of understanding of the technology, the need for new regulations, the need for appropriate governance framework of blockchain, the cost of adoption and implementation of blockchain, the need for standardizing the information exchange processes, among other factors. Focusing on blockchain technology used for managing supply chain sustainability, Saberi et` al. (2019) identified four groups of barriers that may hinder the adoption of this technology: intra-organizational barriers, inter-organizational barriers, system-related barriers, and external barriers. Building on Saberi et` al. (2019) and using the Technology, Organization, and Environment (TOE) framework, Kouhizadeh et` al. (2021) analyze the relations between the four groups of barriers and their impact on the adoption of blockchain solutions for managing sustainability in supply chains. Their results demonstrate that the lack of management commitment and support, lack of knowledge and expertise, lack of cooperation, coordination and information disclosure between supply chain members, lack of policies and industry involvement are prominent barriers to blockchain adoption for the sustainable supply chain management.

The above works are mostly oriented towards identifying impediments and challenges of blockchain technology implementation in supply chains. Adopting a different perspective, Kamble et` al. (2020) examined the enabling factors of blockchain adoption for traceability in agriculture supply chain and highlighted the positive influence of the blockchain-enabled reduction of transaction cost, information sharing and data security. In a study of the organizational enablers of blockchain adoption in supply chains, Clohessy and Acton (2019) found that top management support and organizational readiness are significant determinants of blockchain adoption, and large companies are more likely to adopt blockchain than small to medium-sized enterprises (SMEs). Using the TOE framework and survey results, Wong et` al. (2020) find that blockchain complexity, cost and relative advantage have significant effects on the intention to adopt blockchain technology for supply chain management in Malaysian SMEs. Considering blockchain adoption by individual users in supply chain context, Kamble et` al. (2019) find that perceived usefulness is a determinant factor of technology adoption by practitioners. Queiroz and Wamba (2019) also build and test a model for blockchain adoption by supply chain practitioners and demonstrate that higher performance expectancy (i.e., improvement in job activities that blockchain can bring for the SCM professionals) encourages adoption.

In our study, we adopt a comprehensive approach and use elements from all the above studies to build an extended list of blockchain adoption enablers in the supply chain. We then evaluate the levels of influence of these enablers and their interactions using DEMATEL methodology. Kamble et` al. (2020) and Kouhizadeh et` al. (2021) are the closest research papers to our work as they also use DEMATEL. However, multiple differences between this literature and our study do exist and allow us to add new results and insights to the extant literature. A fundamental difference that distinguishes our study from Kamble et` al. (2020) is that our approach is not restrained to any particular sector while Kamble et` al. (2020) is focused on blockchain adoption in agriculture supply chain. As for Kouhizadeh et` al. (2021), our study is different from this paper from various perspectives, including the theoretical background, the scope, the methodology, the survey sample and the analysis. The theoretical background used in Kouhizadeh et` al. (2021) is composed of force field theory and TOE framework, while we use the DOI theory combined with the Business Technology Adoption model developed in Iacovou et` al. (1995). With regards to the scope, Kouhizadeh et` al. (2021) studies the barriers to blockchain adoption

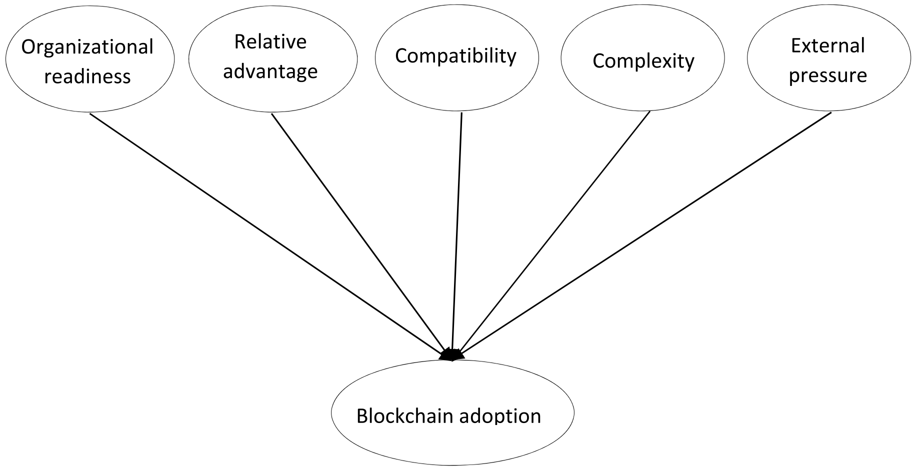

Fig.` 1. Theoretical research model for blockchain adoption.

and use the broader scope of sustainable supply chain management that encompasses economic, social and environmental aspects of supply chain management while we analyze enablers of adoption using the traditional approach to supply chain management which focuses mainly on the economic aspect of management. Though there exist some overlapping between the scopes of the two studies leading to similarities between some of the factors investigated, the lists of factors used in the two studies present much more differences than similarities. Differences are mainly due to the fact that we consider enablers and have a deep focus on the economic pillar of supply chain management while Kouhizadeh et` al. (2021) consider barriers and widen the scope to integrate social and environmental pillars. From a methodology perspective, Kouhizadeh et` al. (2021) proceed hierarchically by investigating the influences between categories of barriers and then between the barriers within each category. Contrasting with this hierarchical approach, we acquire the respondents' evaluations of direct mutual influences between all the enablers taken together. While each method has its advantages and limits, ours allows for capturing and analyzing the direct mutual influences among all the enablers. Lastly, our analysis is focused on getting insights from practitioners in different industries and sectors, while a major part of the work in Kouhizadeh et` al. (2021) is dedicated to comparing results from academics with those obtained from practitioners. Given these differences with existing literature, our study adds new results and insights.

3. Theoretical framework and enabling factors of blockchain technology adoption in the supply chain

In this section, we present the theoretical framework for blockchain adoption in the supply chain. Then we use this framework to identify the adoption enablers based on an extensive review of the literature.

3.1. Theoretical framework

The theoretical approach used in this study is based on two complementary theories on innovation and technology adoption. The first theory is the diffusion of innovation (DOI) (Rogers, 2010). DOI posits that adoption of any new technological innovation is largely determined by five attributes that are: the complexity of the innovation, its compatibility with the organization, the benefit or advantage that it offers compared to other existing technological choices, its observability and trialability. Two of these factors i.e., trialability and observability have often been dropped from IT innovation literature (Chong et` al., 2009). This is because, by nature of organizational adoption of technology, these become top-down activity where the organization imposes the new IT innovation with limited trialability for its constituents. For the same reasons, observability of new IT innovation within the organization is also limited and hence the factor is not included in DOI-based models when analyzing IT innovations (Chong et` al., 2009; Oliveira et` al., 2014). While DOI focuses on the innovation's characteristics responsible for adoption and diffusion of new technologies, it is widely recognized that IT adoption at the firm level is subject to organizational and external context-related factors(Oliveira and Martins, 2011). Hence, it is imperative to study organizational and context-related factors in any firm level technology adoption. Given these concerns with taking a single theoretic approach to study technology adoption and the limitations of DOI, researchers have argued for and utilized multi-theoretical approaches (Hong et` al., 2021; Wamba et` al., 2020). A theoretical framework like DOI needs to be supplemented with a more organization and external context specific framework to embrace the complete array of factors impacting the adoption. Iacovou, Benbassat and Dexter (1995) provide an appropriate lens to fulfill this purpose. Indeed, the framework in Iacovou et` al. (1995) was developed to provide a deeper understanding of the way organizational, external and technology specific factors impact the adoption of technology by firms. It includes organizational factors related to the technological and financial readiness of the adopting organization along with external factors related to the organization's environment, such as partners, regulations and competition. As such the model provides a perfect complementary view to the DOI framework to study various factors that have a role to play in technology adoption by organizations.

Based on the above discussion, we argue that five groups of enablers that include three innovation characteristics (relative advantage, compatibility and complexity) in addition to organizational and external context-related factors shape the situation where a firm must make the decision to adopt blockchain technology in the supply chain, as shown in Fig.` 1. In the following sub-sections, these five categories of enablers are further explained and the enablers that compose each one of them are identified based on an extensive review of the literature.

3.1.1. Organizational readiness

Organizational readiness refers to the organization's financial and technological capacities that affect the implementation and use of the technology (Iacovou et` al., 1995). Implementing blockchain technology requires investing in various kinds of software and hardware and using sophisticated information systems for collecting, storing and communicating data (Iansiti and Lakhani, 2017). Therefore, in our model of blockchain adoption in the supply chain, this dimension comprises factors that reflect the technological capabilities of the firm (Behnke and Janssen, 2020; Bumblauskas et` al. 2019; Janssen et` al., 2020); the knowledge and expertise in using the technology (Behnke and Janssen, 2020; Mendling et` al., 2018; Wang et` al., 2019; Janssen et` al., 2020)

Table` 1
Enablers of blockchain technology adoption in the supply chain.

Category	Enabler	Enabler Name	Enabler Description	References
Organizational Readiness	E1	Technological capabilities	To implement and use blockchain technology a firm needs to use sophisticated information systems for collecting, storing and communicating data. Availability of such systems and capabilities encourages adoption.	Iansiti and Lakhani (2017); Behnke and Janssen (2020); Bumblauskas et` al. 2019; Janssen et` al. (2020)
	E2	Knowledge and expertise in using the technology	Implementing blockchain technology requires specific and new technical expertise. The availability of such expertise in the firm would thus encourage the implementation of the blockchain technology.	Behnke and Janssen (2020); Mendling et` al. (2018)
	E3	Availability of financial resources	Blockchain adoption and implementation requires investing in sophisticated technology and the availability of sufficient financial resources encourages such investment.	Wang et` al. (2019); Janssen et` al. (2020)
	E4	Management commitment	Management commitment allows for devoting the necessary resources for implementing blockchain technology. Firm's management also plays an important role in encouraging and accompanying the cultural and organizational changes that the implementation of the technology may require.	Gunasekaran and Ngai (2008); Kouhizadeh et` al., 2021; van Hoek, 2019
Relative Advantage	E5	Integrity of data on the blockchain	Blockchains are designed to guarantee that it is much difficult to erase or change already stored data. This may encourage adoption, as data is more secure and trustful.	Casey and Wong (2017); Babich and Hilary (2020); Kouhizadeh and Sarkis (2018); Montecchi et` al. (2019)
	E6	Improved data availability from multiple sources and supply chain members	One of the main characteristics of blockchain technology is that it makes all the recorded data virtually continuously available for all the network participants.	Casey and Wong (2017); Babich and Hilary (2020); van Hoek, 2019
	E7	Lower transaction cost	Blockchain allows for reducing the cost of transactions between supply chain members, especially due to disintermediation and the application of smart contracts.	Kshetri (2018); Schmidt and Wagner, 2019; Tönnissen and Teuteberg (2020); Wamba et` al. (2020)
Compatibility	E8	Ease in implementing process and organizational changes to accommodate blockchain adoption and use	Implementing blockchain technology requires re-engineering of related processes to support availability of required data. Therefore, the ease in implementing organizational changes encourages the adoption of the technology.	Mendling et` al. (2018); Chang et` al. (2019); Wang et` al. (2019); Janssen et` al. (2020)
	E9	Availability of credible and accurate data from internal processes	Using blockchain for sharing information among supply chain members requires accurate and credible data to be collected from their internal processes. Thus, the availability of such data enables the supply chain members to share it and may encourage the adoption of blockchain technology for this purpose.	Mendling et` al. (2018); Wang et` al. (2019); Behnke and Janssen (2020); Janssen et` al. (2020)
	E10	Cultural aspects related to the propensity for transparency among the supply chain members	Using blockchain technology is usually intended to increase supply chain transparency. Thus, a culture of transparency among supply chain members encourages the adoption of this technology.	Wang et` al. (2019); Janssen et` al. (2020); Kouhizadeh et` al., 2021
	E11	Cooperation between supply chain members to agree on common rules for data disclosure and confidentiality issues	A data disclosure policy that identifies the data that will be shared between the supply chain members and the rules for accessing the data on the blockchain is a first step towards data disclosure and for making it available on the blockchain.	Wang et` al. (2019); Behnke and Janssen (2020); Kouhizadeh et` al., 2021
	E12	Cooperation between supply chain members for process standardization and agreement on the type and level of details of the data to be shared on the blockchain	To share data on blockchain, supply chain members need to agree on standard processes, thee types, formats, and level of details of the data to be shared.	Casey and Wong (2017); Bumblauskas et` al. 2019; Wang et` al. (2019); Behnke and Janssen (2020); Janssen et` al., 2020
	E13	Cooperation between supply chain members to adopt common supply chain objectives from using the technology	Agreeing on common objectives from using blockchain technology among the supply chain members increases the chance of adoption and use of this technology by them.	Babich and Hilary (2020); Wang et` al. (2019); Kouhizadeh et` al., 2021
Complexity	E14	Developing and harmonizing blockchain technology standards	Blockchain protocols are not stable yet. There is also a lack of standardization of the technology and the format of data and interfaces with other systems. Advances in this regard would encourage adoption.	Lacity (2018); Wang et` al., 2019; Janssen et` al. (2020)
	E15	Establishing appropriate and clear governance rules for blockchain platforms	To be trusted and to work efficiently, a blockchain should have an appropriate governance structure and clear rules for decision-making, and conflict resolution.	Babich and Hilary (2020); Wang et` al. (2019); Janssen et` al. (2020)
	E16	Establishing rules and standards for interoperability between blockchains and between blockchains and other systems	A company may be part of multiple blockchains. Thus, there is a need to know how these blockchains may interact with each other.	Mendling et` al. (2018); Wang et` al., 2019
External Pressure	E17	Customer interest in the traceability information and other product-related data on blockchain	Interest of customers in traceability information and other data available on the blockchain would push firms and supply chains to adopt this technology for	Lacity (2018); Kshetri (2018); Montecchi et` al., 2019; van Hoek, 2019

(continued on next page)

Table` 1 (*continued*)

Category	Enabler	Enabler Name	Enabler Description	References
			supply chain management to ensure data availability for customers.	
	E18	Industry wide initiatives to promote blockchain technology adoption and use	Adoption of blockchain technology may be encouraged by initiatives to promote adoption that are taken on the level of the entire industry.	Casey and Wong (2017); Lacity (2018); Behnke and Janssen (2020)
	E19	Establishing regulatory framework for using blockchain technology	Establishing new regulations that are adapted to blockchain-enabled transactions may encourage adoption, as the current regulatory framework doesn't not cover the transactions and the new business models made possible by blockchain technology.	Casey and Wong (2017); Mendling et` al. (2018); Lacity (2018); Wang et` al. (2019); Janssen et` al. (2020)
	E20	government pressure for implementing blockchain technology	Government could adopt regulations to mandate the implementation and use of blockchain technology, for traceability and authentication purposes in some sectors, such as in pharmaceutical production.	Lacity (2018)

and the availability of the financial resources required for implementing the technology (Wang et` al., 2019; Janssen et` al., 2020). Extant literature identifies top management commitment as being influential on the adoption of inter-organizational information systems (Gunasekaran and Ngai, 2008). Indeed, management commitment allows for devoting the necessary human and financial resources for implementing the technology and the organizational change (Saberi et` al., 2019; Kouhizadeh et` al., 2021; van Hoek, 2019). Thus, we posit management commitment as an enabler of blockchain adoption and map it to the organizational readiness dimension.

3.1.2. Relative advantage

The relative advantage of an innovation can be defined by the increase in the economic benefit and the impact that the innovation brings compared to existing systems that it replaces (Rogers, 2010). Relative advantage is often found to be positively correlated with the adoption of innovations (Kapoor et` al., 2014). It is also found to be an antecedent of technology adoption in the supply chain context (Brandon-Jones and Kauppi, 2018). Literature reports that, compared to other existing systems, blockchain technology better ensures data integrity (Casey and Wong, 2017; Babich and Hilary, 2020; Kouhizadeh and Sarkis, 2018; Montecchi et` al., 2019), improve data availability from multiple sources and supply chain members (Casey and Wong, 2017; Babich and Hilary, 2020; Kouhizadeh and Sarkis, 2018; van Hoek, 2019). In addition, it is widely admitted that using this technology reduces the cost of transactions between supply chain members (Kshetri, 2018; Schmidt and Wagner, 2019; Tönnissen and Teuteberg, 2020; Wamba et` al., 2020). Note that the transaction cost considered here is different from the concept of overall cost of ownership of blockchain. Indeed, while studies like Kshetri (2018), Schmidt and Wagner (2019), Tönnissen and Teuteberg (2020) and Wamba et` al. (2020) point out the contribution of blockchain to lowering transaction cost, other works like Wang et` al. (2019) and Janssen et` al. (2020) insist on the challenging nature of blockchain implementation cost. To our knowledge, a thorough study of the overall cost-related impact of blockchain adoption (cost of implementation, the resulting reduction in transaction costs and the return on investment) doesn't exist yet. This represents a critical gap in literature, where the cost-related implications of blockchain adoption in a supply chain need to be studied. In our study, we focus on the enablers of adoption. We thus include the capacity of blockchain to lower transaction cost in our list of enablers.

We map the three enablers discussed above to the relative advantage dimension in our theoretical framework.

3.1.3. Compatibility

The compatibility refers to the degree of consistency between the innovation and existing values, experience and needs of the organization (Rogers, 2010). Blockchain technology is typically used in supply chain management to create and share unique data records among trade partners to increase transparency and visibility of information through the whole supply chain (Casey and Wong, 2017; Babich and Hilary, 2020; Montecchi et` al., 2019). Its implementation may require changing internal operational processes to maintain internal traceability and support the required level of details in data (Mendling et` al., 2018; Tönnissen and Teuteberg, 2020). It also requires the willingness and capacity of supply chain members to share data and to cooperate for establishing common process standards, rules for information disclosure and related supply chain objectives. Therefore, we map to the compatibility dimension the enablers related to these aspects, which are: ease in implementing process and organizational changes to accommodate blockchain adoption and use (Mendling et` al., 2018; Chang et` al., 2019; Wang et` al., 2019; Janssen et` al., 2020); availability of credible and accurate data from the internal processes (Behnke and Janssen, 2020; Wang et` al., 2019); cultural aspects related to the propensity for transparency among the supply chain members (Wang et` al., 2019; Janssen et` al., 2020; Kouhizadeh et` al., 2021); cooperation between supply chain members to agree on common rules for data disclosure and confidentiality issues (Wang et` al., 2019; Behnke and Janssen, 2020; Kouhizadeh et` al., 2021); cooperation for process standardization and agreement between supply chain members on the type and level of details of the data to be shared on the blockchain (Casey and Wong, 2017; Bumblauskas et` al. 2019; Wang et` al., 2019; Behnke and Janssen, 2020; Janssen et` al., 2020); cooperation between the supply chain members to adopt common objectives from using the technology (Babich and Hilary, 2020; Wang et` al., 2019; Kouhizadeh et` al., 2021).

3.1.4. Complexity

Complexity indicates to which degree the innovation is perceived as being difficult to understand and use (Rogers, 2010). Blockchain is a disruptive and relatively complex technology (Crosby et` al., 2016; Iansiti and Lakhani, 2017), and this may hurts its adoption. Thus, we map to this dimension factors in the literature that help in alleviating the effect of the complexity of the technology and act as enablers for its adoption and use for supply chain management. These factors are: developing and harmonizing blockchain technology standards (Lacity, 2018; Wang et` al., 2019; Janssen et` al., 2020); establishing appropriate and clear governance rules for blockchain platforms (Mendling et` al., 2018; Wang et` al., 2019; Janssen et` al., 2020); establishing rules and standards for interoperability between blockchains and between blockchains and other systems (Mendling et` al., 2018; Wang et` al., 2019).

3.1.5. External pressure

External pressure to adopt the innovation refers to the influences originating from the organization's environment (Iacovou et` al., 1995). Indeed, the influence exerted by external parties may be determinant in the adoption of inter-organizational information technologies (Teo et` al., 2003). In our theoretical model for blockchain adoption within the context of supply chain management, this dimension comprises pressures that originate from the organization's environment as well as encouraging factors in this environment. Building on this and on findings in the extant literature, we map the following enablers to the external pressure category: customer interest in the traceability information and other product-related data on the blockchain (Lacity, 2018; Kshetri, 2018; Montecchi et al., 2019; van Hoek, 2019); industry-wide initiatives to promote blockchain technology adoption and use (Casey and Wong, 2017; Lacity, 2018; Behnke and Janssen, 2020); establishing regulatory framework for using blockchain technology (Casey and Wong, 2017; Lacity, 2018; Wang et al., 2019; Janssen et al., 2020); and government pressure for implementing blockchain technology (Lacity, 2018).

3.2. Enablers of blockchain adoption in the supply chain

Table 1 summarizes the results of the literature review we conducted to identify the enablers of blockchain adoption in the supply chain. Information in Table 1 provides the answer to our research question RQ1 and informs our model for blockchain adoption in the supply chain by providing a list of enablers of adoption organized in five catagories as per the model in Fig. 1.

4. Research method

To evaluate the levels of influence of the enablers identified in Section 3 and analyze their relationships, we use the DEMATEL method. DEMATEL is a decision-making support tool that helps in acquiring the input of experts regarding complex problems, and appropriately using this information to improve our understanding of such problems. This tool is particularly adapted for studying problems in which multiple intricate factors mutually influence each other and contribute together to forming an overall situation (Gabus and Fontela, 1973). It helps in evaluating the relative importance or impact of the factors under consideration and establishing causal relationships between them. DEMATEL has been widely used for studying a variety of supply chain management-related topics, such as analyzing and modeling sustainability practices in supply chains (Gandhi et al., 2015; Govindan et al., 2011; Kaur et al.2017; Lin, 2013); modeling supplier selection criteria (Chang et al., 2011); analyzing enablers of supply chain risk mitigation (Rajesh and Ravi, 2015); and analyzing traceability implementation (Haleem et al., 2019).

4.1. Steps for applying DEMATEL

As previously mentioned, DEMATEL is based on experts' input regarding the interaction between factors related to a given problem (Li and Mathiyazhagan, 2018; Bai et al., 2017). Once the factors to be studied are identified, DEMATEL is implemented as follows.

Step 1: Acquiring the evaluation of the factors from a panel of experts.

The first step in implementing DEMATEL is to collect data from experts on how they think the different factors impact each other. For this purpose, experts are asked to make pairwise evaluations of the impact of factors on each other. Let n be the number of factors under consideration, a matrix of size $n \times n$ is formed with all these factors in the lines and in the columns. The experts are then asked to fill in the cells of this matrix with their evaluation of the influence of each factor in the lines on the different factors in the columns. Let K be the number of experts participating to the study. Each expert k (with $k \in [1, K]$) will return a matrix $A_k = [a_{ij}^k]$ that contains his evaluation (a_{ij}^k) regarding the influence of each factor (i) in the lines on each factor (j) in the columns. Note that the size of the matrix A_k is $n \times n$, as the same factors are reported in the lines and in the columns of the matrix. As for the evaluations a_{ij}^k, they take numerical values that represent the expert's evaluation of the influence between factors. The values on the diagonal of any matrix A_k are, of course, set to zero (i. e., $a_{ij}^k = 0$; $i = j$) as a factor could not influence itself.

Step 2: Computing the direct relation matrix (B).

Using the output from *Step 1*, one single direct relation matrix $A = [a_{ij}]$ is computed by aggregating the K matrices A_k using the formula in Equation (1).

$$A = \frac{1}{K}\sum_{k=1}^{K} A_k \tag{1}$$

Step 3: Computing the normalized direct relation matrix.

In this step, the direct relation matrix A is normalized as follows. The sum of elements in each line of the matrix is computed and the maximum sum (S) is selected as in Equation (2).

$$S = \max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij} \tag{2}$$

Then, the normalized direct relation matrix B is computed as in Equation (3).

$$B = \frac{1}{S} A \tag{3}$$

Step 4: Computing the total relation matrix (T).

The total relation matrix ($T = [t_{ij}]$) is computed using the normalized direct relation matrix as in Equation (4).

$$T = B + B^2 + B^3 + B^4 \ldots = B(I - B)^{-1} \tag{4}$$

Step 5: Computing the total influence between factors.

The total influence a factor *(i)* exerts on the other factors is computed by taking the sum of the elements in the corresponding row (R_i) in the total relation matrix *(T)*, as in Equation (5). As for the influence that a factor *(j)* receives from the other factors in the system, it is equal to the sum of the elements in the corresponding column (C_j) in the same matrix *(T)*. Equations (5) and (6), show how these two elements are computed.

$$R_i = \sum_{j=1}^{n} t_{ij};\ \boldsymbol{i}, \boldsymbol{j} \in [1, \boldsymbol{n}] \tag{5}$$

$$C_j = \sum_{i=1}^{n} t_{ij}; \boldsymbol{i}, \boldsymbol{j} \in [1, \boldsymbol{n}] \tag{6}$$

Step 6: *Computing the prominence (P_i) and the net effect (E_i) of the factors.*

Then, for each factor (i) the overall importance (prominence) (P_i) and the net effect (E_i) are computed using the expressions in (7) and (8).

$$P_i = R_i + C_j / i = j \tag{7}$$

$$E_i = R_i - C_j / i = j \tag{8}$$

The prominence (P_i) of a factor (i) represents the sum of the influence that this factor exerts on and receives from the other factors in the system. The net effect (E_i) of a factor (i) represents the difference between the influence that this factor exerts on the other factors and the influence of the other factors of the system on it.

Table` 2
Semantic of the pairwise evaluation of influence between factors.

Description of the influence of enabler *i* in the line on enabler *j* in the column	Corresponding value (a_{ij})
No impact	0
Low impact	1
Moderate` impact	2
High` impact	3
Very High` impact	4

Table` 3
Profile of the respondents.

Business sector	**Frequency**
Manufacturing	23
Sales and distribution	4
Services provider	3
Consulting	7
Size of the firm (Nb of employees)	**Frequency**
Less than or equal to 10	8
Between 11 and 50	21
Between 51 and 250	3
More than 250	5
Function/Department of the respondent	**Frequency**
Operations, logistics or supply chain management	16
IT department	9
CEO	7
Consultant	5
Number of years of experience	**Frequency**
From 5 to 10	14
From 10 to 15	15
From 16 to 20	4
More than 20	4

At this stage, all the information regarding the influence of the factors is obtained and can be illustrated using diagrams and graphics. But a further step that allows for focusing on the significant relationships between the factors could be performed by discarding all the values in the matrix *(T)* that are lower than a threshold (α). Notice that choosing a small value of the threshold leads to discarding very few relationships and results in complex diagrams between factors due to the high number of direct relations considered. On the other hand, a high value of the threshold (α) could lead to discarding too many relations that could be interesting to consider. Given the high number of factors we deal with in this study, we choose to use a threshold value that exceeds the average of the elements in the total relation matrix *(T)* by one standard deviation. Thus, (α) is calculated using the expression (9).

$$\boldsymbol{\alpha} = \boldsymbol{Mean}\left(t_{ij}\right) + \boldsymbol{SD}\left(t_{ij}\right);\ \boldsymbol{i}, \boldsymbol{j} \in [1, \boldsymbol{n}], \tag{9}$$

4.2. Sampling respondents and collecting data

We targeted a sample of 160 potential respondents who have sufficient expertise in supply chain management or information technology applications in supply chains. Following similar studies which are based on experts' opinion such as Agi and Nishant (2017), Bokrantz et` al. (2017) and Wang et` al. (2019), we used two main criteria to select potential respondents: (1) the number of years of experience within the field and (2) the position in the company. Thus, all the members of our targeted sample have at least 5 years of work experience in functions related to supply chain management or information technology management with direct linkages to supply chain processes. All the experts in our panel work in middle or higher management positions in their respective companies, or as confirmed or senior consultants. We built the targeted sample using our network and asked for help from the Brittany Chamber of Commerce (CCI-Bretagne), France to identify potential respondents. Given the emerging nature of blockchain technology applications in supply chain management, the respondents didn't need to be experts in blockchain technology. However, in the e-mail we sent to them to ask if they are willing to take part to the study, they were informed that they should be aware of blockchain technology attributes and its current and potential use in supply chain management in order to fill in the questionnaire. Finally, as our study is not restricted to a specific sector, targeted respondents came from companies operating in a variety of sectors including manufacturing, distribution, service, and consulting.

We followed a two-step process in collecting answers from respondents, as explained in Appendix I. In a first step, we sent e-mails to all the 160 potential respondents to give them a full explanation of the objective of the study and ask if they are willing to contribute by filling the matrix of mutual influence between the 20 factors. Then, an Excel file representing the evaluation matrix with the 20 enablers in the rows

Table` 4
Prominence and net effect of the enablers.

Category	Enabler	Enabler Name	R	C	Prominence (R` +` C)	Net Effect (R–C)	Rank (R` +` C)
Organizational Readiness	E1	Technological capabilities	0.587	0.793	1.380	−0.206	17
	E2	Knowledge and expertise in using the technology	0.596	0.827	1.423	−0.231	16
	E3	Availability of financial resources	0.453	0.298	0.751	0.154	20
	E4	Management commitment	1.003	1.367	2.370	−0.364	3
Relative Advantage	E5	Integrity of data on the blockchain	1.166	0.661	1.826	0.505	14
	E6	Improved data availability from multiple sources	0.620	1.460	2.079	−0.840	9
	E7	Lower transaction cost	1.166	1.621	2.787	−0.454	1
Compatibility	E8	Ease in implementing process and organizational changes	0.371	0.911	1.282	−0.540	19
	E9	Availability of credible and accurate data from internal processes	0.451	1.682	2.132	−1.231	8
	E10	Cultural aspects related to the propensity for transparency	1.581	0.620	2.200	0.961	7
	E11	Cooperation to agree on common rules for data disclosure and confidentiality issues	0.693	1.507	2.200	−0.814	6
	E12	Cooperation for process standardization	0.820	1.401	2.221	−0.581	5
	E13	Cooperation to adopt common supply chain objectives	0.776	1.296	2.072	−0.520	10
Complexity	E14	Developing and harmonizing blockchain technology standards	1.113	0.616	1.730	0.497	15
	E15	Establishing appropriate and clear governance rules for blockchain platforms	1.026	0.938	1.964	0.089	11
	E16	Establishing rules and standards for interoperability	1.274	0.591	1.865	0.683	13
External Pressure	E17	Customer interest in the traceability and other product-related data on blockchain	1.919	0.839	2.758	1.080	2
	E18	Industry wide initiatives	1.112	0.777	1.888	0.335	12
	E19	Establishing regulatory framework	1.735	0.577	2.313	1.158	4
	E20	Government pressure	0.841	0.521	1.362	0.319	18

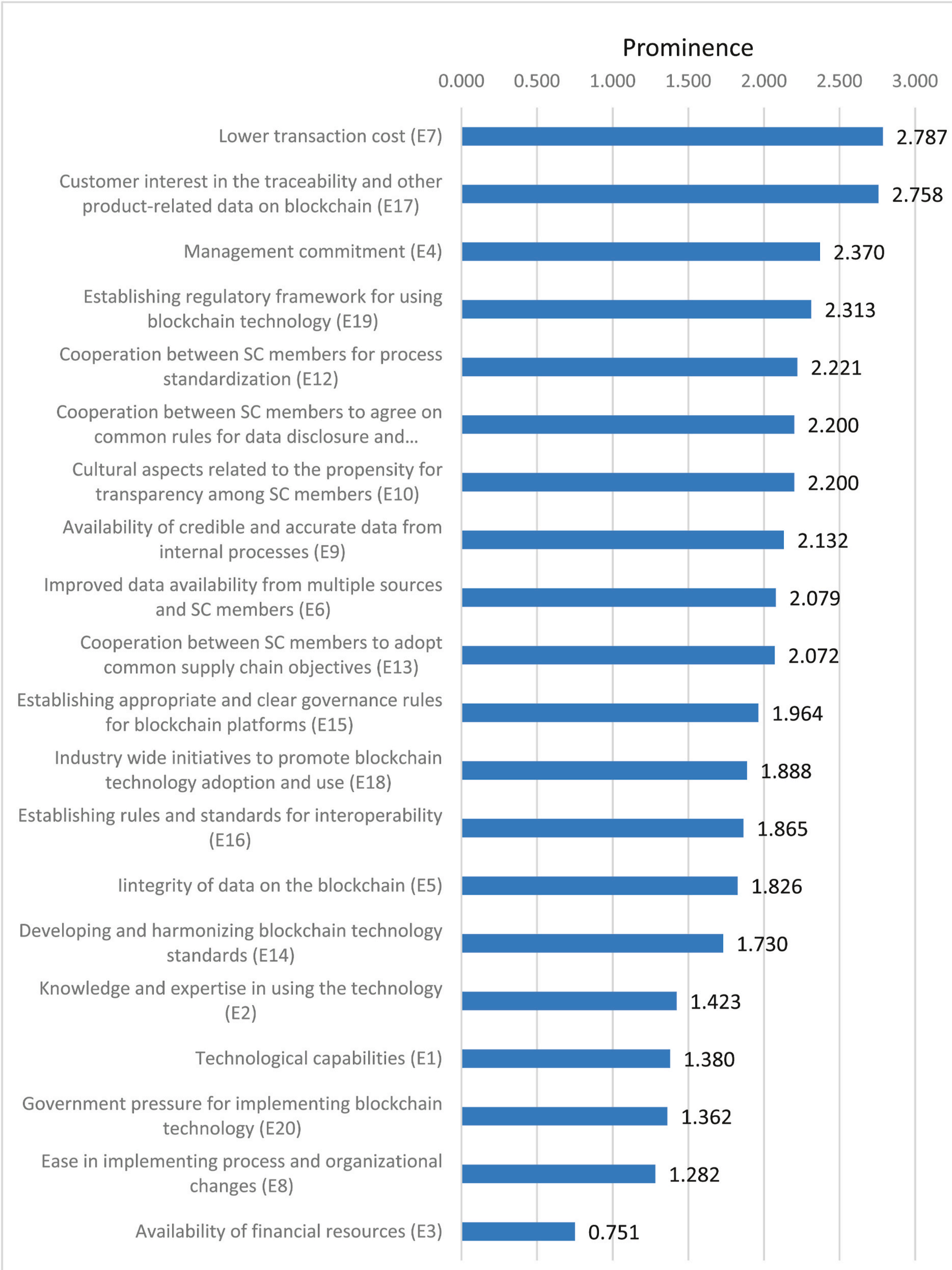

Fig.` 2. Prominence levels of the enablers.

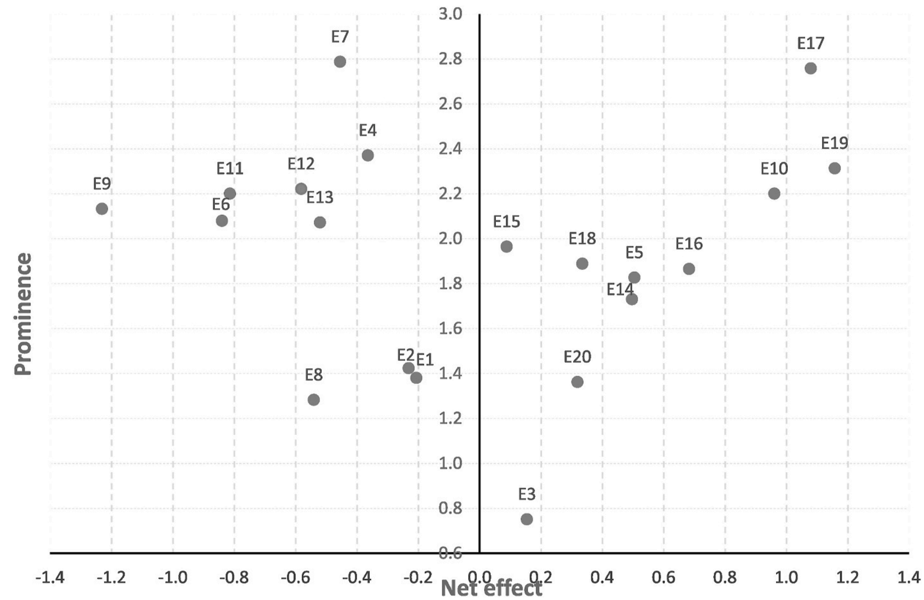

Fig.` 3. Prominence and net effect diagram.

and the columns, and the evaluation grid (Table` 2) were sent to the 52 respondents who declared their willingness to take part to the study. Data collection took place from mid-January to mid-March 2021. In a limited number of cases, we had to call the respondents and give explanations on the way they should proceed for filling in the Excel sheet. The use of the Excel sheet in collecting answers helped to limit the typing errors, as the data was ready to be exploited directly in Excel. Out of the 52 respondents who initially accepted to fill in the matrix, 37 returned useable responses in which answers to all the questions are obtained and the Excel file is entirely completed.

Table` 3 shows the overall characteristics of these 37 respondents. From Table` 3, we notice that out of the 37 respondents, 16 work in supply chain management related functions, 9 in IT management with supply chain applications, 7 are CEOs and 5 are consultants. It is also to be noted that most of the respondents (23 out of 37) have more than 10 years of work experience in the field of the study.

DEMATEL method is different from similar survey-based exercises for two reasons. First, the respondents are individuals with significant information about the phenomenon under investigation in addition to being experts in the field (Bai et` al., 2017; Li and Mathiyazhagan, 2018). Hence, even a low number of respondents could provide detailed insights into the phenomenon being studied. Secondly, the method relies on the respondents' critical evaluation of theoretically chosen factors to help the researchers establish the relative importance and mutual dependence of these factors. As such a small sample size is expected to help the research reach a level of theoretical saturation (Kamble et` al., 2020; Li et` al., 2018). It needs to be established that the generalizations that are drawn from the result trace themselves as much to the theory being established as to the empirical data. Hence, we are claiming theoretical generalization as against statistical generalization of the results (Jha et` al., 2016). Theoretically generalized results are considered to be robust due to their grounding in critically evaluated theoretical paradigms and utilized widely in circumstances where limited access to data prohibits statistical generalization (Maxwell and Chmiel, 2014).

Table` 5
Prominence and net effect of the categories of enablers.

Category	Average Prominence
Relative Advantage	2.231
External Pressure	2.080
Compatibility	2.018
Complexity	1.853
Organizational Readiness	1.481

5. Analysis and results

Our analysis started by applying Equation (1) to compute the direct relationship matrix based on the 37 useable responses returned by the experts. Then, we computed the normalized direct relation matrix *(B)* using Equations (2) and (3). The total relation matrix *(T)* is then computed using Equation (4). This matrix is presented in Appendix II. The total influence an enabler (i) exerts on and receives from the other enablers in the system, respectively (R_i) and (C_i), are computed using Equations (5) and (6). Then, the levels of importance (prominence) (R` +` C) and the net effect (R–C) of the enablers are computed by applying Equations (7) and (8). Results obtained from this step are shown in Table` 4. Based on information in Table` 4, we order the 20 enablers according to their prominence scores and graphically depict these scores in Fig.` 2.

Note that the prominence of an enabler indicates its overall importance in the system (Bai et` al., 2017; Govindan et` al., 2015). Thus, information in Table` 4 and Fig.` 2 answers the second research question in this study (RQ2) by providing an evaluation of the level of importance of the various enablers with regards to the adoption decision. From Table` 4 and Fig.` 2, we notice that lowering transaction cost (E7) is the most prominent enabler, followed by customer interest in the traceability information and other product-related data on blockchain (E17), management commitment (E4), establishing regulatory framework for using blockchain technology (E19) and cooperation between supply chain members for process standardization and agreement on the type and level of details of the data to be shared on the blockchain (E12), respectively. On the other hand, enablers that have the lowest prominence scores are the availability of financial resources (E3), Ease in implementing process and organizational changes (E8), the government pressure (E20), the Technological capabilities (E1) and the knowledge and expertise in using the technology (E2).

While the prominence score indicates the overall importance of an enabler, the net effect informs us if this enabler should be categorized as a cause or as an effect enabler. Cause enablers have positive net effect scores, which indicate that they exert more impact on the other enablers in the system than they are impacted by them. Therefore, these enablers may be addressed relatively independently of the situation of the other

Table` 6
The most significant relation coefficients between enablers.

		Impacted enablers							
		E4	E6	E7	E9	E11	E12	E13	E15
Impacting enablers	E4				0.112				
	E5	0.108	0.106	0.119	0.122	0.113	0.106	0.102	
	E7	0.102			0.108				
	E10	0.109	0.118		0.137	0.124	0.121	0.113	
	E14		0.103						
	E15		0.106	0.109		0.103			
	E16	0.105	0.106	0.108		0.116	0.106	0.104	
	E17	0.131	0.134	0.000	0.143	0.139	0.133	0.127	0.110
	E19	0.125	0.127	0.129	0.129	0.126	0.112	0.105	0.111

enablers, and potentially benefit the whole system. By contrast, effect enablers are those enablers with negative net effect scores, indicating that they are more impacted by the other enablers of the system than they exert impact on them. Fig.` 3 position the 20 enablers of blockchain adoption under investigation relative to the two dimensions: prominence and net effect. The vertical axis in Fig.` 3 represents the prominence. It is graduated from 0.6 to 3.0 to accommodate the values that we had in our analysis. The horizontal axis represents the net effect, and it ranges from -1.4 to $+1.4$ with negative and positive values indicating effect and cause enablers, respectively.

From Table` 4 and Fig.` 3, we notice that half of the 20 enablers of blockchain adoption considered in our study are cause enablers and half of them are effect enablers. We also notice that among the five most prominent enablers, customer interest in the traceability information and other product-related data on blockchain (E17) and establishing regulatory framework for using blockchain technology (E19) are cause enablers, while lower transaction cost (E7), management commitment (E4), and cooperation between supply chain members for process standardization and agreement on the type and level of details of the data to be shared on the blockchain (E12) are effect ones.

6. Discussion and implications

In this section, we further analyze and discuss the results obtained in the previous section (Section 5). We do this first by considering the prominence of the enablers by category of enablers as per the theoretical model presented in Section 3. Then, we focus on the most eminent enablers and analyze their relationships and interactions with the rest of the system. Subsequently, we use the result of our analysis to elaborate implications and managerial insights.

6.1. Prominence by category of enablers

Taking a categorical construct level view of the enablers, Table` 5 shows the average prominence scores computed for each category of enablers that compose the theoretical model described in Section 3. Categories in this table are ordered according to the average prominence of the enablers that compose them.

From Table` 5, we notice that relative advantage and external pressure have the highest average prominence values, respectively, while organizational readiness has the lowest average prominence value. Thus, blockchain adoption in the supply chain is mainly influenced by the benefits (relative advantage) that this technology offers in comparison with other existing technologies (integrity of data, improved data availability and lower transaction costs), followed by the external pressure for adoption exerted by customers and public authorities, in particular. To the opposite, organizational readiness seems to have a limited impact on the adoption decision. This last result suggests that adoption decision may be taken regardless of the organizational readiness, so that blockchain would often be the driver of wider organizational transformation. This result finds support in the extant literature of digital transformation that states that organizational digitalization would be a result of major technological adoption (Andriole et` al., 2017; Hartley and Sawaya, 2019).

6.2. Prominence and relationships between enablers

Lower transaction cost (E7), customer interest in the traceability information and other product-related data on blockchain (E17), management commitment (E4), establishing regulatory framework for using blockchain technology (E19) and cooperation between supply chain members for process standardization and agreement on the type and level of details of the data to be shared on the blockchain (E12) are top five prominent enablers of blockchain adoption in the supply chain, as evidenced in Table` 4. A careful look in the total relation matrix *(T)* enables a full understanding of the impact of these enablers by uncovering their interactions with the rest of the system. However, due to the big number of enablers investigated in this study, we analyze relationships and interactions among them and answer the third research question of the study (RQ3) by focusing on the meaningful relationships in the total relation matrix *(T)*. To do this, we apply a threshold so that only the values in the total relation matrix *(T)* that are higher than the threshold would be considered. Applying a threshold and focusing on the most significant relationships among factors is a common practice in DEMATEL studies (Kouhizadeh et` al., 2021; Fu et` al., 2012). Table` 6 shows the remaining values from the total relation matrix *(T)* after applying the threshold defined in Equation (9).

Data in Table` 6 shows that the capacity of blockchain to lower transaction cost that represent the most eminent enabler (E7) is significantly impacted by a number of enablers including the existence of a regulatory framework (E19), standards for interoperability (E16) and appropriate and clear governance rules for blockchain (E15), in addition to the integrity of data on the blockchain (E5). This suggests that supply chain professionals believe that grasping the benefit of lower transaction const due to blockchain adoption in the supply chain is subject to the establishment of appropriate conditions for using the technology: an appropriate regulatory framework, operability standards and governance rules. In its turn, E7 seems to significantly enhance the management commitment (F4) and promote the availability of credible and accurate data from internal processes (E9).

As for the second most prominent enabler: customer interest in the traceability information and other product-related data on blockchain (E17), data in Table` 6 shows that this enabler exerts a significant impact on management commitment (E4), data availability from internal firm's processes (E9) as well as from all the participants in the blockchain (E6). It also appears that E17 triggers four cooperation-related enablers at the supply chain level. These are cooperation between supply chain members to agree on: common rules for data disclosure and confidentiality issues (E11), process standardization and the type and level of details of the data to be shared on the blockchain (E12), common supply chain objectives from using the technology (E13) in addition to establishing appropriate and clear governance rules for blockchain platforms (E15). The high-level impact of E17 on multiple other enablers as demonstrated above suggests that a big portion of the motivation for adopting blockchain technology in the supply chain is related to customers' requirements regarding traceability and other product-related data.

Management commitment (E4) is identified as the third most prominent enabler for blockchain adoption in the supply chain. In-depth examination of the role of this enabler using information in Table` 6 shows that management commitment acts as a bearing point in the system. It appears as an effect enabler leveraged, mainly, by the integrity of data on blockchain (E5), the potential for lowering transaction cost (E7), The cultural propensity for transparency (E10), the existence of rules for interoperability (E16), the customer interest in the information on blockchain (E17), and the existence of a regulatory framework for using blockchain technology (F19). On its turn, management commitment significantly contributes to enhancing the availability of credible and accurate data from internal processes (E9) and the cooperation between supply chain members to agree on common rules for data disclosure and confidentiality issues (E11), process standardization, type and level of details of the data to be shared on the blockchain (E12), and common supply chain objectives from using the technology (E13).

Our results also show that establishing regulatory framework for using blockchain technology (E19) is an important cause enabler ranked fourth in prominence. It significantly enhances management commitment (E4), the availability of data from firm's internal processes (E9) and from various other sources and supply chain members (E6), in addition to supporting reduction of transaction costs (E7). E19 also provides a favorable legal environment for cooperation between supply chain members to agree on common objectives, rules and standards related to sharing data on blockchain, as demonstrated by the significant effect of this enabler on E11, E12, E13 and E15.

Like management commitment at the firm's level, cooperation at the supply chain level seems to be very important for blockchain adoption. This is highlighted by the ranking of the cooperation between supply chain members for process standardization and agreement on the type and level of details of the data to be shared on the blockchain (E12), ranked fifth in prominence. Data in Table` 6 shows that this enabler is significantly impacted by customer interest in product traceability (E17), the cultural propensity for transparency in the supply chain (E10), the establishment of regulatory framework for using blockchain technology (E19), the existence of rules for interoperability (E16) and the integrity of data on blockchain (E5). Data in Table` 6 also shows that the two other enablers related to the cooperation between supply chain members (E11) and (E13) are also significantly impacted by the same enablers as (E12). Thus, our findings suggest that having supply chain members cooperating for adopting blockchain in the supply chain is subject to the customer interest in product traceability, the cultural propensity for transparency in the supply chain, the existence of regulatory framework for using blockchain technology and the existence of rules for interoperability.

6.3. Implications and managerial insights

Our results demonstrate that firm's management commitment and cooperation between supply chain partners on various aspects related to data sharing, confidentiality and system governance are both of primary importance for adopting blockchain technology in the supply chain. Findings also reveal that management commitment and cooperation between supply chain members for blockchain adoption are mainly triggered and supported by factors that may be addressed by extending efforts in three main directions. First, for raising awareness among consumers and firms' managers about the usefulness of the availability of product data and the capability of blockchain to provide such data availability. Second, for developing and harmonizing the technology standards, in addition to enhancing blockchain interoperability. Third, for preparing a regulatory environment that favors the adoption and use of the technology.

Consumers are a primary source of pressure on firms. Our findings show that consumer interest in product-related data, including traceability, encourages firms' managers to adopt the blockchain technology and enhances collaboration among supply chain partners for data sharing on blockchain. This enabler may be addressed by conducting awareness campaigns to sensitize consumers on the usefulness of data that may be provided using blockchain. Such awareness campaigns may be conducted by consumers associations, NGOs or industry representative bodies. It may concern a wide range of data related to products as well as production and supply chain processes. For instance, consumers' awareness about sustainability aspects in production motivates them to put more pressure for getting detailed and accurate information from all supply chain members regarding the social and environmental practices. Similarly, campaigns against fraud and counterfeit products in fashion and luxury industries encourage consumers to be more demanding for extensive and tamper-proof product information. In addition to consumers, awareness campaigns may also target firms upper and middle management to demonstrate the various advantages of blockchain in comparison with other technologies, especially its potential to lower the cost of transactions, which appears to be an impactful enabler of blockchain adoption in the supply chain. Actions of industry representative bodies, consulting firms and technology solutions promotors are crucial in this regard. Concretely, they may organize seminars, meetings, and workshops where new blockchain-enabled business models can be discussed and the value proposition of the technology as a platform for sharing tamper-proof information and reducing the costs of transactions can be demonstrated and clarified for managers. Consortiums or industry representative bodies may also conduct, or offer support to, blockchain applications proof of concept (Lacity, 2018), which may give confidence in the new technology and constitute a first step towards implementing real solutions. Companies may also conduct industry specific collective initiatives to develop and agree on the best practices and governance structure for blockchain technology (Casey and Wong, 2017; Behnke and Janssen, 2020).

Our results also point out the importance of developing universal standards for blockchain technology, improving the interoperability between different blockchains and with firms' information systems and establishing appropriate and clear governance rules. Thus, solutions providers need to work on adopting universal standards for this technology (Janssen et` al., 2020) and enhancing interoperability between different blockchains, as well as between blockchain and firms' information systems (Wang et` al., 2019). Solutions providers may also work with legislators and user communities to build appropriate governance structures that define the rights and obligations of the different parties involved in blockchain management and use and determine the decision-making rules and the procedures for preventing information misuse and solving conflicts (Babich and Hilary, 2020).

Finally, results demonstrate that establishing regulatory framework for using blockchain technology is critical with regard to adoption. This suggests that legislators are also required to put efforts to create new regulations or adapt the existing ones to support blockchain-enabled business models and exchange processes. Indeed, it is widely admitted that regulations related to data security and privacy impact the blockchain potential use (Lacity, 2018; Wang et` al., 2019) and making new regulations or changing existing ones may be necessary to support the adoption of this technology.

7. Limitations and conclusion

The limitations to our study are mainly related to the respondents' sample. Our respondents come exclusively from France. This may introduce a bias in the results. Future research work may thus be conducted in another country, a developing economy for example. Results may then be compared with ours for further insights. Special consideration may be given to factors like government pressure in these circumstances as presence (or absence) of legislative frameworks can alter the scope and possibility of blockchain adoption significantly in different geographies. As previously indicated, the transaction cost considered in our study refers to the cost of individual transactions. This cost is thus different from the overall cost of ownership that should also include the implementation cost. Future research may address this issue. Additionally, adopting a theory-driven approach, we have focused on identifying a comprehensive list of enablers and their inter-relationships as identified from the established theoretical literature. Given the emergent nature of technology, a grounded theoretic approach has the potential to bring to light new factors that could be explored in subsequent studies.

However, within its limitations, this study makes a significant contribution to extant literature on blockchain adoption in the supply chain. Indeed, our work is one of the first empirical studies that attempt to analyze and understand blockchain adoption in the supply chain. The findings allowed to uncover the role of 20 enablers of blockchain adoption in the supply chain with regard to the adoption decision and to establish a series of insights on how to encourage such decision.

We found that external pressure and relative advantage are the two most prominent categories of enablers that impact blockchain adoption in the supply chain. Findings also suggest that raising awareness among customers and supply chain professionals about the advantages of blockchain over existing technologies is key for stimulating its adoption. Our study also reveals that to motivate blockchain adoption in supply chains, it is crucial to develop technology standards, provide interoperability among different blockchains or between blockchains and firms' systems, and adapt laws and regulations to support blockchain-enabled business models and exchange processes.

Appendix I. Description of the survey procedure and the questionnaire

Potential respondents were first approached by e-mail. In a first e-mail, we gave potential respondents an explanation of the survey objectives and asked them if they were willing to take part to it.

The questionnaire was then sent by e-mail only to those respondents who accepted to take part to the survey. This second e-mail contained a breif reminder of the objectives of the study and two attached files: a Word file with the questions and an Excel file that contained the direct relation matrix that the respondent should fill in.

The questionnaire in the Word file was organized in two parts as follows:

Part 1

This part contained questions with the objective of acquiring the following information:

- The size of the company.
- The sector in which the company is operating.
- The department the respondent works in.
- The position of the respondent in the company.
- The number of years of experience of the respondent in the current function.
- The total number of years of experience the respondent has in supply chain or IT related activities.

Part 2

This part contained one single question with the objective of acquiring the respondent's evaluation of the interdependencies among the twenty enablers.

The respondent was asked to fill in each cell of the matrix in the Excel file by one of the following numbers:

0 if he thinks that there is no impact of the factor in the line on the factor in the column of the cell
1 if he thinks that there is a low impact of the factor in the line on the factor in the column of the cell
2 if he thinks that there is a moderate impact of the factor in the line on the factor in the column of the cell
3 if he thinks that there is a high impact of the factor in the line on the factor in the column of the cell
4 if he thinks that there is a Very High impact of the factor in the line on the factor in the column of the cell

NB1: The list of the 20 enablers and their definitions were supplied in an appendix to the questionnaire.

NB2: As one factor could not impact itself, we already put "0" in the diagonal.

NB3: The Excel file contained a 20` × ` 20 with all the enablers listed in the columns and in the lines. To avoid confusion and filling errors, A note was incorporated in each cell in the table to indicate what the cell should contain. The note gave the full names of the impacting enabler in the line of the cell and the impacted enabler in the column.

NB4: Analysis considered only responses in which answers to all the questions are obtained and the Excel file is entirely completed.

Appendix II. Total Relation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Ri
Technological capabilities	F1	0.013	0.042	0.008	0.040	0.011	0.026	0.076	0.073	0.065	0.045	0.025	0.043	0.037	0.010	0.014	0.010	0.019	0.012	0.010	0.007	0.587
Knowledge	F2	0.053	0.013	0.005	0.037	0.008	0.045	0.076	0.077	0.060	0.046	0.025	0.038	0.036	0.011	0.014	0.008	0.016	0.012	0.008	0.008	0.596
financial resources	F3	0.067	0.065	0.003	0.034	0.004	0.015	0.021	0.054	0.033	0.009	0.033	0.037	0.033	0.006	0.008	0.006	0.014	0.005	0.005	0.003	0.453
Management commitment	F4	0.087	0.078	0.054	0.025	0.013	0.043	0.055	0.092	0.112	0.017	0.090	0.089	0.093	0.013	0.075	0.010	0.025	0.012	0.010	0.009	1.003
Integrity of data	F5	0.030	0.026	0.013	0.108	0.012	0.106	0.119	0.029	0.122	0.023	0.113	0.106	0.102	0.023	0.034	0.022	0.093	0.028	0.025	0.035	1.166
Improved data availability	F6	0.022	0.018	0.009	0.086	0.011	0.020	0.084	0.018	0.035	0.014	0.031	0.033	0.027	0.016	0.024	0.015	0.036	0.047	0.037	0.038	0.620
Lower transaction cost	F7	0.061	0.063	0.018	0.102	0.022	0.046	0.051	0.032	0.108	0.023	0.101	0.097	0.059	0.076	0.087	0.028	0.034	0.059	0.054	0.044	1.166
Ease in implementing changes	F8	0.009	0.009	0.003	0.016	0.006	0.038	0.061	0.007	0.069	0.008	0.025	0.029	0.028	0.007	0.010	0.008	0.010	0.014	0.007	0.006	0.371
Availability of credible and accurate data	F9	0.014	0.016	0.007	0.022	0.009	0.036	0.084	0.016	0.021	0.018	0.026	0.025	0.023	0.012	0.016	0.012	0.047	0.020	0.014	0.012	0.451
Cultural aspects transparency	F10	0.077	0.078	0.014	0.109	0.055	0.118	0.093	0.066	0.137	0.026	0.124	0.121	0.113	0.060	0.095	0.048	0.097	0.080	0.040	0.028	1.581
common rules for data disclosure	F11	0.017	0.019	0.011	0.055	0.011	0.081	0.094	0.034	0.090	0.019	0.026	0.037	0.050	0.018	0.026	0.017	0.044	0.020	0.014	0.012	0.693
process standardization	F12	0.023	0.018	0.009	0.048	0.013	0.096	0.100	0.055	0.095	0.017	0.086	0.028	0.060	0.021	0.024	0.017	0.058	0.023	0.015	0.015	0.820
adopt common objectives	F13	0.021	0.027	0.008	0.049	0.012	0.091	0.092	0.040	0.077	0.024	0.090	0.088	0.023	0.015	0.022	0.012	0.039	0.021	0.013	0.012	0.776
Developing and harmonizing blockchain standards	F14	0.023	0.033	0.010	0.072	0.080	0.103	0.088	0.034	0.091	0.023	0.084	0.066	0.063	0.018	0.054	0.081	0.051	0.058	0.040	0.041	1.113
Establishing clear governance rules	F15	0.020	0.018	0.007	0.043	0.076	0.106	0.109	0.047	0.085	0.033	0.103	0.092	0.093	0.038	0.022	0.021	0.041	0.032	0.021	0.021	1.026
Establishing rules and standards for interoperability	F16	0.028	0.052	0.013	0.105	0.083	0.106	0.108	0.055	0.077	0.031	0.116	0.106	0.104	0.033	0.062	0.016	0.034	0.062	0.047	0.039	1.274
Customer interest in the information	F17	0.099	0.100	0.058	0.131	0.041	0.134	0.086	0.052	0.143	0.086	0.139	0.133	0.127	0.085	0.110	0.092	0.042	0.095	0.087	0.080	1.919
Industry wide initiatives to promote blockchain	F18	0.055	0.056	0.016	0.097	0.056	0.080	0.056	0.040	0.078	0.054	0.085	0.073	0.071	0.043	0.069	0.022	0.050	0.021	0.045	0.045	1.112
Establishing regulatory framework	F19	0.041	0.066	0.019	0.125	0.091	0.127	0.129	0.069	0.129	0.083	0.126	0.112	0.105	0.075	0.111	0.087	0.066	0.096	0.027	0.055	1.735
government pressure	F20	0.036	0.031	0.013	0.063	0.048	0.042	0.040	0.023	0.057	0.020	0.060	0.049	0.051	0.037	0.061	0.059	0.024	0.059	0.057	0.012	0.841
	Cj	0.793	0.827	0.298	1.367	0.661	1.460	1.621	0.911	1.682	0.620	1.507	1.401	1.296	0.616	0.938	0.591	0.839	0.777	0.577	0.521	

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