Technology adoption and impact in supply chains: An empirical study of early-stage distributed ledger technology-based transparency solutions

D I S S E R T A T I O N

of the University of St.Gallen,

School of Management,

Economics, Law and Social Sciences

and International Affairs

to obtain the title of

Doctor of Philosophy in Management

submitted by

Dominik Röck

from

Germany

Approved on the application of

Prof. Dr. Erik Hofmann

and

Prof. Dr. Andrea Back

Dissertation no. 5014

Difo-Druck GmbH, Untersiemau 2020

The University of St.Gallen, School of Management, Economics, Law, Social Sciences and International Affairs hereby consents to the printing of the present dissertation, without hereby expressing any opinion on the views herein expressed.

St. Gallen, May 18, 2020

The President:

Prof. Dr. Bernhard Ehrenzeller

Acknowledgments

In this thesis, a three-year journey finds its end. The path of this dissertation led through many ups and downs, but it also gave me the opportunity to explore my passion for research, to meet inspiring people, and to gain interesting insight into various organizations. The journey was an invaluable experience for me. I take this opportunity to express my deepest gratitude to those who supported me along this way; without them, the valleys would have been much deeper.

To begin with, I would like to express gratitude to my doctoral advisor and co-author, Professor Erik Hofmann, who has given me endless support and advice, inspired me countless times, encouraged me in my endeavors, and helped me grow my passion for academic research. I am also thankful to my second supervisor, Professor Andrea Back. Her insightful feedback and ideas helped me to sharpen my arguments and take the storyline to a new level. Moreover, I thank Professor Alexander Pflaum for being my third supervisor and helping especially with his feedback on my first study. Furthermore, I thank Professor Wolfgang Stölzle for his feedback in countless Ph.D. colloquiums, which helped me to crystalize the practical relevance of my dissertation.

I owe many thanks to my co-authors Professor Henrik Sternberg and Professor Dale Rogers. Their insights, ideas, and experience helped me greatly along the journey. Furthermore, I am grateful to all the interview partners who allowed me to gain unprecedented access to their practices and solutions. The empirical contribution of this thesis would not be possible without them.

Over the past three years, I have spent countless hours at the Institute of Supply Chain Management of the University of St. Gallen (ISCM-HSG). Despite all the hard work, I enjoyed every day. This is also due to the people who spent time with me at the ISCM-HSG with me; for this, I thank Mathias Mathauer, who was my sparring partner and accompanied me throughout my journey, and Dr. Martin Haensel, who shared his experience and helped me get off to a good start years ago. Moreover, am thankful for the numerous talks and exchanges of ideas with

Stefan Selensky, which helped me especially for my single-authorship paper. Furthermore, I would like to thank Raphael Preindl, Philipp Wetzel, Maximilian Enthoven, Victor Wildhaber, Tim Brandl, and Julian Hess. Moreover, I want to thank Florence Hafner for creating a great work environment at the ISCM-HSG. In addition, I express my gratitude to all the interns and working students who supported me in the research projects at the ISCM-HSG and who helped me free up time for my own research: Matthias Giesbert, Michael Greger, Marvin Greifenstein, Leon Vossgröne, Davide Burkhart, Finn Stadler, Thomas Haskamp, Iva Mihaylova, Georgios Eleftheroudis, Helen Kment, Vanessa Heinrich, Marina Veselcic, Max Buder, Christian Plöscher, and Maren Gierlich.

I am thankful to my friends Dr. Tobias Mönch and Moritz Classen, both of whom encouraged me to start this endeavor in St. Gallen. I also thank Dominik Kohr and Dr. Erwin Hettich; our bike tours in the mountains around St. Gallen and in the Swiss Alps helped to refuel my energy along this journey.

I am extremely thankful to my wonderful girlfriend, Julia. With her endless optimism, encouragement, and love, she supported me every step of the way. Thank you for giving me confidence when I lost it and helping me up when I struggled the most. Thank you, Julia.

Von ganzem Herzen möchte ich meinen Eltern und meiner Schwester danken. Ihr habt mich seit 29 Jahren bedingungslos unterstützt und den Weg bereitet. Ohne Euch wäre nichts von all dem möglich. Danke für alles. Euch sei diese Dissertation gewidmet.

St. Gallen, May 2020 Dominik Röck

Table of contents

List of tables

List of figures

List of abbreviations

AI	Artificial intelligence
BCT	Blockchain technology
BDA	Big data analytics
BI	Behavioral intention to use
DAG	Directed acyclic graph
DLT	Distributed ledger technology
DOI	Diffusion of innovation
DSR	Design science research
EDI	Electronic data interchange
IoT	Internet of things
GPS	Global positioning system
PEOU	Perceived ease of use
PoW	Proof of work
PoS	Proof of stake
PU	Perceived usefulness
SCF	Supply chain finance
SCM	Supply chain management
SME	Small and medium-sized enterprises
STS	Socio-technical systems
TAM	Technology acceptance model
TCE	Transaction cost economics
TRA	Theory of reasoned action
TRAM	Technology readiness and acceptance model
TSC	Transparency in the supply chain

Abstract

In the era of digitalization, distributed ledger technology (DLT) is one of the most promising technologies that has caught the attention of practitioners and academic scholars in the field of supply chain management (SCM). Given the promise of DLT to enhance transparency, enable trust, improve the flow of information between organizations, and reduce the role of intermediaries, DLT appears to be uniquely positioned to tackle long-standing challenges in SCM. Hence, numerous DLT applications are being tested in pilot projects to leverage the potential of the emerging technology. However, despite the interest in DLT, the adoption of DLT applications is moving slowly. Moreover, the impact of the few applications that have been implemented remains unclear. Thus, SCM practitioners are struggling to assess DLT, as they continue to face uncertainty about the technology itself, its functionalities, its applications, and the existing adoption barriers.

This thesis illuminates the adoption and impact of DLT in supply chains, focusing on DLT applications that aim at enhancing transparency in the supply chain (TSC), referred to as DLT-based TSC solutions. Therefore, the thesis draws on case study research and design science research to fill the void of empirical research on the nascent phenomenon of DLT in supply chains. The thesis comprises four studies. The first study classifies DLT applications in supply chains and identifies the value contributions of each class of DLT application. The second study operationalizes TSC as the application context of DLT-based TSC solutions. The third study analyzes adoption decisions related to DLT-based TSC solutions by providing insight from the perspectives of multiple supply chain actors. The fourth study sheds light on the impact of early-stage DLT-based TSC solutions on cost and governance structures in supply chains.

The findings of this thesis provide academic scholars with early-stage empirical findings and pave the way for future, more application-specific research on DLT in supply chains. Moreover, the thesis helps supply chain managers to understand DLT-based TSC solutions, their application context, adoption decisions in supply chains, and the impact of adoption.

Zusammenfassung

Im Zeitalter der Digitalisierung scheint die Distributed Ledger Technology (DLT) angesichts der Versprechen, die Transparenz zu erhöhen, Vertrauen zu schaffen, den Informationsfluss zwischen Organisationen zu verbessern und die Bedeutung von Intermediären zu reduzieren, in einer einzigartigen Position zu sein, um substantielle Herausforderungen im Supply Chain Management (SCM) zu bewältigen. In zahlreichen Pilotprojekten wird daher das Potential der neuen Technologie getestet. Jedoch kommt die Einführung von DLT-Anwendungen nur langsam voran. Zudem sind die Auswirkungen der wenigen Anwendungen, die bereits implementiert wurden, noch unklar. Daher haben Praktiker Schwierigkeiten, DLT zu bewerten.

Diese Arbeit beleuchtet die Einführung und die Auswirkungen von DLT in Lieferketten, wobei der Schwerpunkt auf DLT-Anwendungen liegt, die auf eine Verbesserung der Transparenz in der Lieferkette (TSC) abzielen, die als DLT-basierte TSC-Lösungen bezeichnet werden. Die Dissertation umfasst vier Studien. Die erste Studie klassifiziert DLT-Anwendungen in Lieferketten und identifiziert den Wertbeitrag jeder Klasse von DLT-Anwendungen. Die zweite Studie operationalisiert Transparenz in der Lieferkette als den Anwendungsbereich von DLT-basierten TSC-Lösungen. Die dritte Studie analysiert Adoptionsentscheidungen im Zusammenhang mit DLT-basierten TSC-Lösungen. Die vierte Studie beleuchtet die Auswirkungen von DLT-basierten TSC-Lösungen im Frühstadium auf Kosten- und Governance-Strukturen in Lieferketten.

Die Ergebnisse dieser Arbeit liefern akademischen Wissenschaftlern frühe empirische Erkenntnisse und ebnen den Weg für zukünftige, anwendungsspezifischere Forschung über DLT in Lieferketten. Darüber hinaus hilft die Dissertation Supply Chain Managern, DLT-basierte TSC-Lösungen, ihren Anwendungskontext, Adoptionsentscheidungen in Supply Chains und die Auswirkungen der Einführung zu verstehen.

1 Introduction: In the dust of hype – Adoption and impact of distributed ledger technology in supply chains

Nine years after the introduction of blockchain technology (BCT) by Nakamoto (2008), the most prominent distributed ledger technology (DLT), stood in the spotlight of public awareness. Fueled by the hype of cryptocurrencies, BCT and other DLTs entered the main stage of public awareness. After the cooldown of the cryptocurrency markets at the end of 2017, the focus slowly shifted to DLT, the underlying technology of cryptocurrencies. DLT is a computing protocol that orchestrates the storage and distribution in distributed networks.[1] The technology is praised for its potential to provide transparency (Martyn, 2018), promote trust (Beck, Stenum Czepluch, Lollike, & Malone, 2016), reduce the role of intermediaries (Gupta, 2017), and settle transactions in near real-time and at low cost (Catalini, 2017b). Thus, the application of DLT has been explored by companies, governments, research institutions, and non-governmental organizations in various fields, such as finance, governance, health care, insurance, and supply chain management (SCM) (Catalini, 2017a). In a survey by Deloitte, it was found that SCM is at the forefront of all fields of application (Pawczuk, Massey, & Schatsky, 2018). The study revealed that 53% of the 1,053 surveyed companies work on a DLT use case in their supply chains.

Supply chains are inter-organizational networks, consisting of multiple nodes (e.g., suppliers and customers) and edges (i.e., the relations between those nodes) (Carter, Rogers, & Choi, 2015). Mentzer et al. (2001) define *supply chains* as

> "a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer" (p. 4).

The management of the supply chain is called *SCM*, which is defined as follows:

[1] Described in detail in Study 1, also found in Appendix A.

> “[T]he systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole” (Mentzer et al., 2001, p. 18).

With these definitions of supply chains and SCM, Mentzer et al. (2001) underline the inter-organizational characteristic and multi-object characteristic of the supply chain, as it comprises product, service, financial, and information flows that stretch across multiple organizations.

With the emergence of DLT, both practitioners and academic scholars in the field of SCM see the potential to address substantial challenges in SCM (e.g., Babich & Hilary, 2019; Casey & Wong, 2017; Wang, Singgih, Wang, & Rit, 2019). Still, to this day, modern supply chains are characterized by a lack of information sharing between the involved partners (Zhou & Benton Jr., 2007), leading to a lack of transparency (Williams, Roh, Tokar, & Swink, 2013) and trust (Ireland & Webb, 2007). Consequently, supply chain managers are battling with the resulting negative effects, such as the bullwhip effect (Lee, Padmanabhan, & Whang, 1997), opportunistic behavior (Williamson, 2008), and the need for intermediaries, which lead to rising transaction costs (Grover & Malhotra, 2003).

Given these challenges in SCM and the matching potential of DLT, the technology appears to be a sure-fire success in SCM. For example, several companies and start-ups are testing DLT to determine whether it can provide product traceability for goods such as gemstones (Cartier, Ali, & Krzemnicki, 2018; Torcasso, 2018), diamonds (Paton, 2018), clothing (Gonzalez-Rodriguez, 2019), and food (Aitken, 2017; IBM, 2019). In addition to tracing products, DLT applications target supply chain finance (SCF) by seeking to speed up transactions, reduce transaction costs, and reduce the role of intermediaries such as banks and insurance companies (Hofmann, Strewe, & Bosia, 2018).

However, up to the time of writing, the success of DLT has been limited. The Gartner Hype Cycle for 2019 placed BCT—the most prominent representative of

DLT—on the threshold of the so-called "trough of disillusionment" (Panetta, 2018). The position is a reflection of the current public perception of DLT. Pilot projects and proofs of concept are being abandoned, as the initially claimed potential has not yet materialized. Instead, supply chain actors are struggling to adopt the novel technology (Schmahl et al., 2019). As DLT applications in SCM constitute inter-organizational information systems (IOIS), the successful use of the technology requires the adoption of multiple supply chain actors to unleash the potential of DLT and its applications. Hence, DLT must deliver benefits for all relevant actors for successful adoption and, thus, to achieve the potential impact that has been forecast by practitioners and academic scholars.

Despite the slow adoption of DLT, interest in the technology remains, as evidenced by the large number of DLT projects in SCM today (Dimitrov, 2019; Pawczuk et al., 2018). Thus, against the backdrop of the slow adoption of DLT and the simultaneous great interest in the enormous potential of DLT for SCM, conducting research on the adoption and the impact of DLT in supply chains is important and valuable.

1.1 Scholars' difficulty in grasping the adoption and impact of distributed ledger technology in supply chain management

The core of technology adoption is an individual's or organization's decision to adopt a specific technology. In the era of digitalization and digital transformation, technology adoption is yet again the center of attention, as the digitalization of supply chains entails technology adoption decisions (e.g., Heim & Peng, 2019). DLT represents one of the most frequently discussed technologies in the age of digitalization, especially when it comes to the digitalization of the supply chain and the inter-organizational collaboration of firms within a supply chain (Hofmann, Sternberg, Chen, Pflaum, & Prockl, 2019). Given the extant literature on technology adoption—and particularly on the adoption of IOIS—academic scholars can draw on the established models to study the adoption of DLT in supply chains. These models (e.g., Iacovou, Benbasat, & Dexter, 1995) enable to gain a basic understanding, as they reveal the core elements and their relationships with technology adoption as a general phenomenon.

However, studying the adoption and resulting impact of DLT in supply chains entails three facets that have not yet been illuminated by extant research on technology adoption and impact. First, DLT applications in supply chains are built up according to the network effect (Schmidt & Wagner, 2019). With each adopter, the application becomes more valuable. In contrast, a lack of adopting supply chain actors reduces the efficiency of DLT application. Thus, the network effect entails the need for the adoption of DLT applications by multiple supply chain actors. Second, the types and targets of DLT applications in supply chains, their underlying technological protocol, and their user groups are quite different. Unlike research on the adoption of other IOIS such as electronic data interchange (EDI) (Iacovou et al., 1995; Premkumar & Ramamurthy, 1995) or collaboration systems (Grover, 1993), DLT solutions in supply chains represent heterogeneous units of observations and thus cannot be studied as a homogenous technology. Third, DLT applications in supply chains constitute a nascent phenomenon with a rather small number of DLT initiatives at an early stage, which is amplified by the aforementioned heterogeneity. Thus, the current state of DLT in supply chains does not allow us to study the adoption based on a large-scale empirical data set at the time of this writing. In parallel, academic scholars cannot build their research on a large foundation of empirical contributions. Consequently, conducting research on the adoption and impact of DLT is like breeding a new plant in a well-known field with only partly fitting tools—it requires both exploratory and explanatory research (Schmidt & Wagner, 2019).

Explaining the adoption and impact of DLT in supply chains—the new plant in a well-known field—requires understanding the reasons that lead organizations to decide to adopt DLT applications in their supply chains. Existing technology adoption models—the partly fitting tools—illustrate three (e.g., Premkumar & Ramamurthy, 1995) or five (e.g., Grover, 1993) generic antecedents that cause organizations to adopt technologies. The model by Iacovou et al. (1995)

summarizes these by presenting *perceived benefits*, *organizational readiness,* and *external pressure* as the factors that cause positive adoption decisions. In this way, they constitute a core element of technology adoption models: the antecedents to adoption decisions.

When focusing on the adoption of DLT in supply chains, the first factor, perceived benefits, remains unknown, given the novelty of the technology and the absence of empirical contributions. The existing contributions about DLT in supply chains have revealed long lists of potential benefits, yet they lack empirical evidence. Moreover, the literature does not account for the heterogeneity of DLT applications in supply chains. This heterogeneity rather requires a study of the perceived benefits on the level of specific applications. In addition, the discussed benefits are partially contradictory, as revealed in the study by Wang et al. (2019). While some potential benefits, such as disintermediation, are frequently discussed in the literature (Wang, Han, & Beynon-Davies, 2018), the experts in the study of Wang et al. (2019) do not list disintermediation as a potential benefit of DLT in supply chains. Hence, a structured exploration of the perceived benefits is lacking but constitutes a key to understanding and explaining adoption decisions.

In addition, while some supply chain actors may perceive a specific value contribution of DLT to be a benefit, other actors might not. Thus, the benefits depend on the perspective. For example, the enhanced traceability of DLT-based solutions is perceived as a benefit in some industries, such as in the diamond and gemstone industry, as brands such as Brilliant Earth or Tiffany & Co. can disclose the origin and journey of a diamond to the end customer. The enhanced level of traceability ultimately allows storytelling and fulfills the end customers' request for more traceability, thus justifying a surcharge and leading to a financial profit for the retail company. Logically, jewelry brands are often the initiators of such solutions (Hsu, 2019; Robinson). However, miners, cutters, and polishers do not take advantage of the enhanced traceability in the same way. Instead, they must upload additional data to enable the DLT-based traceability solution.

Following these arguments, the present thesis aims to contribute to the exploration and understanding of the adoption of DLT in supply chains, including the perceived benefits, by accounting for the heterogeneity of DLT applications in supply chains and the different perspectives of individual supply chain actors. This first requires an understanding of the heterogeneity of DLT applications in supply chains, which will help in defining the value contributions of these applications, enabling further, more detailed studies on the adoption and impact of DLT in supply chains, both within the present thesis and in future research.

The aforementioned heterogeneity of DLT applications in supply chains suggests that a specific application of DLT in supply chains should be selected when studying the adoption and impact of DLT in supply chains. DLT applications that aim to enhance transparency in the supply chain (TSC)—hereafter referred to as DLT-based TSC solutions—are frequently discussed by practitioners (e.g., Casey & Wong, 2017; Kewalram, 2019) and academic scholars (e.g., Cartier et al., 2018; Jahanbin, Wingreen, & Sharma, 2019). DLT-based TSC solution summarize DLT applications that aim to enhance traceability of products and the visibility of supply chain actors and their processes. They build on DLT as an underlying technology to orchestrate the storage and distribution of data, and rely on multiple databases for data input and include additional technologies such as sensors for data gathering.[2] These DLT applications represent 75% of the DLT initiatives in the field of SCM.[3] The emergence of DLT appears to be right on time, as global supply chains are in desperate need of transparency (Schmahl et al., 2019). Extant literature emphasizes the importance of TSC as the demand for TSC steadily increases (Williams et al., 2013). On one hand, end customers are demanding information disclosure about products concerning sustainability, corporate social responsibility, and quality issues (Miller, Fugate, & Golicic, 2017). On the other hand, organizations need to enhance TSC in the light of globalized supply chains

[2] According to the classes of Study 1, DLT-based TSC solutions comprises the classes the product traces (class 1) and the supply chain supervision (class 3). For further details, see Appendix A.
[3] As revealed in an earlier version of Study 1, in Roeck (2020).

and the increasing outsourcing of value creation to orchestrate their supply chains (Linch, 2014; Schmahl et al., 2019).

However, TSC as a target for many DLT initiatives is fuzzy in itself. Extant literature on TSC has not operationalized TSC (Williams et al., 2013). Thus, it remains unexplored how organizations can enhance TSC (Swift, Guide Jr., & Muthulingam, 2019). While existing literature on TSC has revealed several antecedents, such as data accessibility, accuracy, and availability (Srinivasan & Swink, 2018; Zhu, Song, Hazen, Lee, & Cegielski, 2018), a structured and comprehensive analysis of the determinants of TSC, which must be attained to enhance TSC, is missing. Consequently, the perceived benefits of novel technologies such as DLT for enhancing TSC remain intangible for both practitioners and academic scholars (Lacity, 2018; Weking, Mandalenakis, Hein, Hermes, Böhm, & Krcmar, 2019). Therefore, this thesis sets out to operationalize TSC by identifying the determinants of TSC and explaining how organizations can enhance TSC.

With a focus on DLT-based TSC solutions, it is necessary, for most applications of DLT in the field of SCM, to understand the adoption decision in the supply chains (Babich & Hilary, 2019; Schmidt & Wagner, 2019). However, only a specific focus on a homogenous class of DLT applications can allow for an in-depth understanding of the adoption decision to be developed. While information systems (IS) research has, in particular, dealt with adoption of novel technologies and the behavior of markets, organizations, and individuals (e.g., Davis, Bagozzi, & Warshaw, 1989; Iacovou et al., 1995; Venkatesh & Davis, 2000), DLT adoption requires an analysis of the drivers for and against adoption in detail, along with a consideration of the different perspectives of the individual supply chain actors, as illustrated above. However, fully understanding adoption includes not only the study of a number of supply chain actors' adoption decisions independently but also of the interdependencies of the adoption decisions of each actor in the supply chain. Only in this way can a detailed understanding of adoption decisions be reached and help future research address the adoption issues surrounding DLT in SCM.

Following the adoption decision, the resulting impact of the adoption of DLT-based TSC solutions also remains unexplored. While conceptual research has outlined the potential of DLT-based TSC solutions (Saberi, Kouhizadeh, Sarkis, & Shen, 2019; Tian, 2016), empirically grounded evidence of its actual impact is thus far missing. However, studying the impact is important, as it contributes to an understanding of the value of DLT applications in supply chains and enables a comparison of the great potential DLT is thought to have with the actual application results (e.g., Casey & Wong, 2017; Gupta, 2017). Moreover, the resulting impact of DLT adoption will drive other organizations to adopt the technology, as they will expect a similar impact, which influences their individually perceived benefits (Rogers, 1962). That said, the impacts of the adoption of DLT-based TSC solutions can be diverse. Hence, studying its impact on various structures and processes appears to be reasonable, as these are more than just incremental improvements and will ultimately affect costs as well.

As organizations' adoption decisions about DLT form cost-driven investment decisions, it is also important to analyze their financial impact. In this regard, DLT-based TSC solutions must showcase a positive return to justify the adoption decision (Higginson, Nadeau, & Rajgopal, 2019). Through transaction cost economics (TCE), SCM scholars can draw on a theoretical concept that provides the basis on which to study structures and processes (e.g., governance structures) and analyze costs of transactions in supply chains (Grover & Malhotra, 2003). Given the promise of DLT-based TSC solutions that aim to enhance transparency and thereby enable trust between supply chain actors (Catalini & Gans, 2016; Schmidt & Wagner, 2019), an empirical analysis of the impact of DLT-based TSC solutions on transaction costs appears to be a worthwhile investment. Thus, this dissertation aims to explore the impact of DLT-based TSC solutions on transaction costs and to explain the effect mechanisms.

1.2 Supply chain actors are slow to adopt despite the promise of distributed ledger technology

DLT is one of many digital technologies that supply chain managers are considering as they seek to address challenges in their supply chains or to harness the potential of novel technologies to improve supply chains. The following example of the restaurant Chipotle Mexican Grill (Chipotle) illustrates the importance of addressing such challenges adequately.

The example of Chipotle Mexican Grill

The multiple food safety incidents that have occurred at the fast-casual food chain Chipotle underlines the need for supply chain managers to address challenges in their supply chains. By early 2015, Chipotle was a success story in the restaurant business. The brand grew in just 13 years from 1 restaurant to more than 2,000 restaurants in the United States (US), with an increase in the stock price of 1,000% over a period of less than 10 years (Walker & Merkley, 2017). The restaurant was publicly celebrated for serving "food with integrity" after banning pork meat for six months, when Chipotle's supply chain managers were unable to secure pork meat that met the company's standards (Kim, 2015). Unlike other restaurant chains, Chipotle sourced its ingredients from smaller regional and local farmers (a maximum of 350 miles from a given restaurant) to ensure fresh and high-quality food for their customers (Walker & Merkley, 2017).

In this way, Chipotle's supply chain was rather more complex than its competitors' supply chains, which used a small number of large-scale suppliers such as Cargill (Jargon, 2015). Given its large number of local suppliers, Chipotle was unable to source directly and thus decided to purchase ingredients via third parties and to use 24 third-party owned and operated distribution centers (Walker & Merkley, 2017). Chipotle only accepted the selection of suppliers (especially farmers) offered by these third parties after screening them initially. With a large number of

> suppliers and a lack of direct contact with the local farms, Chipotle's supply chain managers lacked TSC, a challenge that presented them with a ticking time bomb, which exploded in August 2015.
>
> Within three months, Chipotle's food caused food poisoning from salmonella (Minnesota and Wisconsin), norovirus (California), and Escherichia coli (E. coli) (Oregon and Washington). In total, 181 fell ill, 36 restaurants were affected, multiple restaurants closed (e.g., all 43 in Oregon and Washington) (Walker & Merkley, 2017), stock prices decreased by around 42% (Saberi et al., 2019), and sales decreased by around 16%. Due to the lack of TSC, Chipotle was unable to consistently monitor its suppliers to avoid such incidents and trace back the food in the restaurants to recall contaminated food in time.

The example of Chipotle[4] is one of many cases that illustrates a lack of transparency as one of the main challenges that supply chain managers have been facing for decades and the risk of not addressing this challenge effectively. As in the case of Chipotle, the horsemeat scandal that occurred in Europe in 2013[5] revealed a lack of traceability on the product level (Linch, 2014). Moreover, an explosion at a production site of Evonik Industries[6] caught numerous automotive original equipment manufacturers (OEMs) off guard and caused supply shortages, as the OEMs lacked visibility in their upstream supply chain and failed to disclose the strategic importance of the nexus supplier Evonik Industries. The company's production site accounted for over 50% of the worldwide production of PA 12, a supplement that was indispensable for most fuel lines and brake lines in the automotive industry (Yan et al., 2015). Given these examples of a lack of TSC, it is obvious why supply chain managers are embracing the emergence of novel digital technologies such as DLT that, among other things, promise to enhance TSC. Numerous retailers in the food industry, such as Walmart (Aitken, 2017),

---

[4] More on the food incidents of Chipotle can be found in the teaching case of Walker and Merkley (2017).

[5] More on the horsemeat scandal in Europe in 2013 can be found in Linch (2014)

[6] More on the incident at Evonik Industries can be found in Yan, Choi, Kim, and Yang (2015) and Evans (2012).

Carrefour (Aitken, 2017), Carrefour (Metcalfe, 2019), and Auchan (Vanoye, 2018), are trying to address the lack of traceability through DLT projects.

However, the aspiration to make use of DLT to enhance TSC or address other challenges and leverage the potential of the technology is not limited to the food supply chain. A significant number of large enterprises in a number of industries have launched DLT projects in SCM, such as the automotive (including companies such as Bosch, BMW, Volkswagen, and Volvo), transportation and logistics (e.g., Maersk, CMA CGM, and Kühne + Nagel), pharmaceutical (e.g., Bayer, Roche, Novartis, and Boehringer Ingelheim), jewelry (e.g., Tiffany & Co., Cartier, and Brilliant Earth), and chemical (e.g., BASF) industries. Aside from enhancing traceability, these projects aim to do the following:

- Digitize and automize processes, such as in the example of TradeLens,[7] which digitally distributes shipping documents to enable digital processing for customs authorities and port operators.
- Enable secure information sharing and trusted records, such as in the example of TradeIX,[8] which leverages DLT to reduce transaction costs and thus provide corporates and especially SMEs with option to finance their supply chain operations (e.g., inventory finance).
- Verify product authenticity, such as in the example of Boehringer Ingelheim and SAP,[9] which designed a process to allow supply chain actors in the pharmaceutical industry (e.g., wholesalers and drug stores) to digitally verify products.

According to Deloitte's global survey on DLT conducted in 2019, 53% of the participants viewed DLT as one of the top five strategic priorities (Pawczuk, Massey, & Holdowsky, 2019), which is in line with Dimitrov (2019), who argued that an increasing number of large enterprises were seeking to use DLT in 2019. While this underlines the importance of DLT in general, Deloitte's DLT study

[7] Link to company website: https://www.tradelens.com/
[8] Link to company website: https://tradeix.com/
[9] Link to project website: http://bit.ly/2O4HnuF

from 2018 indicated that 53% (N = 1,053) of the participants worked on DLT projects in the field of SCM, ranking the discipline in first place (Pawczuk et al., 2018). The survey participants of Deloitte's 2018 study further underline the significance of DLT, as 65% of the participants indicated that their organizations would spend more than US$1 million on DLT projects in 2019 (Pawczuk et al., 2018).

Despite the importance of DLT for practitioners and the great potential of the technology in supply chains (e.g., Casey & Wong, 2017; Gupta, 2017), supply chain actors are slow to adopt DLT applications (Schmahl et al., 2019). First, the novel technology is in a testing phase than being implemented on a large scale, as evidenced by a large number of DLT pilot projects but an absence of large-scale implementation in the field of SCM (Pawczuk et al., 2019). Second, the vast majority of DLT projects are initiated by large enterprises, with little involvement of SMEs (Dimitrov, 2019). According to Pawczuk et al. (2019), organizations see barriers to adoption in regulatory issues, the replacement of and adaption to established infrastructure, security issues, an uncertain return on investment, the lack of internal capabilities, concerns over information disclosure, and the lack of a compelling application. In other words, the respondents listed high-level barriers that fall into the category of negative factors for technology adoption, including perceived obstacles (security issues, an uncertain return on investment, concerns over information disclosure, and the lack of a compelling application), external resistance (regulatory issues), and organizational immaturity (replacement of and adaption to established infrastructure and the lack of internal capabilities).

Another perceived obstacle was described by Wang et al. (2019). The experts in the study explained that "many organizations are still unsure of blockchain technicalities, functions or benefits" and "the concept of the technology is complex and difficult to grasp" (Wang et al., 2019, p. 231). These explanations underline the lack of clarity about DLT for supply chain managers, which presents a key adoption barrier. Furthermore, a Swiss-based survey among logistics and supply chain managers by Mathauer and Hofmann (2020) confirmed these barriers and added another characterizing barrier for SCM: over 75% of the respondents were worried that not all relevant supply chain actors will adopt DLT because they do not see enough benefit for themselves (Mathauer & Hofmann, 2020). Another substantial barrier that was described by the experts consulted in the study of Wang et al. (2019) is the complex adoption decision in supply chains, illustrated in the following example of TradeLens.

> *The example of TradeLens*
>
> In March 2017, the world's largest ocean carrier, Maersk, and the technology giant International Business Machine (IBM) announced that they were jointly launching TradeLens, a DLT-based ecosystem that aimed to digitalize the document flow of global trade and to include all relevant stakeholders for global container shipping operations. Although several relevant actors—including port authorities, terminal operators (e.g., APM and KAPM in Rotterdam), additional ocean carriers (e.g., ZIM, PIL, and Seaboard Marine), and customs authorities—decided to join the ecosystem, at first, other terminal operators, ocean carriers (e.g., CMA CGM, MSC, and Hapag Lloyd), and customs authorities refused to adopt TradeLens or decided to build their own DLT-based ecosystem (Cosgrove, 2019). Although Maersk's largest competitors, CMA CGM, MSC, and Hapag Lloyd, similarly identified the potential of DLT, they refused to join a platform that was built by and developed to address the needs of their competitors (Andersen & Vogdrup-Schmidt, 2018). Data privacy issues, trust in the other users of the platform including their competitors, and the fear to lack control over the platform led them to develop their own DLT applications at first. In May 2019, CMA CGM and MSC announced that they would adopt TradeLens and integrate their own functionalities as well (Cosgrove, 2019; Linnet, 2019).

The example of TradeLens illustrates that adoption decisions about DLT applications are complex. Most DLT applications in supply chains, such as TradeLens, require a large number of relevant actors to adopt the technology to make use of the potential. At the same time, the adoption decision can be quite complex from an actor's perspective, as the decisions made by CMA CGM and MSC underline. Several DLT applications such as TradeLens build industry-wide ecosystems that affect the competition and interorganizational collaboration (Lumineau, Wang, & Schilke, 2020). Especially for SMEs—which may not have the same resources as do large enterprises to test and build up knowledge with DLT pilots and proofs of concept—adoption decisions related to DLT in SCM remain a substantial challenge.

Aside from the adoption of DLT in supply chains, the impact of DLT on supply chains and their management remains unclear. While a declining majority of practitioners still view DLT as a disruptive innovation (56%), a growing number (43%) see DLT as overhyped (Pawczuk et al., 2019). Despite an increasing number of DLT projects in SCM, little evidence has indicated the impact of the novel technology. One issue is that only a few DLT pilots have shared their results. For example, the DLT pilot of GS1 Switzerland provided evidence that DLT can, in fact, help reduce the time needed for pallet exchange in the transportation industry by speeding up the process (Haas-Hamannt & Feda, 2018), while Carrefours' sales volume increased after introducing DLT (Thommson, 2019). However, the impact described in both examples is certainly not evidence of disruptiveness, as the early perception of DLT suggested, and only partially assesses the discussed potential of the technology.

In sum, DLT as an emerging technology is of great interest to supply chain managers due to its potential to address substantial challenges in the field. However, despite an increasing number of DLT projects, adoption in supply chains is slow and appears to be a complex phenomenon. Moreover, practitioners lack a clear picture of the impact of DLT in supply chains. Thus, the relevance of this dissertation is two-fold: First, the present thesis sheds light on the adoption of DLT-based TSC solutions, taking both the actor and the network perspective. Second, it sheds light on the observable impact of DLT-based TSC solutions.

1.3 Thesis goal: Exploring the adoption and the impact of distributed ledger technology in supply chains

Despite the great interest of both practitioners and academic scholars in DLT applications in supply chains, the adoption of these is still slowly moving forward and has not received substantial attention in the field of SCM. In the same way, the impact of DLT applications in supply chains remains unclear. However, both are tightly connected, as adoption is a prerequisite to impact, and impact is an influencing factor upon adoption decisions (Rogers, 1962). Thus, this thesis aims to contribute to this void and help form an understanding of the adoption and impact of DLT applications in SCM. However, the heterogeneity of DLT applications in the field of SCM limits the generalizability of studies on DLTs. As such, to make a valuable contribution, it is instead necessary to focus on a specific and relevant DLT application in the field of SCM. Thus, this thesis centers around the most deployed and tested DLT applications in supply chains. These are DLT-based solutions that aim at enhancing TSC. Therefore, the focus of this thesis is DLT-based TSC solutions. DLT-based TSC solutions consist of an underlying DLT protocol that orchestrates (i) data storage and distribution among supply chain actors (ii), and include additional information technology (IT) and draw on databases for data input.[10] Consequently, the focus of this thesis is on DLT-based TSC solutions, which leads to the definition of the overall goal of the present thesis:

Thesis goal: Explaining the adoption and impact of DLT-based TSC solutions.

With this goal in mind, the main topic of this thesis is limited to this type of DLT application and clearly focuses on SCM. To achieve this goal, four steps must be taken. First, the goal requires diving deep into the different types of DLT-based applications in SCM and carving out the classes to clearly delimit DLT-based TSC solutions from other DLT applications and describe their core value contributions. Second, the goal requires understanding the application context of

[10] As revealed in Study 1, which can be found in Appendix A.

DLT-based TSC solutions, which leads to the need to shed more light on the phenomenon of TSC to understand and explain the value of DLT for TSC. Third, the goal requires studying the adoption decisions related to a DLT-based TSC solution in a supply chain with multiple actors. Fourth, the goal requires analyzing the impact of DLT-based TSC solutions.

2 Fundamentals: Made for each other – Distributed ledger technology and transparency in supply chains

2.1 Distributed ledger technology as a new computing paradigm

DLT is an umbrella term that unites several technologies, such as BCTs and directed acyclic graphs (DAGs) (Schueffel, 2018).[11] This thesis focuses on these two technologies as BCTs are the most frequently used DLTs in SCM, while DAGs are just emerging at the time of this writing.[12] DLT—and, thus, these two subordinate technologies—are built on a protocol that defines the orchestration of (i) data distribution, (ii) data storage, (iii) applied consensus mechanism, and (iv) permission rights. While BCTs and DAGs protocols lead to the same results in terms of data distribution, data storage represents the distinguishing characteristic between the two DLTs. Furthermore, the consensus mechanism and permission rights further distinguish different BCTs and different DAGs.

2.1.1 Data distribution of DLTs

As indicated by the name DLT, data is stored in distributed ledgers in a network of at least two entities (also referred to as nodes). In this way, a decentralized network is created, in which each entity in the network holds a record of the exact same ledger with the same data duplicates (Tapscott & Tapscott, 2016). The protocol of DLTs defines that every time new data is entered, all ledgers of each entity will be updated via peer-to-peer communication. Thus, no central authority is needed that communicates an update and thus holds the position of being the single source of truth (Swan, 2015). In contrast, in a distributed ledger, all entities

[11] This sub-section partially draws upon the content of Study 1, which is found in Appendix A.
[12] As revealed in an earlier version of Study 1, in Roeck (2020).

pose ledgers with the same records and are able to check the correctness of each ledger by comparing it to the ledgers of the other network entities (Schlatt, Schweizer, Urbach, & Fridgen, 2016). As each entity can see the records in another entity's ledger, a comparison is carried out continuously. As such, the integrity of the ledgers within each network is checked continuously, and a manipulated ledger will be detected based on the disparity between it and the other ledgers in the network (Rauchs, Blandin, Bear, & McKeon, 2019). BCTs and DAGs contain protocols that orchestrate such a data distribution to achieve a decentralized network of distributed ledgers that automatically maintains its integrity.

2.1.2 Data storage of DLTs

BCTs and DAGs differ in their applied storage of data, orchestrated by their protocols. BCTs aggregate individual transaction data and store these data in blocks. The number of transactions that are aggregated in a single block varies between different blockchains.[13] As new transactions are issued, they are chronologically aggregated into a new block. This block is directly linked to the previous block of the currently existing chain of blocks. Each block has a unique block header, its unique identifier, which is converted into a hash (Yli-Huumo, Ko, Choi, Park, & Smolander, 2016). As such, each new block is linked to the previous block via the hash of the header of the previous block, as illustrated in Figure 1. In this way, the chain of blocks is extended with a new block. Using the hash of the previous block, the blocks are chronologically and immutably connected, enabling users to trace back each transaction in blocks, as computers simply have to follow back along the chain of blocks.

[13] Bitcoin has a maximum block size of 1 megabyte (Croman et al., 2016). Ethereum's average block size depends on the complexity of the content in the block and is currently between 17 kilobytes and 58 kilobytes (Etherscan, 2020).

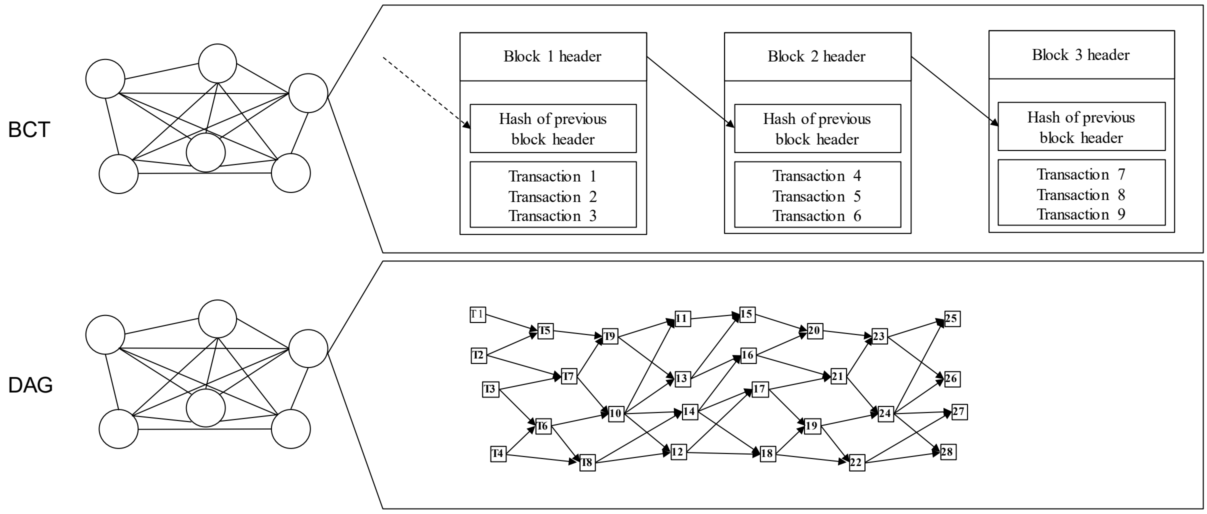


Figure 1: Exemplifying BCTs and DAGs[14]

In contrast to BCTs, DAGs store individual transactions and link them to each other (in Figure 1 represented by boxes with TX, which stands for "transaction x"). Hence, they are not aggregated in a block. Instead, each individual transaction is stored in a separate data node (Weisenberger & de Knegt, 2019). To enter a new transaction, an entity in the distributed network must enter the transaction data and reference one or (as in the case of IOTA) two previous data nodes, which form tips in the network (Schueffel, 2018). By establishing this reference, the entity that adds a new node must validate at least one previous node. In this way, the integrity of the network is ensured, while the edges also enable the tracing back of individual transactions (Schueffel, 2018). Figure 1 illustrates both data distribution in a network and data storage in BCTs and DAGs.

2.1.3 Consensus mechanisms of DLTs

In addition to data distribution and data storage, DLTs' protocols also define how an agreement on transaction data is reached. This is defined in the consensus mechanism, which verifies individual transactions (DAGs) and blocks (BCTs) to maintain consistent and correct ledgers in the network (Weisenberger & de Knegt,

[14] The example of BCT is here the Bitcoin blockchain, as the number of transactions in each block is equal. The example of DAG is here the IOTA DAG, as each new node has a reference to two parent nodes (represented by two incoming edges).

2019). Different DAGs vary in their concrete realization of the applied mechanism to maintain the integrity of the network.[15]

BCTs, for instance, apply proof-of-work (PoW) as a consensus mechanism. In a PoW, new blocks are created by miners (Swan, 2015). These miners solve mathematical puzzles to find a new block. In doing so, they validate new transactions that are waiting to be stored in blocks. The puzzles require substantial computing power, while all miners compete to find the solution for the puzzle. The miner that is the first to solve the puzzle establishes a new block to aggregate multiple transaction data and therefore gets a reward (e.g., payment) (Schlatt et al., 2016). Through this process, the network is validated, new blocks are generated, and the integrity of the network is maintained. The bitcoin blockchain makes use of such a PoW consensus mechanism.[16] As multiple miners are simultaneously computing to find the solution, a PoW has its disadvantages in terms of its high energy consumption and corresponding costs for mining, and thereby maintaining, the ledger (Spirakis & Tsigas, 2017). Moreover, as the blocks have only a limited size, transactions must wait until they can be stored in new blocks (Beck et al., 2016). Thus, the scalability is limited to a certain number of transactions per second (Yli-Huumo et al., 2016). As DAGs directly store the transaction data, applications with a high transaction volume reach the limit of BCTs and thus favor the use of DAGs (Schueffel, 2018; Thake, 2018).

2.1.4 Permission rights of DLTs

Realizations of both BCTs and DAGs differ in their design of the permission rights. In general, DLTs are divided into public, private, and consortium DLTs. Public DLTs (e.g., Bitcoin or IOTA) can be joined by everybody; each participant can join and leave the network upon their own decision and can participate in the consensus mechanism (O'Leary, 2017). Within a public DLT, all transactions are

[15] For example, IOTA requires the verification of the two previous nodes in the graph, and Hashgraph uses a mechanism called *gossip*. For further reading, the author suggests the following articles: Schueffel (2018), Lee (2018), Popov (2018), and Baird, Harmon, and Madsen (2019).

[16] Other realizations of BCT (e.g., Hyperledger Fabric) use, for example, proof-of-stake or proof-of-elapsed time. For further reading on these consensus mechanisms, see Spirakis and Tsigas (2017), Tosh, Shetty, Liang, Kamhoua, and Njilla (2017) and MacKenzie, Ferguson, and Bellekens (2018).
Note: The cryptocurrency Bitcoin is capitalized while the underlying BCT is named bitcoin blockchain.

viewable by all network participants, yet the content of transactions are only disclosed to the involved transaction partners. In most cases, the participants use pseudonyms, yet the occurrence of transactions are transparent to all. In contrast, private DLTs (e.g., Hyperledger Fabric) require participants to hold an access right to the network, a permission. This permission can be granted by the network or an assigned gatekeeper. Thus, the network members are mostly known. Their transactions are as well visible to others, yet the content of a transaction is only disclosed to the transaction partners. A consortium DLT requires a permission as well. In contrast to a private DLT, a consortium establishes channels for transactions, so that the occurrence of a transaction is only visible to the transaction partners and not to the rest of the DLT network.

2.2 Transparency in supply chains as a cornerstone of supply chain management

The emergence of DLT in the field of SCM appears to be right on time. Transparency, one of the promising value contributions that DLT has to offer, is one of the most discussed and relevant topics in SCM (New, 2010). Both SCM scholars (e.g., Morgan, Richey, & Ellinger, 2018; Wieland, Handfield, & Durach, 2016) and practitioners (e.g., Brown, 2020; Linch, 2014)) have a great interest in the topic of transparency. However, transparency is a complex topic in supply chains, and *TSC* is a comprehensive term that is often used interchangeably with *supply chain transparency* (SCT) and the expression *transparent supply chain*. Moreover, *supply chain visibility* (SCV) and *traceability* represent additional terminologies that are often misused. Thus, these terminologies must be differentiated properly to facilitate clear understanding.

2.2.1 Untangling transparency in the context of supply chains

TSC describes the state of a supply chain or a segment of a supply chain from the perspective of a focal company. *TSC* is defined as follows:

> A state of a focal company's upstream and downstream supply chains that allows visibility of actors, products, services and processes, as well as traceability of products and services with their history along their journey

> in the supply chains to improve a specific performance dimension. (Carter & Easton, 2011; Adapted from Carter, Rogers et al., 2015).

Using the perspective of a focal company, TSC is based on the idea of Carter, Rogers et al. (2015), who state that supply chains are "bounded by the visible horizon of the focal agent [company]" (p. 93). Thus, transparency is limited to both sides (i.e., upstream and downstream) from the perspective of the focal company. Moreover, the definition of TSC includes the understanding that companies enhance TSC in an aspiration to enhance a specific performance dimension linked to transparency (e.g., lead time or inventory reduction). However, the definition shows that the terminology is broadly formulated, uniting transparency regarding actors, products, services, and processes. This is evidenced by the two enablers—*visibility* and *traceability*—that are entailed in this definition. These are defined as follows:

> *Visibility* describes the ability of a focal company to purposefully gain permitted access to information of other supply chain actors that are of importance to their supply chain operations. (Adapted from Barratt & Oke, 2007; Williams et al., 2013)

> *Traceability* describes the ability of a focal company gain permitted access to information of other supply chain actors that reveal the current or historical state of products and services beyond its own organizational boundary. (Adapted from Carter & Rogers, 2008; Cheng & Simmons, 1994)

In order for the focal company to gain these abilities, which form the enablers of TSC (Morgan et al., 2018), focal companies deploy different mechanisms. These are referred to as *TSC mechanisms.* While TSC is defined broadly, TSC mechanisms allow for greater focus. As they can address specific topics, including actors, products, services, and processes, can be applied upstream or downstream, and enable visibility or traceability, they specifically define the scope of an effort to enhance TSC. Hence, TSC can be understood as an umbrella term, describing the state of a supply chain concerning transparency, which entails the deployment of a more specific TSC mechanism and the attainment of visibility or traceability. Study 2 of the present thesis describes the seven most prominent TSC mechanisms (i.e., screening and assessing, forecasting, monitoring, tracking and tracing, mapping, event watching, and auditing) in detail.[17] Therefore, the current sub-section is limited to the aforementioned description of the role of these TSC mechanisms.

In addition to TSC, several SCM scholars (e.g., Chen, Zhang, & Zhou, 2019; Egels-Zandén & Hansson, 2016) and practitioners have discussed *SCT* (e.g., Linch, 2014). Like TSC, *SCT* is also to be understood from the perspective of the focal company. However, it does not describe a state but a management practice, embedded in the management of the supply chain operations of a focal company. As such, *SCT* is defined as follows:

> A management practice of a focal company that makes use of TSC to manage (i.e., design, plan, operate, and control) its supply chains to achieve improved performance.

The definition of *SCT* describes TSC as an enabler and thus entails the purposeful use of a TSC mechanism. For example, by deploying auditing as a TSC mechanism, a focal company enhances visibility regarding specific capabilities and characteristics of its supplier. Through the achieved TSC, paired with additional practices such as defining and surveilling improvement measures, the focal company enables strategic supplier development. As a result, improved supplier performance can be achieved, which constitutes the targeted performance dimension. In this case, auditing is used as a TSC mechanism to enhance TSC, which enables the TSC-driven management practice—SCT (Morgan et al., 2018). Both TSC and SCT are associated with a focal company's aspiration to improve a performance dimension that is linked to SCM and the supply chain operations. While TSC improves performance dimensions directly linked to TSC (e.g.,

[17] This can be found in Appendix B.

inventory), SCT covers performance dimensions on a higher level of SCM (e.g., flexibility).

In addition, the expression *transparent supply chain* is used in the academic (e.g., Doorey, 2011) and practitioners' literature (e.g., New, 2010). This expression focuses on the disclosure of information about the provenance of a product to the end customer (i.e., the consumer). Thus, a transparent supply chain is understood from the perspective of the end customer rather than of a company within the supply chain. It entails providing provenance to the end customer and is defined as follows:

> A quality of a supply chain that entails the disclosure of the journey of a product or service along the supply chain to the end customer.

However, from the perspective of the end customer, it is vital that retailers, distributors, and OEMs, as well as their upstream suppliers, enable a transparent supply chain (Doorey, 2011). Thus, both traceability and visibility are required at the point of the retailer, distributor, or OEM, to enable a transparent supply chain. Only through this can information cascade downstream to the end customer. Information disclosure mechanisms enable the traceability of products and the visibility of involved actors. However, unlike TSC mechanisms, which aim to enhance TSC and enable SCT for focal companies, these information disclosure mechanisms are not deployed to help manage or improve supply chain operations; instead, they are limited to offering information to end customers concerning a specific product, to improve sales performance. Thus, a transparent supply chain is not directly linked to SCM. The present thesis therefore focuses on TSC and SCT, which are directly associated with SCM.

Figure 2 draws on the aforementioned definitions and illustrates the relationships of the different terminologies to help untangle them.

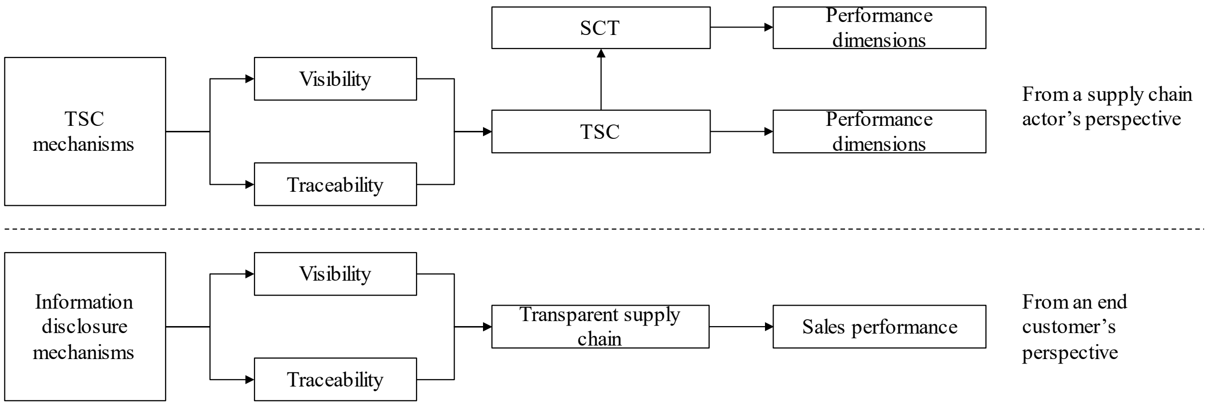


Figure 2: Overview of terminologies in the context of transparency in SCM

2.2.2 Integrating transparency in the supply chain and supply chain transparency in the context of supply chain management

Following the definitions and delineation of *TSC* and *SCT*, both terminologies must be integrated into the context of SCM. While *SCT* is defined as a management practice in SCM and *TSC* as a state of a supply chain, this sub-section sheds light on the context in which both terminologies are used. By setting TSC and SCT in the context of SCM, the importance of both is underlined once again.

TSC is used in the context of SCM tasks and target figures. Herein, TSC is seen as an enabler to improve planning and replenishment (Jin, Williams, Tokar, & Waller, 2015; Mentzer, Min, & Michelle Bobbitt, 2004), incident/product recalling (Wowak & Boone, 2015), and supply chain analytics (Srinivasan & Swink, 2018). The authors of these contributions discuss several TSC mechanisms, such as forecasting (Jin et al., 2015) and tracking and tracing (Wowak & Boone, 2015), and elaborate on the link between the achieved level of TSC and the improved carrying out of SCM tasks such as planning and replenishment. In addition to SCM tasks, SCM scholars discuss TSC in the context of collaboration (Holweg, Disney, Holmström, & Småros, 2005), responsiveness (Williams et al., 2013), resilience (Brandon-Jones, Squire, Autry, & Petersen, 2014), flexibility (Wang & Wei, 2007), and integration (Schoenherr & Swink, 2012). Again, TSC is seen as an enabler for these SCM target figures, thus underlining the importance of TSC in today's supply chains.

In relation to SCT, several other SCM practices are linked to SCT. The literature demonstrates an enabling role here once more, as SCT helps to enable supply chain risk management (Basole & Bellamy, 2014), sustainable SCM (Egels-Zandén & Hansson, 2016; Gold, Seuring, & Beske, 2010), multitier management (Wilhelm, Blome, Bhakoo, & Paulraj, 2016), supplier management (Morgan et al., 2018), and quality management (Lee & Whang, 2005). SCT as a practice enables focal companies to improve the related SCM practices and thus improves specific performance dimensions that are associated with these SCM practices. From an academic perspective, SCT is closely related to these SCM practices, which are ranked as relevant research topics in the field of SCM (Wieland et al., 2016). Hence, the importance of SCT is justified by its enabling role and by its importance to other SCM practices. Figure 3 illustrates both the context of TSC and of SCT, to give an overview of the related topics.

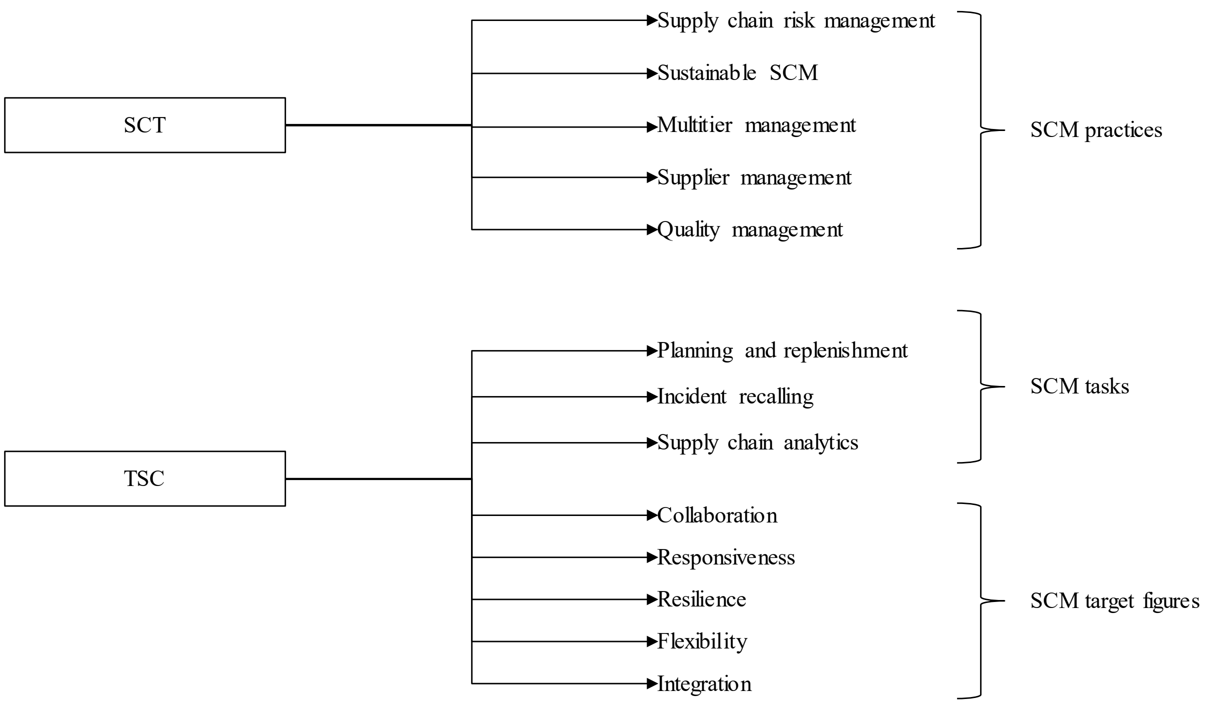


Figure 3: Overview of topics related to TSC and SCT

2.3 The interplay of distributed ledger technology and transparency in the context of supply chain management

After having introduced DLT, TSC, SCT, and the transparent supply chain in the previous sub-sections, the merging of these topics must next be discussed in order to shed more light on the application of DLT in the context of transparency in SCM. This includes three aspects, which are presented in Figure 4 and will be discussed in the following sub-sections.

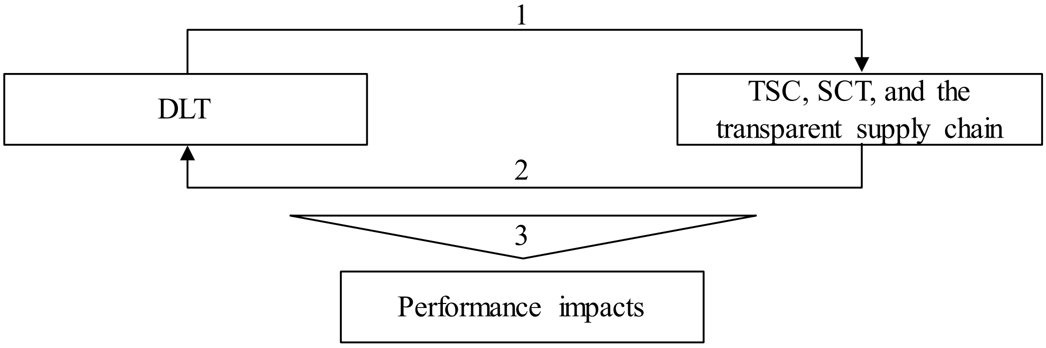


Figure 4: Aspects related to the merging of DLT and transparency in SCM

2.3.1 Distributed ledger technology as an application in the context of transparency in supply chain management

DLT has an enabling role in the context of transparency in SCM (e.g., Hald & Kinra, 2019). As such, DLT is understood to be the underlying technology that supports TSC mechanisms and information disclosure mechanisms, as illustrated on the left of Figure 2. The characteristics of DLT, such as data availability, integrity, accessibility, and distribution, in turn address determinants of TSC mechanisms.[18] A detailed analysis of the determinants and the role of DLT is presented in Study 2. Similar to supporting TSC mechanisms, DLT's characteristics are beneficial for information disclosure mechanisms that offer product information to end customers. An example of this is the DLT application of Provenance.org, which allows the end customer to trace back products and get to know more about the individual value creation steps along the supply chain

[18] As revealed in Study 2, which can be found in Appendix B.

(Wheeler, 2017). Thus, DLT applications are deployed to enhance TSC and the transparent supply chain.

2.3.2 Transparency as an antecedent to distributed ledger technology applications in supply chain management

DLT applications that are deployed in the field of SCM require the adoption of multiple supply chain actors (Schmidt & Wagner, 2019). In order to deploy these DLT applications, a certain amount of TSC must be established for the supply chain actors to initiate a DLT application. Without being able to identify the relevant supply chain actors, a deployment is not realizable. Thus, DLT applications in SCM require TSC as a prerequisite to successful deployment. DLT applications that aim to enhance TSC for supply chain actors (e.g., IBM Food Trust) or enable a transparent supply chain for end customers (e.g., Provenance.org) particularly depend on the involvement of relevant actors in the supply chain being visible. This reveals the mutual dependency between DLT applications in SCM and transparency in the context of SCM, as evidenced by sub-sections 2.3.1 and 2.3.2.

2.3.3 Projected performance impacts of distributed ledger technology in the context of transparency in supply chain management

As a large number of DLT applications aim to enhance TSC—also referred to as DLT-based TSC solutions—and to enhance information disclosure, the targeted impact has a clear focus on transparency in the context of SCM.[19] With a focus on the impact on SCM, enhanced TSC can contribute to reducing costs (e.g., transaction costs), affecting governance structures and relationships (Schmidt & Wagner, 2019). Moreover, additional impacts, such as increased trust, automation, and digitization, have been discussed in the literature (Babich & Hilary, 2019; Wang et al., 2019). However, deploying DLT applications in SCM can lead to several by-products. As described in sub-section 2.3.2, transparency is seen as an antecedent to deploying DLT in supply chains in order to identify other supply chain actors to adopt a DLT application. Thus, before an

[19] As revealed in an earlier version of Study 1 and in Roeck (2020).

adoption, certain levels of interaction, collaboration, and integration are needed, which can be seen as by-products of adopting DLT applications in a supply chain.

3 Literature background: Breeding new plants on well-known fields with partly fitting tools – Technology adoption and impact of distributed ledger technology in supply chains

Given the overall goal of this thesis, the following sub-sections focus on the adoption and impact of DLT-based TSC solutions. Thus, the literature background is divided into two parts, including the reviews on (i) technology adoption and its impact, and (ii) DLT in SCM. The literature background aims to lay the groundwork for the thesis by identifying the known findings of extant literature while also reflecting on them. The review of technology adoption and its impact (i) aims to derive a well-fitting frame for studying the adoption and impact of DLT-based TSC solutions. As DLT is a rather new phenomenon, both in SCM and in general, the number of academic publications is just starting to increase, while a large amount of grey literature (e.g., blog articles and consultancy reports) is already available. The grey literature also has an impact on the published academic contributions—especially the early ones that include numerous references to grey literature. Then, the review of DLT in SCM (ii) focuses exclusively on peer-reviewed journal and conference articles from the field of IS and SCM and discloses the research approach of these scholarly articles to enable a critical reflection.

3.1 Research on technology adoption and its impact

The concept of technology adoption emerged from the phenomenon of diffusion of innovation (DOI) in the field of innovation management and the theory of reasoned action (TRA). Following the seminal work of Rogers (1962) on DOI and of Ajzen and Fishbein (1980) on TRA, several fields of research, such as IS, operations management, SCM, and management science have drawn extensively on DOI and TRA literature. Over the years, two largely separate literature sub-streams have been developed by scholars. Since the late 1980s and early 1990s, studies on the adoption of technology innovations have grounded their research on either the technology acceptance model (TAM) or technology adoption model. While the TAM originates from the TRA literature, the technology adoption model draws on the DOI. Based on these two model types, several scholars have studied technology diffusion, adoption, or acceptance.

3.1.1 The models of technology diffusion, adoption, and acceptance

Davis et al. (1989) established the basis for scholars drawing on the TAM by building on the TRA. According to the scholars drawing on the TAM, "technology adoption decisions (i.e., individual intentions to use the technology) are driven by an individual's affective response (attitude) toward the use of the innovation" (Agarwal & Prasad, 1998, p. 205). Thus, the contributions of the TAM literature sub-stream analyze technology adoption on the level of individuals. Following the initial TAM, both perceived ease of use (PEOU) and perceived usefulness (PU) affect an individual's behavioral intention to use (BI) a novel technology (Davis et al., 1989). BI leads to the actual use of the technology. Moreover, the TAM indicates a direct impact of PEOU on PU, while BI constitutes a moderator of actual use. Over the years, the TAM was refined by Venkatesh and Davis (2000), who identified seven factors affecting PU. Furthermore, TAM 3 was established with the contribution of Venkatesh, Morris, Davis, and Davis (2003), who carved out eight factors that affect BI.

In the early 1990s, a second literature sub-stream emerged, founded by several IS contributions (e.g., Grover & Goslar, 1993; Iacovou et al., 1995; Premkumar, Ramamurthy, & Nilakanta, 1994). In contrast to the TAM studies, these contributions assume the perspective of an organization instead of an individual and primarily discuss the factors affecting the adoption decision itself, not the intention to use a technology. Their models include several positive and negative factors affecting the adoption decisions of organizations, which are referred to as *antecedents for adoption*. The core of their studies centers around these antecedents, not the psychological process of individuals, such as decision-makers, which differentiates the focus of their models from that of the TAM.

When reviewing different papers about the adoption of technologies, readers are confronted with a variety of terminologies. In fact, the terminologies surrounding technology adoption are used interchangeably and are blended. As Lanzolla and Suarez (2010) outline, research has "equated technology adoption (i.e., the purchase of technology) to technology use" (p. 837). However, in their contribution, Lanzolla and Suarez (2010) reveal that technology adoption does not necessarily lead to actual use. Furthermore, the use of terminologies also varies with the level of analysis and, unfortunately, across contributions studying the same level. Figure 5 illustrates the predominant usage of different terminologies at the different levels of analysis.

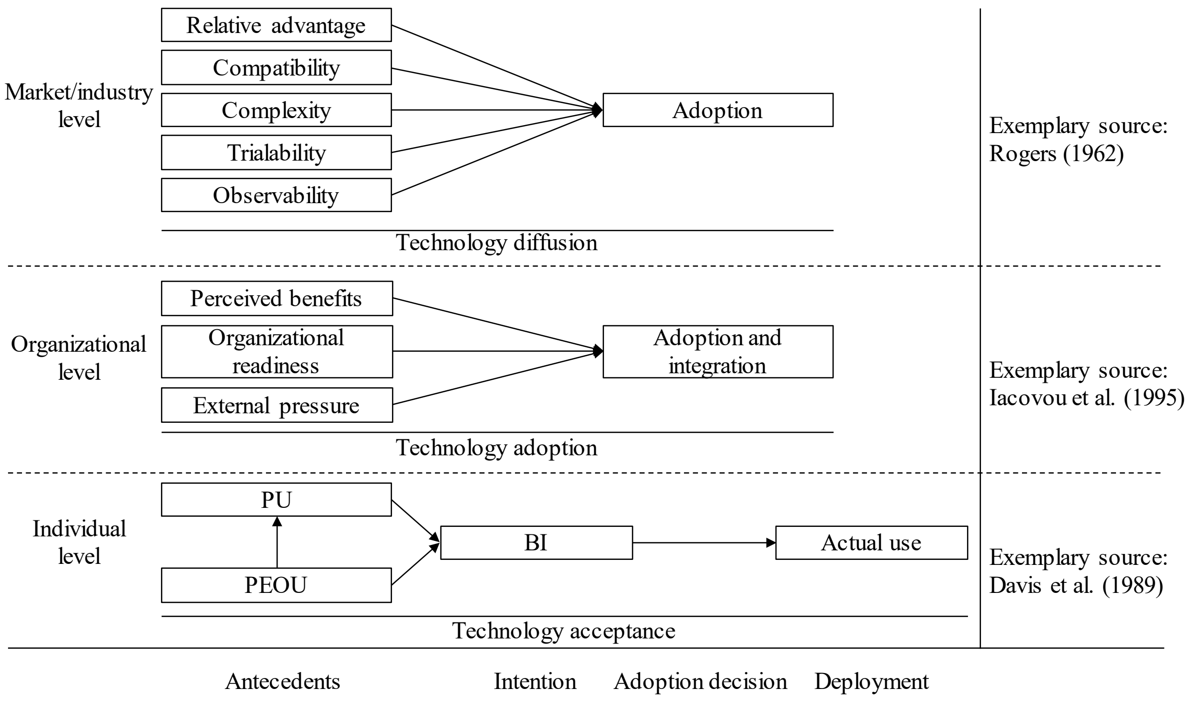


Figure 5: Terminologies surrounding technology adoption

In an effort not to leave the reader confused amidst the myriad of overlapping terminologies, following is a delineation of the terminologies used for the remainder of this thesis:

- *Antecedents:* The factors driving individuals or organizations and, ultimately, entire markets/industries to decide to apply a certain technology (Cooper & Zmud, 1990).
- *Intention:* The behavior of individuals in considering the use of a certain technology (Davis et al., 1989). Although intention can also be present in an organization, scholars have limited the use of this terminology to individuals in the TAM.
- *Adoption decision:* The decision of an organization to apply a technology, which leads to a subsequent implementation of the novel technology (Iacovou et al., 1995).
- *Deployment:* Following implementation, the technology is applied and is involved in routinization, thus being used on a regular basis by organizations or individuals (Zhu, Kraemer, & Xu, 2006).
- *Technology diffusion:* Rogers (1962) refers to this terminology when describing the result of the adoption decisions of multiple actors in an industry or market.
- *Technology adoption:* This describes the result of an organization in deciding to apply and integrate a technology (Iacovou et al., 1995).
- *Technology acceptance:* This refers to the process individuals go through from building an intention to use a technology to actually using it (Davis et al., 1989).

Given the goal of this thesis, the focus of the literature review is on technology adoption following the understanding of Iacovou et al. (1995), which includes the antecedents to the adoption decision and the adoption decision itself as well as the impact.

3.1.2 Reviewing the different models to study technology adoption

Against the backdrop of the division into two separate literature sub-streams, studying the adoption of DLT in supply chains requires a detailed analysis of the different models to identify an adequate foundation for this thesis. A large number of contributions focus on the DOI, the TAM, and technology adoption. Thus, three groups of models can be distinguished using their perspective. The first group comprises models that enable analysis on the level of an industry, including the seminal contribution of Rogers (1962). The second group includes the TAM (Davis et al., 1989) and related models, including the TAM 2 (Venkatesh & Davis, 2000), the TAM 3 (Venkatesh et al., 2003), and the technology readiness and acceptance model (TRAM) (Lin, Shih, & Sher, 2007), which study adoption behavior on the level of individuals. The third group comprises the models that study technology adoption on an organizational level (Grover, 1993; Iacovou et al., 1995). While all these groups and the individual models have their strengths and weaknesses, it is here necessary to identify an adequate model that can be applied as a theoretical foundation to guide the present thesis in studying the adoption and impact of DLT-based TSC solutions. Thus, seven selection criteria were defined to evaluate the adequacy of these models from the aforementioned three groups and to build on their findings. The selection criteria are as follows:

1. *Enabling the analysis of IOIS*: Following the brief illustration of DLT applications given in SCM in section 1, studying DLT-based TSC solutions requires studying DLT as an IOIS, according to the definition of Johnston and Vitale (1988). Hence, an adequate model will enable the study of the adoption and impact of IOIS.
2. *Enabling the analysis on an organizational level*: DLT-based TSC solutions are adopted by organizations. Given the goal of this thesis, an adequate model will enable an analysis on the organizational level.
3. *Enabling the analysis on a network level*: Alongside the organizational level, understanding of the adoption of DLT-based TSC solutions requires observing the network level and analyzing the adoption and impact of multiple supply chain actors and the interdependencies of their adoption decisions. As such an adequate model will also allow analysis on the network level.
4. *Enabling a focus on the antecedents to adoption decisions*: Given the aim of this thesis, the positive and negative factors affecting adoption decisions

must be studied. Therefore, an adequate model will allow the identification of these antecedents to adoption decisions.

5. *Enabling an analysis of intra-firm, inter-organizational, and environmental factors:* As illustrated by the example of TradeLens (sub-section 1.2), adoption decisions can be affected by a wide range of factors, stemming from different sources that are not limited to the technology itself. Adequate models enable reflection on a wide range of factors, including internal (i.e., organizational) and external (i.e., inter-organizational/supply chain network and environment) factors.
6. *Enabling application with a cross-industry scope:* Supply chains constitute networks of multiple organizations in different industries and of different sizes. For instance, the supply chain of automotive OEMs contains suppliers from the chemical, machinery, and service industries. Thus, an adequate model will enable cross-industry analysis.
7. *Enabling qualitative analysis:* Given the novelty of DLT in SCM, studying the adoption of DLT-based TSC solutions is largely limited to a qualitative approach. Hence, an adequate model will enable the application of qualitative analysis to understand the adoption of DLT-based TSC solutions at this early stage.

Table 1 presents an overview of thirteen models addressing technology diffusion (market/industry level), technology adoption (organizational level), and technology acceptance (individual level). In Table 1, the models are evaluated based on the aforementioned seven selection criteria to ensure the selection of an adequate model to study the adoption and impact of DLT-based TSC solutions. The column “Type of model” enables the allocation of each model to its respective literature sub-stream, to supplement the description of the level of analysis it provides (separate rows in Table 1).

Table 1: Overview of models for studying technology diffusion, adoption, and acceptance

Source	Type of model	1. Enabling analysis of IOIS	2. Enabling analysis on an organizational level	3. Enabling analysis on a network level	4. Enabling focus on the antecedents of adoption decisions	5. Enabling analysis of intra-firm, inter-organizational and environmental factors	6. Enabling application in cross-industry scope	7. Enabling qualitative analysis
Organizational level								
Cooper and Zmud (1990)	Adapted DOI	Material requirements planning - limited applicability	Organizational level - analysis enabled	Organizational level - transfer needed	Focus on technology/innovation - applicable for technology characteristics	Limited to technical facets - expansion required	Applicable	Quantitative
Grover and Goslar (1993)	Adapted DOI	Tele-communication technology - limited applicability	Organizational level - analysis enabled	Organizational level - transfer needed	Focus on initiation, adoption and implementation - refinement needed	Environmental uncertainty, organizational, and IS factors - model all three required factors	Applicable	Quantitative
Iacovou et al. (1995)	Own technology adoption model	EDI - analysis of IOIS enabled	Organizational level - analysis enabled	Organizational level - transfer needed	Focus on factors affecting adoption decision - enabling analysis of antecedents	Perceived benefits, organizational readiness and external pressure - model all three required factors	Applicable	Both quantitative and qualitative
Premkumar and Ramamurthy (1995)	Own technology adoption model	EDI - analysis of IOIS enabled	Organizational level - analysis enabled	Organizational level - transfer needed	Focus on inter-organizational and organizational factors - expansion required	Inter-organizational and organizational factors - expansion required	Applicable	Both quantitative and qualitative
Premkumar et al. (1997)	Own technology adoption model	EDI - analysis of IOIS enabled	Organizational level - analysis enabled	Organizational level - transfer needed	Focus on factors affecting adoption decision - enabling analysis of antecedents	Environmental, organizational, innovation factors - expansion required	Limited, as only focused on organizations in transportation industry	Both quantitative and qualitative
Thong (1999)	Own technology adoption model	IS in general - limited applicability	Organizational level - analysis enabled	Organizational level - transfer needed	Focuses on factors affecting adoption decision - enabling analysis of antecedents	Decision-maker, IS, organizational and environmental characteristics - expansion required	Applicable	Both quantitative and qualitative
Zhu et al. (2003)	Own technology adoption model	E-business platforms -limited applicability	Organizational level - analysis enabled	Organizational level - transfer needed	Focus on factors affecting adoption decision - enabling analysis of antecedents	Technological, organizational, environmental factors - expansion required	Applicable	Quantitative

Source	Type of model	1. Enabling analysis of IOIS	2. Enabling analysis on an organizational level	3. Enabling analysis on a network level	4. Enabling focus on the antecedents of adoption decisions	5. Enabling analysis of intra-firm, inter-organizational and environmental factors	6. Enabling application in cross-industry scope	7. Enabling qualitative analysis
Market/industry level								
Rogers (1962)	DOI	Innovation in general - limited applicability	Market/industry level - transfer needed	Market/industry level - transfer needed	Focus on innovation characteristics - transfer and expansion required	External factors not included	Applicable	Both quantitative and qualitative
Individual level								
Agarwal and Prasad (1998)	Adapted TAM	Internet - limited applicability	Individual level - transfer needed	Individual level - transfer needed	Focus on personal innovativeness - transfer needed	Limited to innovativeness of individuals	Applicable	Quantitative
Davis et al. (1989)	TAM	Computer systems - limited applicability	Individual level - transfer needed	Individual level - transfer needed	Focus on factors leading to BI - expansion required	External variables on individual level - transfer and refinement required	Applicable	Quantitative
Lin et al. (2007)	TRAM	E-services - limited applicability	Individual level - transfer needed	Individual level - transfer needed	Focus on Technological readiness - transfer needed	Limited to technical readiness of individuals - transfer and expansion required	Limited, as only focused on individuals in marketing functions	Quantitative
Venkatesh and Davis (2000)	TAM2	Computer systems - limited applicability	Individual level - transfer needed	Individual level - transfer needed	Focus on determinants affecting PU - transfer and expansion required	Determinants only on individual level - transfer and expansion required	Applicable	Quantitative
Venkatesh et al. (2003)	TAM3	Computer systems - limited applicability	Individual level - transfer needed	Individual level - transfer needed	Focus on determinants affecting BI - transfer and expansion required	Determinants only on individual level - transfer and expansion required	Applicable	Quantitative

Based on this evaluation, the model presented by Iacovou et al. (1995) represents an adequate model for use in this thesis, as it is the model that fulfills the most (i.e., six out of seven) of the selection criteria. Only the analysis of the network level is not explicitly included in the model, so this will require additional consideration when it comes to studying adoption decisions. The study by Iacovou et al. (1995) addresses the adoption and the impact of EDI, another form of IOIS, including the antecedents to adoption decisions (perceived benefits, organizational readiness, and external pressure). Moreover, the model accounts for the broad range of influencing factors, including organizational, inter-organizational, and environmental factors, and enables the application of a qualitative research design. Thus, the model presents the best fit for the goal of this thesis. Models that focus on the individual level (including the TAM) require that they be transferred to the organizational and network levels, therefore demonstrating limited applicability when studying IOIS and favoring quantitative research designs. Moreover, the initial DOI model of Rogers (1962) presents a foundational model for broad applicability, yet this generic model requires substantial refinement to enable an analysis of IOIS on the organizational and network levels and to facilitate a greater focus on the antecedents to adoption. Further, the models that focus on the organizational level fulfill three (e.g., Grover & Goslar, 1993) to five (e.g., Premkumar, Ramamurthy, & Crum, 1997) of the selection criteria, yet they all lack the ability to enable analysis on the network level.

The adoption model of Iacovou et al. (1995), illustrated in Figure 6, includes three components of IOIS adoption from the perspective of a company within the supply chain. First, it includes the antecedents to an adoption decision, which are divided into three categories: perceived benefits, organizational readiness, and external pressure. Although formulated positively and, thus, as drivers of an adoption decision, the authors underline that these categories should be understood as providing structural guidance when listing factors both for and against adoption. For example, when more negative factors are listed, this means there is little or no perceived benefit, organizational readiness, or external pressure, which will likely lead to the decision not to adopt an IOIS. Second, the model includes an analysis of the adoption decision itself, taken by the organization under observation. Herein, the antecedents play a pivotal role. Third, and last, the model includes the impact that results from the adoption decision. While the authors emphasize the role of the three antecedents, the model allows for a structuring and understanding of the entire phenomenon of IOIS adoption from the perspective of an organization. Thus, the model is well suited to guide and structure the present thesis and to address, specifically, the analysis of the adoption decision. However, the interdependencies of the adoption decisions should be taken into account in the present thesis when studying the adoption of DLT-based TSC solutions.

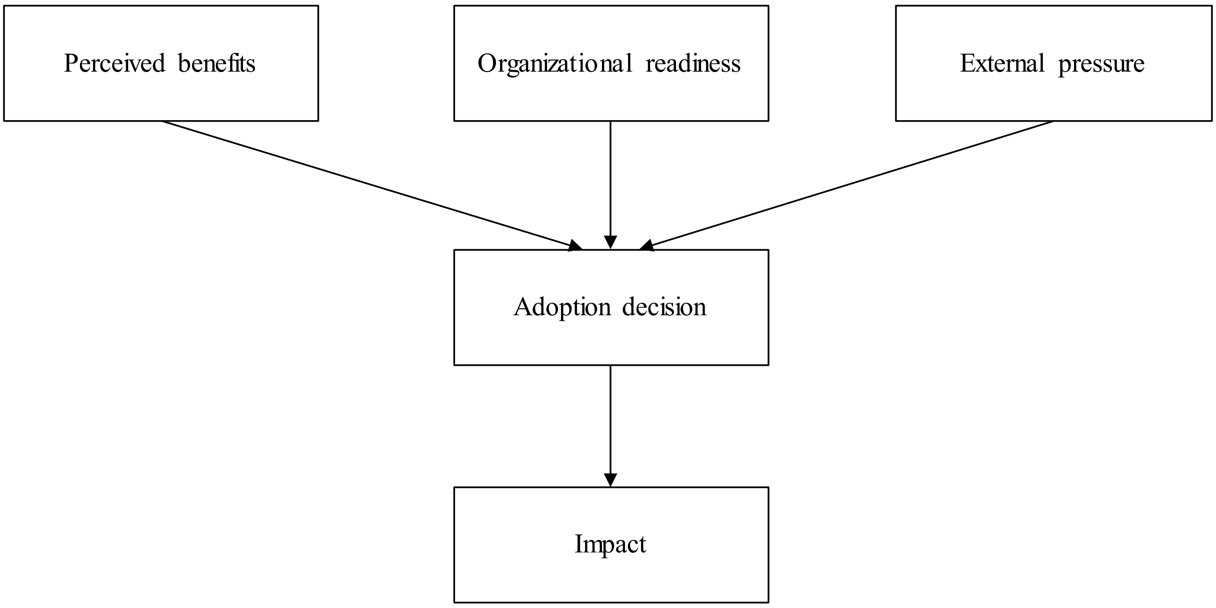


Figure 6: Adapted IOIS adoption model of Iacovou et al. (1995)

3.1.3 Insights on the antecedents to technology adoption in the literature

Despite the fact that the other models do not fulfill all the selection criteria, they still offer valuable insights into specific facets of technology adoption and its impact, and especially into the already identified antecedents. Thus, Table 2 presents the findings in this regard to summarize the literature on the antecedents to technology adoption. In addition to the 14 contributions that develop their own models, the table includes additional contributions that take these models as a theoretical framework or slightly adapt the elements of these models corresponding to their focus, such as that of Autry, Grawe, Daugherty, and Richey (2010). In total, 23 contributions were reviewed. Based on this review, 26 factors (with overlap due to original wordings) were identified that affect the adoption decision of individuals or organizations, given the different levels of analysis of the listed contributions.

Table 2: Literature review on the antecedents to technology adoption

Source	Type of technology studied	Applied model	Focus of analysis	Applied methodology	Findings concerning adoption (excerpt from contributions)
Organizational level					
Autry et al. (2010)	Supply chain technologies (e.g., EDI)	Adapted TAM	Intention to use and implementation	Empirical, survey	Technologically turbulent environments moderate firm's PU, PEOU and BI to use a supply chain technology, while technology breadth negatively affects the firm's BI to use a supply chain technology and the implementation
Chwelos et al (2001)	EDI as IOIS	Technology adoption model of Iacovou et al. (1995)	Intention to adopt	Empirical, survey	Readiness, perceived benefits, external pressure confirmed as significant predictors to adopt EDI
Cooper and Zmud (1990)	Material requirements planning software	Adapted DOI	Effect of technology complexity and compatibility on implementation	Empirical, survey	Technology complexity (-) and compatibility (+) of task and technology affect implementation
Grover (1993)	Customer based IOIS	Own technology adoption model	Adoption factors	Empirical, survey	Organizational, support, policy, environmental and IOIS factors facilitate decision to adopt
Grover and Goslar (1993)	Telecommunication technology	Adapted DIO	Entire process of technology adoption	Empirical, survey	Environmental uncertainties and decentralization of decision making affect adoption
Lanzolla and Suarez (2010)	E-procurement technology	Drawing on technology diffusion theory	Factors affecting the divide of adoption and use	Empirical, survey	Different internal actors (management, IT department) are responsible for adoption decision and use, which demonstrate different information stimuli that cause divide between decision to adopt and use
O'Callaghan et al. (1992)	EDI as IOIS	Own technology adoption model	Adoption factors	Empirical, survey	Relative advantage, system compatibility and external influences adoption decision
Premkumar and Ramamurthy (1995)	EDI as IOIS	Own technology adoption model	Adoption factors	Empirical, survey	Competitive pressure and exercised power (inter-organizational factors) as well as internal need and top management support (organizational factors) affecting organizations' behavior of adoption (proactive, reactive)
Premkumar et al. (1994)	EDI as IOIS	Own technology adoption model	Adoption factors	Empirical, survey	Relative advantage, costs, and technical compatibility are predictors for adoption decision
Premkumar et al. (1997)	EDI as IOIS	Own technology adoption model	Adoption factors	Empirical, survey	Size of firm, competitive pressure, customer support and top management support are factors discriminating adoptors form non-adopters
Thong (1999)	IS is general	Own technology adoption model	Contextual variables of adoption decision	Empirical, survey	Decision-maker and innovation characteristics affect decision to adopt while organizational characteristics affect the extent of IS adoption

Source	Type of technology studied	Applied model	Focus of analysis	Applied methodology	Findings concerning adoption (excerpt from contributions)
Organizational level					
Zhu et al. (2003)	E-business	Own technology adoption model	Adoption factors	Empirical, survey	Technological, organizational, envirnemental context affecting intent to adopt
Zhu et al. (2006b)	E-business	Own assimilation model	Entire assimilation process	Empirical, survey	While contextual factors vary across assimilation stages and environments, competition affects adoption positively, technology readiness and integration affecting adoption decisions
Market/industry level					
Rogers (1962)	Innovation in general	DOI	Entire diffusion of innovations	Conceptual	Five innovation characteristics affecting technology adoption decisions: relative advantage, compatibility, complexity, trialability and observability
Individual level					
Chau (1996)	Software (Microsoft Word and Excel)	Adapted TAM	PU	Empirical, survey	Near-term PU and long-term PU both positively affect behavioral intention to use a technology. No direct relationship between PEOU and behavioral intention was found
Davis et al. (1989)	Software (WriteOne)	TAM	Technology acceptance in general	Empirical, experiment	TAM model
Gefen et al. (2003)	E-commerce	Adapted TAM	Effect of trust on PU and inteded use	Empirical, survey	Trust as important as accepted TAM antecedents (PU and PEOU)
Lin et al. (2007)	E-service	TRAM	Technology readiness	Empirical, survey	The affect of technology readiness on BI is mediated by PU and PEOU
Venkatesh (2000)	Multiple software solutions	TAM	Determinants affecting PEOU	Empirical, experiment	Control, intrinsic motivation, and emotion constitute anchors that determine PEOU
Venkatesh and Bala (2008)	Different types of IT	TAM3	Experience as influence on adoption	Empirical, experiment	Experience as moderator for IT adoption
Venkatesh and Davis (2000)	Computer system	TAM2	Determinants of PU	Empirical, experiment	Expansion of TAM model with seven factors are discovered that affect PU
Venkatesh et al. (2003)	Mixed	TAM3	Determinants of BI	Review & empirical. experiment	Expansion of TAM model with eight factors are carved out that affect BI

The model presented by Iacovou et al. (1995) directly covers 25 factors in terms of perceived benefits, organizational readiness, and external pressure, as illustrated in the allocation of Table 3. In this way, the model facilitates the design of a comprehensive study on the adoption and impact of IOIS and guarantees that a wide range of different positive and negative factors will be captured. Thus, the model by Iacovou et al. (1995) offers great structural guidance for the present thesis and for the analysis of adoption decisions in the context of DLT-based TSC solutions. Only the factor of observability—that is, whether the impact of the adoption of one individual affects the adoption of others—is not covered. Fully transferring observability according to Rogers (1962), requires that the impact of the DLT adoption of one supply chain affects the adoption decision of a competitor's supply chains or even of supply chains in other industries. This dimension is not included in the model of Iacovou et al. (1995).

Table 3: Factors affecting technology adoption

Identified antecedents	**Perceived benefits**	**External pressure**	**Organizational readiness**	**Sources**
Environmental		x		Autry et al. (2010); Grover (1993); Grover and Goslar (1993); Zhu et al. (2003)
Internal technology breadth			x	Autry et al. (2010)
Organizational readiness			x	Chwelos et al (2001); Lin et al. (2007); Premkumar et al. (1997); Thong (1999); Zhu et al. (2003); Zhu et al. (2006)
Perceived benefits	x			Chwelos et al (2001)
External pressure		x		Chwelos et al (2001)
Technology complexity	x			Cooper and Zmud (1990); Rogers (1962)

Technology compatibility	x			Cooper and Zmud (1990); O'Callaghan et al. (1992); Premkumar et al. (1994); Rogers (1962)
Relative advantage	x			O'Callaghan et al. (1992); Premkumar et al. (1994); Rogers (1962)
Trialability			x	Rogers (1962)
Observability				Rogers (1962)
Policy		x		Grover (1993)
Organizational support			x	Grover (1993); Premkumar and Ramamurthy (1995); Premkumar et al. (1997)
Management decision making			x	Grover and Goslar (1993); Thong (1999)
External influences		x		O'Callaghan et al. (1992)
Competitive pressure		x		Premkumar and Ramamurthy (1995); Premkumar et al. (1997); Zhu et al. (2006)
Exercised power		x		Premkumar and Ramamurthy (1995)
Internal need	x			Premkumar and Ramamurthy (1995)
Costs	x			Premkumar et al. (1994)
Size of firm			x	Premkumar et al. (1997)
Customer support			x	Premkumar et al. (1997)
Technology characteristic	x			Thong (1999); Zhu et al. (2003)
Perceived usefulness	x			Chau (1996); Davis et al. (1989); Gefen et al. (2003); Venkatesh (2000); Venkatesh and Bala (2008); Venkatesh and Davis (2000); Venkatesh et al. (2003)

Perceived ease of use	x		Chau (1996); Davis et al. (1989); Gefen et al. (2003); Venkatesh (2000); Venkatesh and Bala (2008); Venkatesh and Davis (2000); Venkatesh et al. (2003)
Trust in technology	x		Gefen et al. (2003)
Experience		x	Venkatesh and Bala (2008)
Characteristics of individuals		x	Venkatesh and Davis (2000); Lin et al. (2007)

3.2 Distributed ledger technology in supply chains

While an adequate adoption model has been selected, the groundwork for discussing the adoption and impact of DLT in SCM—and, in particular, DLT-based TSC solutions—also has to be reviewed. This sub-section successively presents the research approach, the application contexts, the findings concerning the antecedents of adoption decisions, and the projected impacts of the literature on DLT in the context of SCM. As literature on DLT in SCM is scarce, the literature review does not exclusively focus on DLT-based TSC solutions but rather discusses all contributions covering DLT in the field of SCM.

3.2.1 Applied research approaches

The relevant literature is dominated by conceptual contributions. Twelve out of the twenty contributions (60%) reviewed are conceptual pieces. Among the conceptual contributions, five synthesize the body of knowledge from both the literature and practical DLT applications. Five contributions are solely based on the literature, applying systematic literature reviews to derive findings. In addition, two studies apply a design science research (DSR) approach to develop artifacts. Lately, more empirical research has been emerging, through a variety of different methods (Wang et al., 2018). In particular, qualitative studies based on expert knowledge are popular, including expert interviews (e.g., Wang et al., 2019), focus groups (Korpela, Hallikas, & Dahlberg, 2017), and Delphi studies (Kurpjuweit, Schmidt, Klöckner, & Wagner, 2019). Furthermore, qualitative secondary data analysis has been applied to study DLT (Sadhya & Sadhya, 2018). Moreover, a first quantitative, survey-based study was conducted on DLT, drawing on the perceptions of SCM experts (Kamble, Gunasekaran, & Arha, 2018).

However, these empirical contributions are built on expert knowledge and secondary data, as in the case of Sadhya and Sadhya (2018). Only Sternberg and Baruffaldi (2018)[20] study a real DLT implementation in their contribution. Given the novelty of DLT in SCM as a phenomenon, the shift from conceptual contributions to empirical contributions is just beginning, while more empirical work is needed at this stage of research (Schmidt & Wagner, 2019).

3.2.2 Discussed application contexts

This literature review mainly comprises contributions related to DLT applications in the field of SCM, given the focus of this thesis. The contributions stem from the field of SCM and IS and have a clear focus on DLT in an inter-organizational context or demonstrate a suitable transferability to the context of SCM. Sixteen of the twenty contributions are related to DLT applications in SCM. Furthermore, three contributions discuss no specific application context but rather look at DLTs in general. In addition, the contribution of Auinger and Riedl (2018) is focused on DLT applications for electronic payment ecosystems but reveals transferable findings, especially for DLT applications for SCF. Within the 16 contributions on DLT applications in SCM, 8 either do not further specify the applications in question (e.g., Kamble et al., 2018) or do incorporate multiple applications (e.g., Blossey, Eisenhardt, & Hahn, 2019). Six contributions focus specifically on DLT-based TSC solutions (e.g., Tian, 2016).

In addition, the applicability of DLT for SCF (Hofmann, Omran, Henke, & Heines, 2017) and additive manufacturing supply chains (Kurpjuweit et al., 2019)

[20] This conference paper is a previous version of Study 3 and that of Sternberg, Hofmann, and Roeck (2020); this footnote is applicable to all references to this source.

is discussed in the literature. In sum, the extant literature reveals a variety of different applications of DLT in the field of SCM, evidenced by contributions such as Wang et al. (2019), Blossey et al. (2019), and Babich and Hilary (2019); each of these studies discuss multiple DLT applications in SCM, such as proof of provenance, track and trace solutions, audit trails, SCF and payment solutions, and digital document registries. Thus, the literature reveals heterogeneity in terms of the desired targets of DLT applications in SCM. Furthermore, the extant literature gives evidence of a large interest in DLT-based TSC solutions. Given the six contributions that specifically focus on this topic, the literature reflects the interest of supply chain managers.

3.2.3 Findings on antecedents of adoption decisions

In light of the high hopes for DLT in the field of SCM (e.g., Casey & Wong, 2017), the adoption of the emerging technology is listed as topic of high interest for academic scholars in the fields of SCM and IS (e.g., Babich & Hilary, 2019; Schmidt & Wagner, 2019). Although only four studies have explicitly focused on the adoption of DLTs (Kamble et al., 2018; Post, Smit, & Zoet, 2018; Sadhya & Sadhya, 2018; Sternberg & Baruffaldi, 2018), an increasing number of scholars are examining the aspects (both positive and negative) of DLT that may influence the adoption decision of supply chain actors. The DLT literature often incorporates terms such as *benefits* (e.g., Hald & Kinra, 2019), *advantages* (e.g., Tian, 2016), and *strengths* (e.g., Babich & Hilary, 2019) to refer to factors that positively affect the adoption decisions of supply chain actors. In contrast, the negative factors are termed *barriers* (e.g., Sadhya & Sadhya, 2018), challenges (e.g., Wang et al., 2019), and *weaknesses* (e.g., Babich & Hilary, 2019). Table 4 condenses the positive factors, while Table 5 illustrates the negative factors from the extant DLT literature.

Table 4: Positive factors affecting DLT adoption in supply chains

Positive factors	Technical features	Resulting supply chain characteristics	Resulting SCM features	Source
Availability of data	x			Abeyrath and Monfared (2016); Babich and Hilary (2019); Hald and Kinra (2019); Wang et al. (2019)
Immutability of data	x			Abeyrath and Monfared (2016); Hald and Kinra (2019)
Integrity of data	x			Abeyrath and Monfared (2016); Tian (2016); Wang et al. (2018)
Aggregation of data	x			Babich and Hilary (2019)
Validation of data	x			Babich and Hilary (2019)
Consistency of data	x			Hald and Kinra (2019)
Interoperability	x			Hofmann et al. (2017)
Scalability	x			Hofmann et al. (2017)
Security	x			Hofmann et al. (2017); Wang et al. (2019)
Data distribution	x			Wang et al. (2019)
Improved visibility		x		Babich and Hilary (2019); Hald and Kinra (2019); Wang et al. (2019)
Improved traceability		x		Hald and Kinra (2019); Tian (2016)
Enabled trust		x		Hofmann et al. (2017); Wang et al. (2018); Wang et al. (2019)
Enhanced autonomy		x		Hofmann et al. (2017)
Enhanced transparency in supply chains			x	Abeyrath and Monfared (2016); Hofmann et al. (2017)

Automation of supply chain processes						x	Babich and Hilary (2019); Wang et al. (2019)
Failure reduction in supply chain processes						x	Hald and Kinra (2019)
Enhances SC coordination						x	Hald and Kinra (2019)
Enhances SC governance						x	Hald and Kinra (2019)
Reduces complexity						x	Hald and Kinra (2019)
Enables SC restructuring						x	Hald and Kinra (2019)
Enables SC sustainable innovations						x	Hald and Kinra (2019)
Enhances collaboration						x	Hald and Kinra (2019)

Table 5: Negative factors affecting on DLT adoption in supply chains

Negative factors	**Core technology**	**Surrounding technologies**	**Organization**	**Relationship**	**Environment**	**Resulting SCM effect**	**Sources**
Unknown and immature technology	x						Babich and Hilary (2019); Kamble et al. (2018); Kshetri (2018); Kurpjuweit et al. (2019); Saberi et al. (2019); Tian (2016); Sadhya and Sadhya (2018)
Technological inefficiency	x						Babich and Hilary (2019); Sadhya and Sadhya (2018)
Technical performance issues	x						Babich and Hilary (2019); Kurpjuweit et al. (2019)
Security issues	x						Kurpjuweit et al. (2019); Saberi et al. (2019); Wang et al. (2019); Sadhya and Sadhya (2018)

Inter-operability issues	x					Korpela et al. (2017); Kurpjuweit et al. (2019); Wang et al. (2019)
Advanced IT infrastructure required		x				Abeyrath and Monfared (2016); Kshetri (2018); Kurpjuweit et al. (2019); Sternberg and Baruffaldi (2018)
Advanced automation required		x				Abeyrath and Monfared (2016)
Link to physical products required		x				Kurpjuweit et al. (2019)
Smooth data gathering required		x				Sternberg and Baruffaldi (2018); Wang et al. (2019)
Unknown value			x			Babich and Hilary (2019); Sternberg and Baruffaldi (2018)
Implementation costs			x			Babich and Hilary (2019); Kurpjuweit et al. (2019); Saberi et al. (2019); Tian (2016); Sadhya and Sadhya (2018)
Lack of internal technical know-how			x			Babich and Hilary (2019); Kurpjuweit et al. (2019); Saberi et al. (2019); Wang et al. (2019); Sadhya and Sadhya (2018); Johnson, McCurdy, Schechter, and Loch (2020)
Lack of supporting culture			x			Babich and Hilary (2019); Kurpjuweit et al. (2019); Saberi et al. (2019); Wang et al. (2019); Sadhya and Sadhya (2018); Johnson et al. (2020)
Lack of management support			x			Kurpjuweit et al. (2019); Saberi et al. (2019); Johnson et al. (2020)
Switching costs			x			Sadhya and Sadhya (2018)
Unclear governance				x		Blossey et al. (2019); Kurpjuweit et al. (2019); Saberi et al. (2019); Wang et al. (2019);
Unclear data ownership				x		Blossey et al. (2019)
Multiple parties required				x		Kshetri (2018); Kurpjuweit et al. (2019); Saberi et al. (2019); Wang et al. (2019);
Legal/Regul-atory issues					x	Kurpjuweit et al. (2019); Saberi et al. (2019); Wang et al. (2019); Sadhya and Sadhya (2018)

Increases supply chain segregation	x	Hald and Kinra (2019)
Increases surveillance	x	Hald and Kinra (2019)
Reduces supply chain adaptability	x	Hald and Kinra (2019)
Reduces supply chain competencies	x	Hald and Kinra (2019)

Table 4 demonstrates that there are much fewer positive factors than there are negative factors discussed in the literature. The positive factors for adoption are identified in the literature in the following categories: *technical features*, *supply chain characteristics,* and *SCM features*. These three categories represent three levels, as they depend on each other. The category *technical features* includes the technical characteristics of DLT that build the foundation to enable *supply chain characteristics*. For instance, the availability, aggregation, and distribution of data enable both improved visibility and traceability. As such, the *resulting supply chain characteristics* in turn help to achieve *SCM features* such as visibility and traceability, which are enablers of TSC, is in line with Morgan et al. (2018). The promise to achieve these *supply chain characteristics*—and, ultimately, *SCM features*—constitute the perceived benefits that lead organizations to adopt DLT applications in their supply chains.

However, as Table 4 indicates, only one of the known adoption factors, the perceived benefits, is discussed in the literature. When drawing on the model of Iacovou et al. (1995), the two additional factors, organizational readiness and external pressure, are not discussed in the literature as of now. Instead, the existing research focuses on the benefits of DLT solely as underlying technology, not on the entire span DLT applications that often require additional technologies (e.g., IoT) and established IT structures, and processes. Thus, the discussion remains on the level of the underlying technology. However, adoption decisions are made based on the entire DLT applications.

In addition to the positive factors, the extant literature reveals negative factors affecting the DLT adoption in SCM, which can also be clustered into categories. Unlike the categories related to the positive factors, those related to the negative factors are less interconnected, instead describing separate topics that may hinder organizations from adopting DLT. These negative factors are associated with DLT as a technology and are as follows: the *core technology*, the *surrounding technologies*, the *organization* to decide on the adoption, the organization's *relationships* to other supply chain actors, the *environment*, and the *resulting SCM effect*.

In contrast to the three categories related to the positive factors, the existing literature contributes the negative factors with a much wider scope. Several factors, such as privacy issues and technological inefficiency, as well as the category *resulting SCM effects*, represent factors opposing the perceived benefits, according to the adoption model of Iacovou et al. (1995). The category *surrounding technologies* and, for example, a lack technical know-how represents factors opposing organizational readiness. Factors such as the legal/regulatory issues and the requirement for multiple parties oppose the external pressure. Thus, the emergence of more literature shedding more light on not only the potential of the technology and its perceived benefits but also the negative factors are stimulating a fruitful and much-needed discussion about DLT's adoption in supply chains, which is just emerging. However, the negative factors illustrate that the research does not solely focus on the underlying technology but instead on the entire DLT applications. This is in contrast to the discussion about the positive factors, in which a comprehensive view is still lacking.

When looking at the four contributions that explicitly focus on the adoption of DLT in SCM (Kamble et al., 2018; Sternberg & Baruffaldi, 2018) and in general (Post et al., 2018; Sadhya & Sadhya, 2018), all four studies emphasize the negative factors of DLT adoption. Sadhya and Sadhya (2018) and Sternberg and Baruffaldi (2018) limit their findings to uncovering the negative factors of DLT adoption, as illustrated in Table 5, while deriving the positive factors only from the literature. Sadhya and Sadhya (2018) address in their research question only the barriers to DLTs adoption and, thus, limit their contribution to discovering the barriers based on web research. Post et al. (2018) explore the factors that generally affect the adoption of DLT. The authors avoid referring to them as "negative" or "positive" but rather define them as superordinate factors that can have positive and negative peculiarities. Moreover, they do not limit their findings to a specific field of application but rather present a holistic view of these factors. The holistic view is supported as they divide their factors into three levels—strategic, tactical, and operational—which generally cover all three levels of management disciplines.

Kamble et al. (2018) are the only authors to draw their adoption studies on well-established theoretical foundations related to technology adoption. They draw on the TAM, the technology readiness index, and the theory of planned behavior to study the intended adoption behavior of companies in India. Using a survey-based study, their analysis, for example, confirms the findings of TAM contributions (e.g., Davis et al., 1989; Venkatesh et al., 2003) about the positive effect of PEOU on the PU of DLT, and of PU on attitude towards using DLT. Through their findings, the authors see evidence that the adoption of DLT can be studied by drawing on the TAM. However, their findings build on the foundation of adoption intention rather than on experience-based insights from DLT projects. Aside from papers focusing on adoption, in her DSR study, Labazova (2019) states that the following factors affect organizations' evaluation of DLTs and, thus, their adoption decision: the openness to innovate, the design of the DLT solution, the required inter-organizational integration, and the environment surrounding the organization. Similar to Sadhya and Sadhya (2018), Labazova (2019) does not reflect on the general positive or negative connotations of these affecting factors.

3.2.4 Findings on the projected impacts of DLT in supply chains

The findings on the impact of DLT in supply chains are limited to insights from conceptual studies. A key reason for this is the early stage of the technology in SCM resulting in a lack of empirically observable cases from mature field implementations. Thus, the few contributions reveal the projected potential of DLT rather than empirically proven results. While the resulting positive and negative factors, as listed in Table 4 and Table 5, affect the management of supply chains and, thus, the daily work of supply chain managers, the impact of a technology can also be evaluated based on structural or processual changes in the supply chain itself. When empirically observable, the impact is quantified in cost or time and is often associated with the performance of individual firms or entire supply chains (e.g., Fawcett, Loeve, & Lindeijer, 1996; Swift et al., 2019).

In the case of DLT applications in supply chains, such quantifiable evidence is missing at the time of this writing. However, both Kshetri (2018) and Schmidt and Wagner (2019) argue that DLT will impact structures in supply chains, most prominently by reducing the role for intermediaries and, thus, reducing the associated costs. Furthermore, Schmidt and Wagner (2019) point out that DLT can change governance structures as well, as the authors elaborate on TCE to identify the potential impacts of DLT on supply chains. Moreover, Auinger and Riedl (2018) argue that DLT implies a shift of trust between the market actors when studying the literature on electronic payment systems such as Bitcoin. When transferred to DLT applications in SCF, this argument is in line with the notion of Schmidt and Wagner (2019), who claim that the use of DLT creates trust among transaction partners, which can affect governance costs and structures. Except for these findings that center on DLT's impact on costs in supply chains, the literature still lacks relevant insights, especially empirical ones.

Table 6 summarizes the relevant literature and additionally displays the perspective and underlying theories used in the reviewed contributions. Nine of the contributions take on an organizational perspective, meaning they discuss DLTs in supply chains from the point of view of an individual supply chain actor; for example, Hofmann et al. (2017) assume the perspective of a buying company. Furthermore, six contributions discuss DLTs in supply chains from the perspective of the entire supply chain, thus applying a network perspective, such as that of Schmidt and Wagner (2019). The diversity of perspectives that can be assumed must also be kept in mind when revisiting the antecedents to adoption decisions, as well as the impact of DLT in supply chains. As illustrated in section 1, the perspective of both individual organizations and of the entire supply chain must be considered, and the proceeding analysis has to incorporate both levels. Moreover, five contributions reveal findings both for an individual supply chain actor and for the whole supply chain, such as that of Wang et al. (2019).

Alongside the perspective assumed, Table 6 emphasizes that most extant contributions lack underlying theories, which is also confirmed by the literature review conducted by Wang et al. (2018). Only a few contributions apply theoretical lenses to explain the phenomenon of DLT in supply chains (Kamble et al., 2018; Korpela et al., 2017) or elaborate on the theoretical contributions in light of the new phenomenon (Schmidt & Wagner, 2019).

Moreover, the extant literature on DLT in SCM that focuses on aspects of adoption and impact is clearly dominated by studies on BCT. Academic contributions center around applications that use, for example, Bitcoin, Ethereum, or Hyperledger Fabric as the underlying DLT protocol, which are all forms of BCT, as shown in Table 6. This dominance has not been discussed so far. However, few authors reveal the exact specification of the underlying DLT (i.e., BCT). Only a single contribution (Auinger & Riedl, 2018) specifies what the authors are actually referring to, as they define both *BCT* and *DLT*.

This lack of clarity is accompanied by a lack of differentiation between the types of BCT protocols studied. For example, applications running on a Bitcoin protocol represent public blockchains, giving all network participants access to all transactions, although covered by anonymity. In contrast, applications based on a Hyperledger Fabric protocol are private or consortium blockchains, and thus, only a permissioned group of entities is able to participate. Applications based on an Ethereum protocol can either be public or private. In this case, the design of the protocol allows more design freedom, but the level of transparency is different. While public blockchains allow all transactions to be seen by everybody, private blockchains do not provide this visibility by nature. Hence, disclosing the specification of the underlying DLT is important for understanding the positive and negative factors that affect adoption decisions.

Table 6: Literature review on the adoption and impact of DLT in SCM

Source	Research approach	Underlying theories	Application contexts	Context of study	Type of DLT	Findings concerning adoption of DLT in supply chains	Findings concerning the impact of DLT in supply chains
			Organizational perspective				
Auinger and Riedl (2018)	Conceptual, based on literature	-	Payment ecosystems		BCT (Bitocin)		Trust shifts from market players to others.
Hofmann, Omran, Henke, and Heines (2017)	Conceptual, based on literature and DLT applications	-	Supply chain management	Supply chain finance	BCTs	Key drivers of BCT are interoperability, scalability, transparency, trust, security, autonomy, open access.	
Johnson, McCurdy, Schechter, and Loch (2020)	Empirical, expert interviews	-	Supply chain management	Transparency in cold chain supply chains	BCTs	Managerial beliefs, resource availability and change efficacy are impact factors on readiness for change to adopt BCT from the perspective of 3PLs	
Kamble, Gunasekaran, and Arha (2018)	Empirical, survey	TAM	Supply chain management	Various SCM applications	BCTs	Ease of use and usefulness positively affects attitude towards using BCTs, while unknown and immature technology negatively affect attitudes towards using BCTs.	
Korpela, Hallikas, and Dahlberg (2017)	Empricial, focus group	TCE	Supply chain management	Various SCM applications	BCTs	Security and privacy issues are potential barriers for BCTs.	
Labazova (2019)	Conceptual, DSR	-	in general		BCTs	Blockchain innovation, design, inter-organizational integration and environment affecting evaluation of BCTs for organization.	
Post, Smit, and Zoet (2018)	Empirical, expert interviews	-	in general		BCTs	13 factors affecting BCTs' diffusion on a strategy, tactical, operational technical level	
Sadhya and Sadhya (2018)	Empirical, secondary data	TAM	in general		BCTs	16 adoption barriers for BCT are revelad for the general use of BCT.	
Wang, Singgih, Wang, and Rit (2019)	Empirical, expert interviews	None	Supply chain management	Various SCM applications	BCTs	Security and ease of distribution of information sharing and building of trust, operational improvements via automation and data availability represent the advantages of BCTs, while know-how and cultural issues, governance, ease of data gathering, technological immaturity, interoperability, legal, privacy and security issues, as well as implementation costs constitute challenges.	

Source	Research approach	Underlying theories	Application contexts	Context of study	Type of DLT	Findings concerning adoption of DLT in supply chains	Findings concerning the impact of DLT in supply chains
				Network perspective			
Abeyrath and Monfared (2016)	Conceptual, based on literature and DLT applications	-	Supply chain management	Transparency on products' lifecycles	BCTs	Availability and immutability of data as well as enhanced TSC are listed as drivers to DLT use, while an advanced level of IT infrastructure and automation as well as smart contracts are needed.	
Babich and Hilary (2019)	Conceptual, based on literature and DLT applications	-	Supply chain management	Transparency and automation	BCTs	Availability, aggregation, and validation of data as well as improved visibility, enhanced automation and resiliency are strenghts of DLT, while privacy and standardization issues, garbage in, garbage out, unknown and immature technology, technolgical inefficiency and technological performance issues are perceived as weaknesses of DLT.	
Kshetri (2018)	Conceptual, based on literature and DLT applications	-	Supply chain management	Various SCM applications	BCTs	BCTs' barriers are the need to multiple partners, Garbage in, garbage out, a lack of decentralization, the advanced technical infrastructure and the yet immature technology.	BCT can reduce need for third parties, increase automation and thus promising to reduce costs.
Schmidt and Wagner (2019)	Conceptual, based on literature	TCE	Supply chain management	Various SCM applications	DLTs		BCT can limit opportunism, reduce environmental and behavioral uncertainty, reduce transaction costs and affect governance costs and structures
Sternberg and Baruffaldi (2018)	Empirical, case study	-	Supply chain management	Transparency on product's journey with focus on logistics	BCTs	Privacy issues, reuired IT infrastructure, smooth data gathering along processes and unknown value of BCT present challenges for BCTs' adoption.	
Tian (2016)	Conceptual, DSR	-	Supply chain management	Transparency in food supply chains	BCTs	Integrity and improved traceability are the advantages of BCTs while implementation costs and technical immaturity represent disadvantages.	

Source	**Research approach**	**Underlying theories**	**Application contexts**	**Context of study**	**Type of DLT**	**Findings concerning adoption of DLT in supply chains**	**Findings concerning the impact of DLT in supply chains**
Combining perspective of individual firm and entire supply chain							
Blossey, Eisenhardt, and Hahn (2019)	Conceptual, based on literature and DLT applications	-	Supply chain management	Various SCM applications	BCTs	Unclear governance models and data ownership present barriers for supply chain actors to adopt DLT.	
Hald and Kinra (2019)	Conceptual, based on literature	-	Supply chain management	Various SCM applications	BCTs	BCTs reveal four enabling and three constraining characterisitcs in SCM that might affect adoption in supply chains.	
Kurpjuweit, Schmidt, Klöckner, and Wagner (2019)	Empirical, Delphi-study	-	Supply chain management	Additive manufacturing supply chains	BCTs	Unknown technology, standardization interoperability, security, and privacy issues, technical performance, high implementation costs, the need for a link to physical products and advanced IT infrastructure, lack of technical know-how, unclear governance, lack of management support and fitting culture, the need for multiple parties and legal issues represent barriers of BCT for additive manufacturing supply chains.	
Saberi, Kouhizadeh, Sarkis, and Shen (2019)	Conceptual, based on literature	-	Supply chain management	Transparency for supply chain sustainability	BCTs	Intra-organizational, inter-organizational, system related and external factors constitute adoption barriers.	
Wang, Han, and Beynon-Davies (2018)	Conceptual, based on literature	-	Supply chain management	Various SCM applications	BCTs	Drivers for BCT deployment: trust and data integrity are drivers for BCTs deployment	

4 Research gaps and research questions: Addressing the adoption and impact of distributed ledger technology-based transparency solutions

Based on the previous literature related to technology adoption and DLT in SCM, the following sub-sections derive and connect the relevant research gaps that are addressed in this thesis. Herein, each sub-section presents a condensed summary of the detailed research gaps described in each of the four studies of this cumulative thesis. Thus, detailed elaborations on the corresponding literature backgrounds can be found also in the studies in the Appendix.[21]

4.1 Accounting for the heterogeneity of distributed ledger technology applications in supply chains

The heterogeneity of DLT as a technology (described in sub-section 2.1) and of the DLT applications in supply chains (described in sub-section 3.2) are currently understudied by academic scholars and have received little attention from practitioners. Only a few contributions disclose the characteristics of the DLT applications including the underlying protocol and further design characteristics of the studied DLT applications (e.g., Auinger & Riedl, 2018). However, without elaborating on the specific characteristics of DLT applications in supply chains, the findings of generic contributions on DLT in the field of SCM are difficult to evaluate. As benefits and challenges depend on the different DLT applications, the discussion on DLT has to be more application-specific. In fact, this blur presents a substantial challenge for both academic scholars and practitioners, especially when it comes to the adoption and impact of DLT applications in supply chains such as DLT-based TSC solutions (Schmidt & Wagner, 2019).

Academic scholars have a hard time studying the adoption and impact of DLT because the factors making a case for or against adoption—as well as the characteristics that lead to a specific impact—largely depend on the underlying

[21] The sub-sections 4.1-4.2 draw upon the content of Study 1-4, which is found in Appendix A-D.

technology and the specific design of DLT applications. For practitioners, the blur creates substantial uncertainty when facing the task of evaluating DLT and deciding upon adoption (Kurpjuweit et al., 2019; Wang et al., 2019). Thus, providing a clear picture of the diversity of DLT applications in supply chains is required. Taking into account this heterogeneity and classifying the DLT applications allows studying the adoption and impact of specific DLT applications. Therefore, the following research questions (RQs) are defined:

RQ1.1: How can DLT applications in supply chains be classified?

RQ1.2: What are the value contributions of the resulting classes of DLT applications in supply chains?

In order to address both RQs, Study 1 follows a mixed method approach combining DSR and a qualitative data analysis of interview data and secondary data. In this way, the study leads to the development of a taxonomy of DLT applications in supply chains. A sample of 48 DLT applications is used to develop four archetypical classes of DLT applications before the qualitative data analysis elaborates on the relevant attributes for each class and the key value contributions of DLT as an underlying technology. The developed taxonomy presents a classification for future research, especially empirical research, to analyze and compare DLT applications and paint a picture with a finer brush stroke.

4.2 Developing the determinants to enhance transparency in the supply chain for assessing the benefit of distributed ledger technology

A large percentage of DLT initiatives in the field of SCM represent DLT-based TSC solutions (Blossey et al., 2019). However, the application context of these DLT-based TSC solutions, namely TSC, lacks a clear operationalization. Despite the interest of both practitioners and academic scholars in TSC, research has omitted to study the enhancement of TSC in general (Swift et al., 2019). Against the background of a lack of operationalization and a lack of understanding regarding the enhancement of TSC, the benefits of DLT-based TSC solutions for enhancing TSC are hard to evaluate. Although several scholars reveal potential arguments for the contribution of DLT for enhancing traceability and visibility (e.g., Wang et al., 2019) by increasing data availability, accessibility, and verification, the importance of these data characteristics for TSC is unclear. Thus, in order to allow a substantiated analysis of the benefits of DLT-based TSC solutions, the phenomenon of TSC must be decomposed and operationalized to explain the enhancement of TSC from the perspective of a focal company in the supply chain first, before these findings can be used to evaluate the benefits of DLT-based TSC solutions as a whole. This leads to the following RQ:

> *RQ2: How can focal companies enhance transparency in the supply chain?*

This research question leads to a multiple case study design that allows for a deep dive into seven TSC mechanisms (e.g., forecasting, tracking and tracing, and auditing) to carve out the focal companies' initial needs to enhance TSC, the capabilities to do so, and the fit between needs and capabilities. Moreover, 29 TSC determinants are delineated, including the exploration of the roles of IT structures, and processes to obtain these TSC determinants. In this way, the study allows for an analysis of the role of DLT-based TSC solutions and the benefits of these solutions for obtaining the required TSC determinants.

4.3 Empirically studying the adoption decision of distributed ledger technology-based transparency solutions in a supply chain

While DLT-based TSC solutions promise to tackle a relevant challenge facing supply chain managers, the adoption of these applications is slow (Schmahl et al., 2019). As the literature background in sub-section 3.2.3 reveals, extant research has discussed the positive and negative aspects of DLT in the context of SCM that might lead to drivers of (see Table 4) or barriers to (see Table 5) an adoption decision. However, these positive and negative factors have not been connected to specific DLT applications and are the results of an unspecified discussion of DLT applications in the field of SCM. Moreover, the positive factors are solely focused on the technical characteristics of DLT itself, not on the entire DLT applications.

Furthermore, a detailed analysis based on empirical findings is missing. While expert opinions about potential drivers and barriers (Kamble et al., 2018; Kurpjuweit et al., 2019) or conceptual arguments (Saberi et al., 2019) show some merit, they lack empirical evidence, such as the experience of practitioners when using real-world DLT-based TSC solutions. Especially given the complexity of the technology and the required multi-actor involvement in DLT-based TSC solutions, field evidence is needed to bring forth a detailed explanation. Only by analyzing the adoption of a real DLT application can a comprehensive multi-actor perspective be achieved to understand and explain the struggle to adopt DLTs in supply chains, with a focus on DLT-based TSC solutions. For this the focus is put on an in-depth analysis of a pilot project of a BCT-based solution that provides traceability. Thus, the following RQ addresses this research gap:

> *RQ3: Why do supply chains, despite the promising benefits, struggle to adopt BCT?*

RQ3 is addressed in a single case study on a BCT application (i.e., private, Hyperledger Fabric-based BCT) aiming to enhance product traceability in the food retail industry. Based on the empirical data, the findings present the perceived benefits and downsides, the external pressure and resistance, and the organizational readiness and immaturity of the different supply chain actors. These positive and negative factors of DLT adoption are contrasted as they lead to tensions that have to be resolved in order to adopt a DLT application in a supply chain. Moreover, by refining the model of technology adoption of IOIS, presented by Iacovou et al. (1995), a multi-actor perspective is enabled to study the adoption decision on both an organizational and a network level. This model can be applied in future research on IOIS adoption in supply chains.

4.4 Uncovering the impact of distributed ledger technology-based transparency solutions

The adoption and impact of technology show a mutual dependency (Venkatesh et al., 2003): while a positive adoption decision is a prerequisite to impact, the observability of the impact of a novel technology affects the adoption decision of others in turn (Rogers, 1962). In the case of DLT-based TSC solutions, impacts on costs, structures, and processes are likely to affect the decision of supply chain actors to adopt the technology (Carson, Romanelli, Walsh, & Zhumaev, 2018). Hence, analyzing the impact of DLT is of great importance to academic scholars and practitioners alike. However, given the novelty of the technology (Weking et al., 2019) and the early stage of DLT applications in the field of SCM (Schmidt & Wagner, 2019), research has not presented empirical evidence on the impact of DLT in supply chain or, specifically, of DLT-based TSC solutions. As the costs of DLT initiatives present an obstacle for practitioners to adopt BCT (Mathauer & Hofmann, 2020; Pawczuk et al., 2019), the cost-saving impact of DLT is of particular interest in the field of SCM. Thus, analyzing the impact of DLT in the context of supply chain transactions is required. Given the well-established concept of TCE, this theoretical foundation can help to guide research in this regard. Thus, the following RQs are defined:

RQ4.1: What are the implications of distributed ledger technology on the transaction cost economics of supply chains?

RQ4.2: What are the distributed ledger-based causes of these implications?

In order to address these RQs, a multi-case study of real-world DLT-based TSC solutions is conducted that reveals cost reduction and avoidance effects, shifts in power constellations, and dependency effects as impacts of these DLT applications. These effects are induced by 11 DLT-based causes that lead to both positively and negatively perceived impacts. Based on these findings, practitioners are able to understand the impact of DLT-based TSC solutions, while the contribution presents an elaboration of TCE in the light of DLT.

5 Design of the research: Studying the adoption and impact of an emerging technology in supply chains

Following the review of relevant literature and the determination of the research gaps, the thesis is positioned at the intersection of two main research fields: SCM and IS. In line with the view of Gibbons (1994), research at the intersection of multiple disciplines or research fields can only be conducted properly if the respective research paradigms and theoretical understanding are mutually compatible. Thus, the paradigm positioning of this research will be discussed in order for the ontological and epistemological stance to be made transparent. In this vein, the thesis presents the underlying research paradigm, the implications of the theoretical contributions, and the research methods. However, it should be noted that the stance adopted in this thesis is not unification-focused[22] but rather appreciates the diversity of the stances and methodologies present in IS and SCM (Knudsen, 2003).

5.1 An interpretivists perspective on the adoption and impact of distributed ledger technology-based transparency solutions

The research paradigm of the present thesis comprises ontology—that is, the researcher's "view about the nature of reality" (Easterby-Smith, Thorpe, Jackson, & Jaspersen, 2018, p. 61)—and epistemology—that is, the researcher's perspective on how knowledge can be acquired (Guba & Lincoln, 1994). The adopted otology and epistemology must be compatible, as they ultimately lead to the corresponding methodological approach to be used in the research, including the methods and techniques (Saunders, Lewis, Thornhill, & Bristow, 2019).

5.1.1 A relativistic stance to study the adoption and impact of distributed ledger technology in supply chain management

For this thesis, my ontological stance can be classified as that of relativism. *Relativism* embodies the view that "[s]cientific laws are created by people who

[22] That is, it is not understood as melting pot unifying the research paradigms but instead appreciative of the different stances and ideas emerging from different paradigms, without blending incompatible views.

are embedded in a context (so it's in the eye of the beholder)" (Easterby-Smith et al., 2018, p. 66). Thus, there are many truths, and the researcher should therefore take on different viewpoints to capture phenomena in their wholeness. Some researchers also refer to this as *subjective idealism* (Archer, 1988; Walsham, 1995a). The ontological stance of relativism is located next to internal realism, in the middle of the continuum between realism and nominalism. These four positions mark reference points for researchers' ontological positions (Easterby-Smith et al., 2018). While realism and nominalism represent the two poles of this continuum, internal realism differs from relativism, as it assumes reality to be independent of the researcher. Proponents of internal realism believe in the existence of a single truth that is obscure, and they believe that facts can only be captured indirectly (Easterby-Smith et al., 2018).

5.1.2 An interpretive approach to enquiring about phenomena

In line with relativism, my approach to this thesis project is influenced by interpretivism (Gregor, 2006). It must be noted that the term *interpretivism* is well established in IS research. The core aim of interpretivism is "understanding the complex world of lived experience from the point of view of those who live it" (Schwandt, 1994, p. 118). Interpretivists adopt the view that humans determine reality, and the knowledge of reality is constructed by humans (Walsham, 1995b). Thus, the researcher is embedded in the reality he or she studies. Herein, the interests and decisions of humans play a vital role in the research, which generally aims to contribute to the understanding of a phenomenon (Orlikowski & Baroudi, 1991).

Aside from understanding a phenomenon, reconstruction is another aim of inquiry (Lincoln, Lynham, & Guba, 2018). Therefore, researchers favor using research designs, such as case studies and surveys, that capture words and numbers to elaborate on their understanding and allow for a detailed reconstruction. Thus, both qualitative and quantitative methods and techniques are applied to gain knowledge (Walsham, 1995b). Herein, the triangulation of methods and data plays a central role to account for different realities and perspectives (Easterby-

Smith et al., 2018). This stance is taken in the current study because supply chains do not exist, per se, but are constructed by humans (Durach, Kembro, & Wieland, 2017), as is DLT.

5.1.3 Use of theory, qualitative studies, multiangle perspectives, and triangulation as a manifestation of the paradigm positioning

In many respects, my ontological and epistemological stances guide the methodologies applied in the four studies presented in section 6 in many respects. First, in line with an interpretivists view (Walsham, 1995a), all four studies are infused with theoretical contributions, using theoretical contributions as a framework for data collection (Study 1–3), in an iterative process of data collection (Study 4), and in producing forms of theoretical contributions (all four studies), following the definition of Gregor (2006).

Second, concerning the applied methodologies, Study 2, 3, and 4 are all case studies, while Study 1 is based on a qualitative data study combining secondary data and interviews. In all these studies, interviews play a central role in gathering data and deriving findings. In line with Klein and Myers (1999) and Walsham (1995b), qualitative studies are well suited to providing the rich descriptions needed for understanding and reconstructing the studied phenomena. Third, in the design of all four studies, the viewpoint of the research is meticulously addressed, as the studies were designed to glean insights from multiple perspectives on the respective phenomena under observation. Fourth, the research relies on triangulation, primarily of data (all four studies) and methods (Study 1). In all four studies, data from different sources (e.g. interviews, reports, websites, and demonstrations) were gathered to capture the different realities. Study 1 builds on a web search as a method of secondary data collection and on interviews as a method of primary data collection.

5.2 Assembling the theoretical foundation for this thesis

The nature of theoretical contributions has been discussed in several research fields within the management discipline, including management (e.g., DiMaggio, 1995; Sutton & Staw, 1995; Van De Ven, Andrew H., 1989; Weick, 1995) and IS (e.g., Gregor, 2006). Instead of continuing this discussion, this sub-section aims to describe the selection and use of theoretical contributions in the present thesis.

5.2.1 Theoretical foundation: Socio-technical systems, information processing theory, technology adoption model, and transaction cost economics

In line with an interpretivist's stance, theoretical foundations are used in this thesis to help understand and reconstruct the phenomenon of the adoption and impact of DLT-based TSC solutions. Thus, all five types of theoretical contributions outlined by Gregor (2006) are useful, independent of their scale of applicability (i.e., their generalizability). Table 7 gives an overview of the theoretical foundation of this thesis, including the four studies. Afterward, the theories used in Study 1, Study 2, and Study 4 are discussed in more detail. The theoretical foundation of Study 3 and of the thesis itself were discussed and selected in sub-section 3.1. Based on this discussion, the technology adoption model of Iacovou et al. (1995) was found to be the best-suited model to study the adoption and impact of DLT-based TSC solutions in general, as well as to study adoption decisions to address research gap 3 in Study 3.

Table 7: Overview of theoretical foundation of this thesis

Study	Theoretical contribution	Purpose of use according to Walsham (1995a)	Type of contribution according to Gregor (2006)	Exemplary sources
Thesis	Technology adoption model (Iacovou et al., 1995)	Guide and structure thesis (i)	Mainly explaining (type II)	Premkumar and Ramamurthy (1995), Chwelos, Benbasat, and Dexter (2001)
Study 1	Socio-technical systems (STS)	Guide for data collection (i)	Mainly explaining (type II)	Annibal, Henry, and Mark (2019), Kull, Ellis, and Narasimhan (2013)

Study 2	Information processing theory (IPT)	Guide for data collection (i)	Mainly explaining (type II) and explaining and predicting (type IV)	Premkumar, Ramamurthy, and Saunders (2005), Srinivasan and Swink (2018)
Study 3	Technology adoption model (Iacovou et al., 1995)	Guide for data collection (i)	Mainly explaining (type II)	See above
Study 4	Transaction cost economics (TCE)	Iterative process of data collection and analysis (ii)	Mainly predicting (type III) and explaining and predicting (type IV)	Grover and Malhotra (2003), Aron, Clemons, and Reddi (2005)

5.2.2 Criteria for selection the selection of theoretical foundations: Theoretical attractiveness, design orientation, and integrative power

Following the overview of the theoretical foundation of this thesis and of Study 3, it is next necessary to disclose the selection of the theoretical foundations for Study 1, Study 2, and Study 4 and their contribution to the overall thesis. Theoretical foundations constitute theoretical contributions that help craft the research design of a study, understand the studied phenomenon, or affect the process of data collection and analysis in the sense of theory elaboration (Ketokivi & Choi, 2014; Walsham, 1995a). As described above, the theoretical foundation of Study 3 has been discussed in section 3, as it overlaps with the model used to study the adoption and impact of DLT-based TSC solutions overall.

The selection of the theoretical foundation follows the approach of Stölzle (1999). According to this approach, theoretical attractiveness, design orientation, and integrative power are listed as relevant selection criteria for the theoretical foundation of SCM research. These criteria can be further specified to fit with the specific research goals. In the following, these three selection criteria are presented in accordance with the research goal of three studies to discuss the adequacy of different theoretical contributions for the three studies.[23]

- *Theoretical attractiveness* refers to the ability of a theoretical contribution to help address the research goal—and, specifically, the research question—as well as to explain the phenomenon under study. For Study 1, this means that an adequate theoretical foundation helps to guide the classification of DLT applications (addressing RQ1.1) and derive the value contributions of the classes (addressing RQ1.2). For Study 2, a theoretical contribution is attractive as a theoretical foundation if it helps explain how focal companies can enhance TSC (addressing RQ2). For Study 4, this requires helping to address the impact of DLT-based TSC solutions (addressing RQ4.1) and to explain the reasons for this impact (addressing RQ4.2).
- *Design orientation* refers to the ability of a theoretical contribution to help operationalize and decompose a studied phenomenon in its core elements. With regard to Study 1, a theoretical contribution capable of forming a theoretical foundation helps in developing classification categories and thereby operationalizes and decomposes DLT applications in supply chains as well as operationalizes the value contributions. For Study 2, a theoretical foundation is adequate if it helps to operationalize TSC and to draw out the individual elements that enhance TSC from the perspective of a focal company. For Study 4, an operationalization of the impact of DLT-based TSC solutions is needed, which requires a theoretical foundation that is capable of helping to decompose and operationalize a certain target phenomenon of DLT's impact.
- *Integrative power* refers to the ability of a theoretical contribution to be embedded in the theoretical landscape of a research topic and deliver valuable insights to help achieve the research goal. On the level of the

[23] The selection process is oriented around previous dissertations submitted at the Institute of Supply Chain Management, previously the Chair of Logistics Management of the University of St.Gallen, (e.g., Oettmeier, 2017; Haensel, 2018).

present thesis, this requires theoretical contributions that are compatible with other theoretical contributions (i.e., those that are commensurable) and that simultaneously help in developing relevant insight for the overall research goal. While commensurability is required for the theoretical foundations of all four studies, they are also required to develop fitting insights for the overall thesis. For Study 1, this means that the application of a theoretical foundation helps to carve out and structure specific characteristics of DLT applications in supply chains and the value contributions to enable a more detailed, application-specific research in this thesis. For Study 2, the theoretical foundation supports identifying the determinants of enhancing TSC to assess the contribution of DLT to enhancing TSC. For Study 4, a theoretical foundation enables an analysis of the impact of DLT-based TSC solutions and thereby contributes to the fourth research gap identified in the present thesis.

Table 8 lists the theoretical contributions that were considered based on existing research in similar studies in the field of SCM and IS. The sources that used these theoretical contributions as theoretical foundations are represented in the last column of Table 8.[24]

Table 8: Theoretical contributions for consideration

Study	**Theoretical contributions**	**Exemplary sources**
Study 1	Information processing theory	Srinivasan and Swink (2015), Cegielski, Allison Jones-Farmer, wu, and Hazen (2012)
	Socio-technical systems	Kull et al. (2013), Annibal et al. (2019)
Study 2	Resource-based view	Barratt and Oke (2007), Steinfield, Markus, and Wigand (2011)
	Theory of dynamic capabilities	Brusset (2016), Rauer and Kaufmann (2015)
	Contingency theory	Brandon-Jones et al. (2014), Caridi, Crippa, Perego, Sianesi, and Tumino (2010)
	Information processing theory	Williams et al. (2013), Srinivasan and Swink (2018)

[24] This sub-section partially draws upon the content of Study 1, Study 2 and Study 4, which are found in the Appendix.

Study 4	Agency theory	Zsidisin and Ellram (2003), Zu and Kaynak (2012)
	Transaction cost economics	Aron et al. (2005), Grover and Malhotra (2003)
	Network theory	Ketchen and Hult (2007), Pathak, Day, Nair, Sawaya, and Kristal (2007)

In the following sub-sections, the listed theoretical contributions are briefly presented to enable an evaluation of their adequacy as theoretical foundations for Study 1, 2, and 4. Study 1 follows an inductive DSR approach to develop a taxonomy of DLT applications in supply chains. Thus, technology centered theoretical contributions are relevant that help classify DLT applications. All four theoretical contributions in consideration for Study 2 are organizational theories, putting the focus of the analysis on a focal organization, which is most fitting for addressing RQ2; however, the inter-organizational nature of TSC must be accounted for as well. The theoretical contributions for Study 4 stem from economics and enable the analysis both of individuals and of organizations, which well suits the analysis required to answer RQ4.1 and RQ4.2 with regard to the impact of DLT-based TSC solutions. In the following, the listed theoretical contributions are briefly introduced.

Theories in consideration for Study 1:

- *Information processing theory (IPT):* Based on the seminal work of Galbraith (1974) and Tushman and Nadler (1978), organizations face uncertainties that motivate them to process information; hence, they have an information processing need (IPN). In order to cope with uncertainties, firms can either reduce their IPN or enhance their information processing capability (IPC) in order to achieve enhanced performance. According to Tushman and Nadler (1978), organizations strive for a fit between IPN and IPC to efficiently increase a certain performance dimension. While originating from organizational management, Premkumar et al. (2005) transferred IPT to the inter-organizational context of supply chains and thus enable the analysis of the capabilities and processes within a focal company and beyond its organizational boundaries.

- *Socio-technical systems (STS):* Following the seminal work of Bostrom and Heinen (1977), socio-technical systems help to understand the interplay of the social subsystem and the technical subsystem to evaluate the impact of technology. According to STS, four core elements have to be taken into account when studying technologies in its environment. First, the social subsystem comprises structures and people. Second, the technical subsystems comprise the technology and the tasks. All four core elements reveal interdependencies. These interdependencies explain the sources of implementation success and struggles of technology in a specific environment. However, vice versa, IS scholars and behavioral scientists have developed design principles to develop successful socio-technical systems that enable organizations to implement technologies successfully.

Theories in consideration for Study 2:

- *Resource-based view:* Based on the seminal work of Barney (1991), the resource-based view of a firm describes the role of internal resources to establish a sustainable competitive advantage. As such, these resources are seen as scarce, valuable, not substitutable, and hard to imitate, in order to represent a source for competitive advantage. The resource-based view is seen as the origin of theoretical modifications such as the practice-based view (e.g., Bromiley & Rau, 2014) and the knowledge-based view (e.g., Grant, 1996). Against the backdrop of RQ2 (in Study 2), the resource-based view enables an explanatory view of the resources required to enhance TSC within a focal firm. According to the theory, this would allow for the structuring of the research design; however, a link to the competitive advantage of the focal firm is required.
- *Theory of dynamic capabilities:* Based on the contribution of Teece, Pisano, and Shuen (1997), the theory of dynamic capabilities is also related to the resource-based view, which refers to a "firm's ability to integrate, build,

and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organization's ability to achieve new and innovative forms of competitive advantage, given path dependencies and market positions" (Teece et al., 1997, p. 516). For Study 2, this would emphasize the dynamic component of resources for establishing and maintaining a competitive advantage by enhancing TSC. However, here again, the need for a competitive advantage based on the enhanced TSC is troubling when seeking to apply this theory.

- *Contingency theory:* Contingency theory is presented for consideration as a theoretical foundation of Study 2. It states that "organizational effectiveness results from fitting characteristics of the organization, such as its structure, to contingencies that reflect the situation of the organization" (Donaldson, 2001, p. 1). While taking the perspective of a focal company, the emphasis is on the contingency within and outside of the organization under observation. In light of RQ2 (in Study 2), this presents an interesting view of the environment surrounding an organization, yet contingency theory is limited in its explanatory power when it comes to the processes and resources within a focal company, and the corresponding supply chain actors, to enhance TSC.
- *Information processing theory (IPT):* See above.

Theories in consideration for Study 4:

- *Agency theory:* Based on the seminal work of Alchian and Demsetz (1972) and Jensen and Meckling (1976), agency theory centers around the "ubiquitous agency relationship, in which one party (the principal) delegates work to another (the agent), who performs that work" (Eisenhardt, 1989, p. 58). Therein, the unit of analysis is the contract between these two parties. As agency theory makes humanistic (e.g., self-interest), organizational (e.g., information asymmetry), and information-specific assumptions (e.g., information is purchasable), the agency theory enables a discussion of contracts and risk-sharing models.

Thereby, the agency theory allows an explanation and prediction of individuals' or organizations' behavior within different settings and contracts. The initial works of Alchian and Demsetz (1972) and Jensen and Meckling (1976) gave rise to two separate streams: positivists and principal agents (Eisenhardt, 1989). Contributions of the first stream are, for the most part, not compatible with the paradigm position of this thesis, as they aim to measure the impact directly using mathematical models. However, the principal-agent contributions are also limited in their applicability to studying the impact of DLT-based TSC solutions in Study 4, given their explicit focus on the contract, which is not seen as a structural or processual impact in supply chains.

- *Transaction cost economics:* Built on the seminal work of the Nobel laureates Williamson (1985) and Coase (1937), TCE focuses on the governance structure of organizations, given the assumptions of bounded rationality, opportunism, the dimensions of transactions in terms of uncertainty, and asset specificity. Based on these assumptions, TCE explains and predicts the optimal organizational governance structure to minimize transaction costs. TCE is frequently applied in IS and SCM research to discuss the impact of technology innovations on governance structures (e.g., Clemons, Reddi, & Row, 1993; Clemons & Row, 1993) and of make-or-buy decisions in supply chains (e.g., Aron et al., 2005; Williamson, 2008). As governance structures directly affect outsourcing decisions and their related costs, TCE is generally well suited as a theoretical foundation to study the impact of DLT-based TSC solutions in terms of structural and processual changes in supply chains for Study 4.
- *Network theory:* Stemming from mathematics and being applicable to multiple disciplines, such as computer science, biology, and social science, network theory enables the study of the connections (represented as *edges*) between individuals, groups, and organizations (represented as *nodes*) and allows for the analytic characterization of

networks in society. As such, network theory is mainly focused on analyzing established networks and explaining relationships and roles in networks (Ketchen & Hult, 2007). As the level of analysis in Study 4 is the network rather than an individual entity in the network, the theory has limitations concerning its applicability as a theoretical foundation for Study 4 and concerning its compatibility with the perspective of the overall thesis. Thus, network theory is not considered any further.

While network theory is not considered a fit for Study 4, the other theoretical contributions are next evaluated in greater detail in relation to the selection criteria, according to Stölzle (1999). The results of this evaluation are presented in Table 9.

Table 9: Selection of theoretical

	Theoretical contributions	Theoretical attractiveness	Design orientation	Integrative power	Overall suitability
Study 1	Information processing theory	Is limited to explain the information processing within DLT applications. Ability to classify DLT applications is limited to IT, structures and processes of the solution, not the application context.	Operationalization is limited to uncertainties, IPN, IPC, fit between IPN and IPC, structures, processes and IT for building up IPC – lacks environmental aspects.	Assumptions, level and unit of analysis commensurable with technology adoption model.	Medium
	Socio-technical systems	Enables to explain the different elements and their interplay of technologies in their environment. Thereby enables to address RQ1.1. and help classify DLT applications in supply chains.	Operationalization of DLT applications into social and technological subsystem helps to develop a classification.	Assumptions, level and unit of analysis commensurable with technology adoption model.	High
Study 2	Resource-based view	Is limited to studying the (internal) resources needed and requires competitive advantage, which is not inherent when enhancing TSC. Ability to address RQ2 and explanatory power for the phenomenon of TSC is limited.	Operationalization is limited to resources of the focal company, decomposition of phenomenon is limited to resources.	Enables to identify needed resources to enhance TSC from the perspective of a focal company Assumptions, level and unit of analysis commensurable with technology adoption model.	Medium
	Theory of dynamic capabilities	Is limited to studying the (internal) resources needed and requires competitive advantage, which is not inherent when enhancing TSC. Ability to address RQ2 and explanatory power for the phenomenon of TSC is limited.	Operationalization is limited to resources of the focal company, decomposition of phenomenon is limited to resources.	Enables to identify needed resources (with dynamic view) to enhance TSC from the perspective of a focal company Assumptions, level and unit of analysis commensurable with technology adoption model.	Medium

	Theoretical contributions	Theoretical attractiveness	Design orientation	Integrative power	Overall suitability
Study 2 (continued)	Contingency theory	Is limited to studying contingencies for an efficient structure and external factors for enhancing TSC. Ability to address RQ2 and explanatory power for the phenomenon of TSC is limited.	Operationalization of organizational structures, decomposition of phenomenon is limited to structures .	Enables to identify organizational structures and external factors affecting TSC from the perspective of a focal company. Assumptions, level and unit of analysis commensurable with technology adoption model.	Medium
	Information processing theory	Enables to study internal and external capabilities as well as process of information processing. Thereby enables to address RQ and explains phenomenon of TSC.	Operationalization of and decomposition in uncertainties, IPN, IPC, fit between IPN and IPC, structures, processes and IT for building up IPC.	Enables to identify required process, structures and IT to enhance TSC from the perspective of a focal company including corresponding supply chain actors. Assumptions, level and unit of analysis commensurable with technology adoption model.	High
Study 4	Agency theory	Is limited to contract as unit of observation and thus neither structural nor processual implications.	Operationalization is limited to relationship between principal and agent.	Enables to analyze impact in terms of contract design and relationship. Assumptions and level of analysis compatible Unit of analysis not commensurable to technology adoption model as covering only bilateral relation.	Low
	Transaction cost economics	Enables to study transaction costs and governance mode and thus both structural and processual impact in supply chains.	Operationalization of and decomposition in human, organizational and information assumptions, governance structure and resulting transaction costs, which enables to study the impact of DLT-based TSC solutions.	Enables to analyze impact in terms of transaction costs and governance structures. Assumptions, level and unit of analysis commensurable with technology adoption model and information processing theory.	High

Table 9, STS constitutes an adequate theoretical foundation to address RQ1.1 and RQ1.2 in Study 1. With its four elements, STS enables to guide a classification of DLT applications in supply chains and include both technical and social dimensions to characterize these applications. The applicability in SCM is given, as structures are not limited to an individual organization and can be transferred to the supply chain (Clegg, 2000). Furthermore, STS is theoretically attractive and has been deployed to understand the structure and process of applying big data analytics in supply chains (Annibal et al., 2019). Moreover, STS enables to structure and decompose the components of DLT applications in supply chains and thereby supports the development of the classification. In addition, STS is commensurable with the technology adoption model of Iacovou et al. (1995). Both include a technical and environmental (external pressure, organizational readiness) perspective on technology adoption respective technology use. While STS originally focused more on individuals, Clegg (2000) widens the focus to organizations and inter-organizational contexts. Thereby, both theoretical foundations are commensurable on the level of analysis as well.

Following this assessment, the IPT emerges as the most suitable theoretical contribution to build the foundation for addressing RQ2 in Study 2. IPT enables an explanation of the phenomenon of TSC, as enhancing TSC requires processing information within a focal company and across organizational boundaries. Given the transfer from the organizational to inter-organizational context, conducted by Premkumar et al. (2005), and the frequent application of IPT to the study of TSC (e.g., Srinivasan & Swink, 2018; Williams et al., 2013; Zhu et al., 2018), IPT appears to be attractive as a theoretical foundation for Study 2. Moreover, it allows for the detailed structuring and decomposing of TSC and enables the operationalization of enhanced TSC via obtaining the required fit between IPN and IPC.[25] Furthermore, IPT is compatible with the technology adoption model of Iacovou et al. (1995) and STS concerning the assumptions, the level of analysis, and the unit of analysis. All three theoretical foundations enable an analysis on

[25] A detailed argument for this claim can be found in Study 2, in Appendix B.

the level of the organization. The units of analysis of all three, the adoption decisions (technology adoption model), the social-technological interplay (STS), and the elements of information processing (IPT), enable to study technology in the environment and the behavior of supply chain actors (which includes designing of DLT application, adoption decisions, reaction to IPN respective uncertainty). Thus, theoretical commensurability is present. Therefore, IPT is used as a guiding theoretical foundation for Study 2, which helps in designing the data collection (e.g., the interview instrument) and explaining the phenomenon.[26]

In addition, TCE emerges as the most suitable theoretical contribution to build the foundation for addressing RQ4.1 and RQ4.2 in Study 4. TCE is well established in SCM and allows an analysis of the transactions between two or more organizations in a supply chain (e.g., Grover & Malhotra, 2003; Hobbs, 1996; Williamson, 2008). Moreover, several studies have used TCE to analyze the impact of technology innovation in supply chains (e.g., Aron et al., 2005; Bakos & Brynjolfsson, 1993; Clemons et al., 1993). Thus, TCE is theoretical attractive as a theoretical foundation for Study 4. Furthermore, TCE enables the operationalization of transactions in supply chains (e.g., assumptions and dimensions). Hence, TCE allows for a detailed analysis of the impact of DLT-based TSC solutions. Moreover, the assumptions, the level of analysis (i.e., the organizations in supply chains), and the unit of analysis (i.e., transactions) are compatible with the technology adoption model of Iacovou et al. (1995), STS and with IPT. For example, IPT and TCE share the assumption of uncertainty due to a lack of information, and both enable the explanation and prediction of favorable solutions for organizations.[27] Furthermore, the behavior of the supply chain actors (in TCE resulting in governance decisions) is analyzable in all four theoretical foundations. Thus, TCE is used in the process of data collection and analysis to enable a systematic combining of the empirical data and extant literature.[28]

[26] A detailed perspective of the use of IPT in Study 2 can be found in Study 2, in Appendix B.
[27] In the case of IPT, reduce IPN or increase IPC; in the case of TCE, define the governance structure (make or buy).
[28] A detailed perspective of the use of TCE in Study 4 can be found in the Study 4, in Appendix D.

5.3 Crafting empirical research designs for studying emerging technologies

In line with both the epistemological stance and the research questions (RQ1–RQ4.2), this thesis is based on qualitative research designs.[29] Data for the four studies were collected in interviews, from secondary data sources (e.g., reports, webpages, whitepapers, presentations, and manuals), and from demonstrations. Following an interpretivist approach, data from multiple angles (e.g., supply chain actors, and solution providers) were gathered in all four studies to enable data triangulation. A detailed list of data sources (e.g., an overview of interview partners) can be found in each study. The qualitative design of all four studies resulted in the gathering of in-depth insights about the respective phenomenon. Furthermore, the qualitative approach is pursued because DLT applications in supply chains is rather novel phenomenon and thus lack a large number of examples to observe (Schmidt & Wagner, 2019). Based on the derived research gaps, I intended to gain empirical insights into the emerging phenomenon. Thus, at this early stage, a qualitative design suits not only my epistemological stance but also the degree of maturity of the phenomenon under study in this thesis (Holmström, Holweg, Lawson, Pil, & Wagner, 2019).

The data analysis followed a qualitative approach using case study research (in Study 2-4). Study 1 combines both qualitative analysis and quantitative analysis (i.e., cluster analysis) to derive classes of DLT-based TSC solutions. The details of the analysis are described in each study. It should be noted that grounded theory has been used as a concept in data coding but not as an overall research design. This allows middle-range coding to be conducted (in all four studies), while grounded theory is limited to bottom-up coding (Urquhart, 2013). Middle-range coding combines codes suggested from empirical data and from literature.

[29] A detailed description of the respective research designs can be found in the studies (Study 1-4) in the Appendix.

5.4 Integrating the literature, theoretical foundation, and research design to address the goal of this thesis

The integrated framework of the present thesis is illustrated in Figure 7. It integrates the overall research goal, including the sub-topics, which are addressed in the four studies (Study 1–4), the associated RQs, and the theoretical foundations of this thesis. The integrative framework draws on the theoretical and practical relevance described in section 1, the foundations of DLT, and transparency in the context of SCM described in section 2. Furthermore, the framework is based on the literature review of both the technology adoption of IOIS and of DLT in SCM research, provided in section 3. As the thesis includes four theoretical foundations—namely STS, IPT, the technology adoption model of Iacovou et al. (1995), and TCE—the thesis follows an eclectic approach in terms of the underlying theoretical foundation. The integration of multiple theoretical contributions enables the study of four different sub-topics of the overall research goal by applying well-suited, specific theoretical foundations and methodologies to address the individual RQs. Given the complexity of the overall phenomenon of DLT adoption in supply chains, a single theoretical foundation would not be sufficient to gain in-depth insights into the sub-topics of this thesis, according to the goal of the relativistic stance of understanding and reconstructing a phenomenon in detail.

The technology adoption model of Iacovou et al. (1995) constitutes the overarching structure of this thesis, as explained in sub-section 3.1. It helps with structuring and decomposing the phenomenon of the adoption and impact of DLT in supply chains. Moreover, STS represent an explanatory foundation for classifying DLT applications in supply chains and thus enabling a structured characterization of the diverse applications. Given the lack of operationalization of TSC, IPT helps to explain, operationalize and decompose the phenomenon of TSC in order to understand the application context of DLT-based TSC solutions and evaluate the value of DLT for enhancing TSC. Furthermore, the technology adoption model of Iacovou et al. (1995) and its refinement in Study 3 enable the explanation and structuring of adoption decisions in supply chains. In addition, TCE is used as a theoretical foundation to analyze the impact of DLT-based TSC solutions, with special consideration of the impact on transaction costs and governance structures within a supply chain in Study 4.

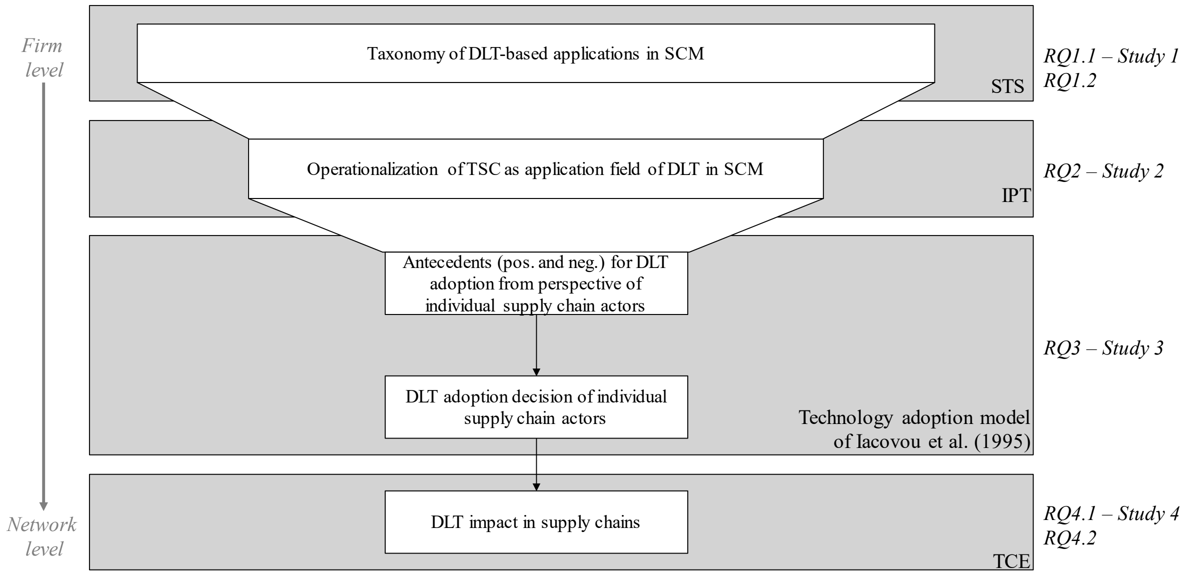


Figure 7: Integrative framework of thesis

In addition, the integrative framework illustrates the level of analysis used. In the present thesis, the level of analysis is mainly on the organizational level. However, Study 3 and Study 4 also reveal important findings on the network level. This is necessary because the overall adoption and impact of DLT-based TSC solutions requires multiple supply chain actors to adopt the solution and leads to an impact that affects multiple actors as well. Hence, analysis at both the organizational level of the individual firms and at the wider network level are required to understand the adoption decision and its impact in detail. Without taking on both levels in Study 3 and Study 4, a full understanding and reconstruction of the adoption and impact of DLT-based TSC solutions could not be formulated. Furthermore, combining both levels of analysis in Study 3 and Study 4 is in line with an interpretivist view of obtaining different perspectives to gain a full understanding of the studied phenomenon.

6 Core findings of this thesis: Illuminating the design, the deployment and application area, and the adoption and impact of distributed ledger technology-based transparency solutions

This section condenses findings of the four studies within the present thesis. Table 10 gives an overview of the four studies, including each study's title, objective, RQs, methodology, and theoretical foundations. Following Table 10, the studies are presented in a condensed form.[30]

Table 10: Overview of studies in the present thesis

	Study 1	**Study 2**	**Study 3**	**Study 4**
Title	Distributed ledger technologies in supply chains: A taxonomy of applications	Decomposition of transparency in supply chains: An information processing perspective	The struggle is real: Insights from a supply chain blockchain case	Distributed ledger technology in supply chains: A transaction cost perspective
Objective of study	Understanding and classifying DLT applications in supply chains and their value contribution for supply chain actors	Understanding and explaining the enhancement of TSC to evaluate the role of emerging technology to enhance TSC	Understanding and explaining the adoption decision of a DLT-based TSC solution in a supply chain	Understanding and explaining the impact of DLT-based TSC solutions in supply chains
Related research questions	RQ1.1: How can DLT applications in supply chains be classified? RQ1.2: What are the value contributions of the resulting classes of DLT applications in supply chains?	RQ2: How can focal companies enhance transparency in the supply chain?	RQ3: Why do supply chains, despite the promising benefits, struggle to adopt BCT?	RQ4.1: What are the implications of distributed ledger technology on the transaction cost economics of supply chains? RQ4.2: What are the distributed

[30] The corresponding full versions can be found in the Appendix (Study 1 – 4), including information related to each study's corresponding publication medium and status.

				ledger-based causes of these implications?
Methodology	DSR and qualitative data analysis	Inductive, multiple case study with 24 cases	Inductive, single-case study	Abductive, multiple case study with 5 cases
Theoretical foundation	STS	IPT	Technology adoption model of Iacovou et al. (1995)	TCE

6.1 Study 1: Classifying distributed ledger technology applications in supply chains to enable more detailed analysis

6.1.1 Illuminating the heterogeneity of distributed ledger technology applications in supply chains

A large number of diverse DLT applications in supply chains is currently discussed by academic scholars and practitioners. Current research brought forth generalized findings on DLT in supply chains. However, the currently tested and implemented DLT applications are heterogenous. The DLT applications differ in characteristics such as the objectives, scope, industry and underlying technology. Thus, an analysis on the adoption can only be detailed if it is conducted on the level of specific applications. Although literature is emerging, a taxonomy for classifying and characterizing the existing DLT applications in supply chains is missing. Therefore, the objective of Study 1 is to enable a more detailed and application-specific analysis of DLT applications in supply chains. Hence, Study 1 is set out to develop a taxonomy of DLT applications in supply chains to enable a characterization of DLT applications and allow the identification of predominant classes. Furthermore, Study 1 aims to derive the value contribution of the predominant classes.

To address RQ1.1 and RQ1.2, a mixed methods approach is applied. In a first step, DSR is applied to develop a taxonomy of DLT applications in supply chains, comprising rigor, relevance and design cycles in accordance to Hevner (2007) and

Nickerson, Varshney, and Muntermann (2013). Following the design of the taxonomy, four classes are derived based on a hierarchical cluster analysis (Punj & Stewart, 1983) on 48 DLT applications in supply chains in a second step. In a third step, a qualitative data analysis of interview and secondary data on the 48 DLT applications is applied to derive the relevant attributes of DLT as an underlying technology in the four application classes and to identify the value contributions of each class.

6.1.2 Developing a taxonomy and deriving the value contributions of the classes of distributed ledger technology applications in supply chains

In a DSR approach, a taxonomy of DLT applications with three meta-characteristics, 16 dimensions and 53 characteristics is developed. Thereby, STS as a theoretical foundation enables to structure the developed taxonomy based on the three meta-characteristics *underlying technology*, *participation structure*, and *targeted task*. The morphological box in Figure 8 illustrates the taxonomy of DLT applications. Following this taxonomy, each DLT application in supply chains can be characterized and described in more detail. Based on the taxonomy, a sample data set of 48 different DLT projects that represent 48 distinct DLT applications in supply chains is clustered to derive homogenous classes. As a result, the study presents four homogenous classes of DLT applications in supply chains. A short description of these four classes can be found in Table 11. Following this clustering, both SCM scholars and practitioners can focus their effort on the classes of interest to enable a more detailed discussion, analysis, or development on the level of a specific DLT application.

Layer	Dimension	Characteristics					
Underlying technology	Underlying protocols [UP]	BCT	DAG				
Underlying technology	Permission right [PR]	Public	Private	Consortium			
Underlying technology	Consensus mechanisms [CM]	Proof-of-work	Permissioned voting	Permissioned notary	DAG consensus		
Underlying technology	Databases as sources for data input [DI]	Single	Multiple				
Underlying technology	Additional technologies for data gathering [AT]	Required	Not required				
Underlying technology	Tag with physical product [TP]	Required	Not required				
Underlying technology	Transaction space [TS]	Only on-ledger	Off-ledger				
Participation structure	Scope of participation network [SP]	Supply chain	Industry	Open			
Participation structure	Participating supply chain actors [PA]	Physical actors	Physical and support actors				
Participation structure	Usage by end customer [UE]	Yes	No				
Participation structure	Role as operator of nodes [RO]	Not required	Operated as a service	Operated by individual actors			
Targeted task	Underlying asset [UA]	Physical product	Information	Financial resources			
Targeted task	Main objective [MO]	Traceability of products	Visibility of actors and processes	Authenticity of products	Digitalization of processes	Financing and escrow	
Targeted task	Industry [IN]	Automotive	Aviation	Chemicals	Food		
Targeted task		Minerals	Pharmaceuticals	Textile	Multiple industries		
Targeted task	Scope of the application [SA]	Transport and logistics	Procurement	Production	Distribution	SCF	SCM
Targeted task	Direction of objective [DO]	Downstream supply chain actors	Upstream and downstream actors	End customers	All		

Figure 8: Taxonomy of DLT applications in supply chains[31]

Table 11: Overview of DLT application classes[32]

Class (C)	Definition	Number of DLT applications
C1: The product traces	Enhancing product traceability in the supply chain	21
C2: The transportation ecosystem	Enabling ecosystem to digitalize information flow in global transportation	9
C3: The supply chain supervision	Enhancing actor and process visibility in upstream supply chain	7
C4: The SCF ecosystem	Enabling financing ecosystem for supply chains	11

[31] This figure is extracted from Study 1, also found in Appendix A. In addition, the acronyms in the squared brackets are used in sub-section 0.

[32] This figure is extracted from Study 1, also found in Appendix A.

Based on the empirical data analysis of interviews and secondary data, Study 1 reveals a list of 13 relevant attributes and associates these to the classes. While ten attributes reveal to be relevant in all four classes, three attributes are associated with individual classes. Moreover, five of the 13 attributes are only conditional. Only a specific configuration of the DLT applications enables to attain these attributes. These mark the conditional dimensions. This emphasis the need to study DLT on the level of the applications, rather than discussing the benefits and negative aspects of DLT on a general level, as previous research has focused on. Furthermore, the study discloses five specific value contributions of DLT applications and identifies the classes that obtain these value contributions. As the value contributions build on the attributes, they depend as well on the configuration of the dimensions. Table 12 summarizes these value contributions, the associated classes and the conditional dimensions in the taxonomy to enable these value contributions.

Table 12: Overview of value contributions

Value contribution	Classes	Conditional dimensions
Transparency	All	PR, DI, AT
Authenticity	All	CM, DI, AT
Trust	All	PR, CM, DI, AT
IOIS	1, 2, 3	None
Ecosystem	1, 2, 4	UP; PR, CM

6.2 Study 2: Decomposing transparency in supply chains to understand the perceived benefits of distributed ledger technology for enhancing transparency

6.2.1 Operationalizing transparency in the supply chain

Following the developed classification and the identification of value contributions in Study 1 (summarized in sub-section 6.1.2), the present thesis focuses on DLT-based TSC solutions. This comprises DLT applications that aim at enhancing traceability and visibility in supply chains. While Study 1 identifies the value contributions of DLT-based TSC solutions, the real benefits of these solutions for supply chain actors remain fuzzy, as TSC lacks a clear operationalization by which to understand the enhancement of TSC in detail. Hence, it is questionable whether the value contributions of DLT-based TSC solutions in fact lead to enhanced TSC or deliver attributes that are not needed to enhance TSC. Especially given the heterogeneity of different TSC mechanisms, as briefly illustrated in sub-section 2.2, it is unclear how the value contributions of DLT-based TSC solutions lead to the enhancement of specific TSC mechanisms. Thus, the objective of this study is to understand and explain the enhancement of TSC to enable an evaluation of the role of DLT in this regard. By operationalizing and decomposing TSC, Study 1 clarifies the role of DLT in enhancing TSC and, thus, identifies the perceived benefits that organizations see when making adoption decisions related to DLT-based TSC solutions. Hence, the study addresses the second research gap and the associated RQ2 (sub-section 4.2).

In order to address RQ2, an inductive, multi-case study design is adopted, based on 24 award-winning and industry-wide good practice solutions of TSC. This research design allows a deep dive into the enhancement of TSC to better understand the entire phenomenon of TSC, including the motivations to enhance TSC, the deployed TSC mechanisms, the needed determinants within the focal company, the corresponding supply chain actors, and the required IT, processes, and structures. Therefore, the TSC mechanism is the unit of observation. The unit of analysis are the TSC determinants that constitute the pivotal link to enhancing TSC from the perspective of the focal company.

Over 6 months, 46 interviews were conducted, and additional data were collected for triangulation (e.g., data from live demonstrations of the TSC mechanisms, webpages, presentations, and manuals). Alongside the focal company, additional interviews and data were collected from solution providers and corresponding supply chain actors (e.g., suppliers) to understand the phenomenon in greater depth and from multiple angles. Following the data collection, the data (e.g., the interview transcripts of more than 49 hours of interviews, and additional data) were coded following open coding, selective coding, and theoretical coding methods, based on Glaser (1992). Based on the analysis, five propositions and a framework were developed to address RQ2.

6.2.2 The seven elements to enhance transparency in the supply chain

Based on the empirical findings of the case study, TSC is decomposed in seven elements. Herein, the authors reveal that focal companies initially face different types of uncertainties (i) that lead to an IPN (ii). In order to address this IPN, focal companies deploy a specific TSC mechanism as an IPC that addresses the IPN (iii). When they achieve a fit between the IPN and IPC (iv), the focal companies are able to enhance TSC and, thus, cope with uncertainty. Each of the TSC mechanisms requires specific TSC determinants (v) in order to deploy the TSC mechanism successfully and, in doing so, enhance TSC. These determinants are attained by IT, structures, and processes (vi). Furthermore, the cases reveal that the context in the supply chains—such as the trust, power, and dependency—affect the enhancement of TSC.

The findings emphasize the pivotal role of TSC determinants in enhancing TSC. Following the data analysis, 29 TSC determinants are revealed, which span five determinant groups: data, organizational, process, relationship, and solution determinants. Each of the seven studied TSC mechanisms reveals a specific set of TSC determinants (ranging from 12 for screening and assessing to 19 for event watching). Following the subsequent decomposition, the exploration of the TSC determinants, and the indicated relationships between the seven elements, the authors develop five propositions and a TSC framework. Both the propositions and the framework emphasize the importance of cross-organizational information processing, represented by TSC determinants, and the importance of the adequate deployment of IT, structures, and processes that have to be attained within the focal company and the corresponding (upstream or downstream) supply chain actors. The propositions are presented in Table 13, while the TSC framework is illustrated in Figure 9.

Table 13: Propositions of Study 2[33]

Propositions of Study 2
Proposition 1: A fit between IPN and IPC enhances TSC.
Proposition 2: Specific TSC determinants enable successful deployment of a TSC mechanism.
Proposition 3: Both the focal company and the corresponding supply chain actors have to attain specific TSC determinants.
Proposition 4: Both the focal company and the corresponding supply chain actors have to establish IT, structures, and processes to attain the specific TSC determinants.
Proposition 5: Context factors affect the deployment of a TSC mechanism.

Following the exploration of the TSC determinants and the TSC framework in Figure 9, Study 2 reveals the role of DLT in enhancing TSC. DLT is a form of underlying IT that helps in attaining several TSC determinants, especially data determinants. Through this study, it is found that DLT can contribute by attaining TSC determinants such as data availability, accessibility, timeliness of data, processable data, verifiable data, periodic update, automated data processing, and standardized data exchange. These are the perceived benefits of DLT-based TSC solutions, positively affecting the adoption decision of organizations.

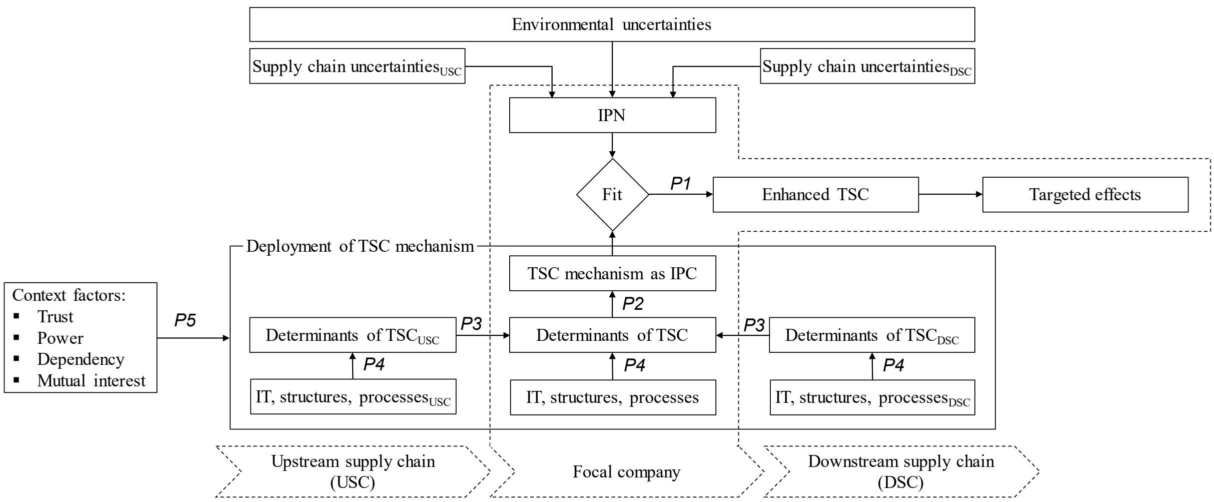


Figure 9: TSC framework[34]

[33] This table is extracted from Study 2, also found in Appendix B.
[34] This figure is extracted from Study 2, also found in Appendix B.

6.3 Study 3: Analyzing the adoption decision of distributed ledger-based transparency solutions

6.3.1 Analyzing adoption decisions in supply chains

According to the combined results of Study 1 and Study 2, DLT-based TSC solutions are able to support the attainment of TSC determinants such as data availability and accessibility. Thus, a DLT-based TSC solution requires an advanced IOIS infrastructure between supply chain actors that addresses information processing across organizational boundaries, a requirement for enhancing TSC, as illustrated by Study 2. Furthermore, the extant literature on DLT applications in supply chains promises secure information sharing and trust as well as improved operational performance (e.g., Wang et al., 2019). Study 2 reveals that, in fact, automated data processing and standardized data exchange are required TSC determinants. Hence, DLT-based TSC solutions promise improved transparency, secured information sharing, and greater trust, as well as improved operational performance. These can be seen as positive antecedents to adoption decisions. With the focus on a BCT-based TSC solution, the goal of Study 3 is to analyze adoption decisions in supply chains. This includes studying the decisions of multiple supply chain actors, such as producers, retailers, and logistics service providers (LSPs). In this way, Study 3 addresses research gap 3 and the associated RQ3 (sub-section 4.3).

In order to address RQ3, a single case study of a two-year BCT pilot project was conducted. In light of the limited number of DLT pilots, the two-year project provided in-depth insights from a real supply chain case and allowed for an understanding of the adoption decisions of individual supply chain actors and the interplay of these decisions. As one of the authors[35] was directly involved in the pilot project, which included three pilot phases over 24 months, this enabled unprecedented access to the project members, their thoughts, experiences, and positions (Jones & Bartunek, 2019). Over the span of two years, interviews were conducted, workshops held, and process mapping and test runs performed, which

[35] Henrik Sternberg, co-author of Study 3.

allowed the authors to collect data from different sources over the course of the project. The data revealed a variety of positive and negative factors influencing the adoption decisions of the participating organizations. The refined technology adoption model enabled the structuring of these antecedents, thus providing an understanding of the adoption decision of each individual supply chain actor. As the authors had protocols and transcripts of the meetings and workshops held, the mutual influence of decisions among the supply chain actors could be captured as well, which is an important aspect in understanding adoption decisions in a supply chain.

6.3.2 The positive and negative factors, as well as the tensions of the adoption of distributed ledger technology-based transparency solutions

Following the refinement of the adoption model of Iacovou et al. (1995) to guide Study 3, the data reveal that supply chain actors see both positive and negative factors for the adopting a DLT-based TSC solution. The findings reveal that perceived benefits are set against perceived obstacles, that external pressure contrasts external resistance, and that organizational readiness opposes organizational immaturity. These contrasts are assessed on the organizational level for each supply chain actor and thus affect the adoption decisions of the other actors as well. While perceived benefits, external pressure, and organizational readiness are positive factors for adopting a DLT-based TSC solution, perceived obstacles, external resistance, and organizational immaturity represent negative factors, hindering adoption.

Table 14 and Table 15 illustrate the positive and negative factors of the case. The tables list the factors, which are revealed in the case and disclose the associated actors for each factor. Primary members refer to the actors, which produce or handle the goods rather than to the support actors, such as software providers and hauler unions. In this way, the study reveals the different perspectives of supply chain actors, which affect not only individual adoption decisions but also the adoption decision of the entire supply chain. Thus, the study identifies a mutual interplay of adoption decisions, given the need to adopt a DLT-based TSC solution in the entire supply chain. Furthermore, the contrasting of the positive and negative factors leads to four tensions that must be resolved or overcome in order to adopt a DLT-based TSC solution as a form of IOIS in a supply chain. Table 16 presents the tensions that are revealed in this case study. The third tension represents a paradox: the trust–investment paradox. While DLT is seen as an IOIS that is able to improve trust between supply chain actors, trust is a necessary prerequisite for investing in DLT solutions. A focal company only invests resources and adopts a DLT-based solution if it trusts its corresponding supply chain partners to establish and maintain the DLT-based TSC solution. Thus, a long-term, trusting relationship between the supply chain actors is needed. However, in this case, a DLT-based solution does not offer more trust, as already established, and hence, trust cannot be seen as a perceived benefit.

Table 14: Positive factors revealed in Study 3[36]

Positive factors	**Description**	**Corresponding actors**
	Perceived benefits (PB)	
PB1. positive awareness of sustainability	Provided possibility of sharing information with end-consumers about environmental and social sustainability	All primary members
PB2. increased product traceability	Enabled tracing product and offered consumers valuable insights on the product's life cycle	All primary members
PB3. enhanced trust	Allowed building a basis for trust among unknown supply chain actors based on enhanced transparency	All primary members

[36] This table is extracted from Study 3, also found in Appendix C and in Sternberg et al. (2020).

External pressure (EP)		
EP1. need for product traceability	Responded to the customer demand to increase product traceability	Suppliers, retailers
EP2. push for revealing social conditions	Improved competitive position by entering data into the BCT solution, thus increasing visibility	LSP, haulers, union
EP3. need for improving traceability	Actively working with improving traceability (improved status updates for shipments) was desired by several stakeholders, motivating them to push other actors to participate	Suppliers, LSP
Organizational readiness (OR)		
OR1. initial investment	Cost for initiation supported by research funding	All actors
OR2. sufficient financial resources	Actors' ability to invest in the BCT solution (financially strong)	LSPs
OR3. adequate technical capability	Actors' IT capabilities, helping adopt the technology in these organizations	Retailers
OR4. data availability	Sufficient availability of data, making the BCT solution easier to use	Retailers, transport booking provider

Table 15: Negative factors revealed in Study 3[37]

Negative factors	**Description**	**Corresponding actors**
Perceived obstacles (PO)		
PO1. decreased operational efficiency	BCT solution requires gathering additional data on a batch level (e.g., scanning parcels) for uploading	All primary members
PO2. incurred nuisance	Employees consider scanning/typing to be annoying	All primary members
PO3. increased IT handling complexity	Operating additional interfaces (data entry into BCT) lead to additional complexity (e.g., in a legacy architecture) and require new IT routines	All primary members

[37] This table is extracted from Study 3, also found in Appendix C and in Sternberg et al. (2020).

External resistance (ER)		
ER1. industry stakeholder resistance	BCT solution reveals personalized data to others (e.g., personal information about frontline SC workers is disclosed)	All primary members' workers, hauler association
ER2. external lack of commitment	Transparency of sustainability information is of minor importance inside the firms, resulting in minor willingness to make significant process and system alterations and to deal with lack of standardization	All primary members
ER3. rival business relations	All participants were part of multiple supply chains, with limited interest in making disproportionate efforts in one selected supply chain	All primary members
Organizational immaturity (OI)		
OI1. necessary IT training investments	Operating the BCT solutions requires additional IT capabilities that must be developed	Supplier, LSP
OI2. needed infrastructure	Deploying the BCT solutions requires additional infrastructures (e.g., scanners and Wi-Fi connection) to fully capture data	All primary members
OI3. increasing coordination demand	BCT solution requires jointly establishing data standards for data upload and agreeing to those standards	All actors
OI4. required openness	BCT solution discloses actor-specific data to other supply chain partners and customers (e.g., warehouse processing of LSPs)	All primary members

Table 16: Tensions in DLT adoption revealed in Study 3[38]

Tensions	**Description**	**Positive factors**	**Negative factors**
Traceability-efficiency	To realize enhanced product traceability's perceived benefit, supply chain actors must overcome the hurdles of inefficiencies largely resulting from organizational immaturity	PB1, PB2	PO1, PO2, OI2, OI3
Visibility-privacy	To enhance visibility in their supply chain and reveal their sustainability awareness, supply chain actors must respond to data privacy concerns of workers and supply chain partners	PB1	ER1, OI4

[38] This table is extracted from Study 3, also found in Appendix C and in Sternberg et al. (2020).

Trust-investment (paradox)	To enhance trust by using BCT-based solutions, supply chain actors must invest in the technology, which, in turn, is only attractive when long-term trust among supply chain partners is already established	PB3	OI1, PO3, OI2
Performance-commitment	To enhance product traceability, visibility, and trust, supply chain actors' long-term commitment is required to establish capabilities, which, in turn, depends on the BCT solution's importance and the associated supply chain	PB1, PB2, PB3	PO3, OI1, OI3, ER2, ER3

With regard to the present thesis, Study 3 enables an understanding of adoption decisions in supply chains. The study describes the positive and negative factors that were identified in section 3 as necessary considerations when studying the adoption of DLT. The study reveals the variety of positive and negative factors that were taken into account by the supply chain actors. By revisiting the positive and negative factors discussed in literature (see Table 4 and Table 5), Study 3 refines this discussion in the light of a BCT-based traceability solution (class 1 in Study 1). Moreover, the study reveals that the model of Iacovou et al. (1995) represents a valuable model for the analysis of adoption decision, as the full range of factors was captured. The single case study represents the first adoption study on DLT in SCM. Study 3 critically reflects on the perceived benefits revealed in combining the findings of Study 1 and Study 2. Thus, the study presents a reflected view that includes multiple perspectives along the supply chain. The study does not solely focus on the individual decisions of supply chain actors but also discloses the interdependency of the adoption decisions within supply chains.

6.4 Study 4: Uncovering the impact of distributed ledger technology-based transparency solutions

6.4.1 Identifying the impact of distributed ledger technology-based transparency solutions

After the focus on the adoption decision in Study 3, Study 4 analyzes the impact of DLT-based TSC solutions in terms of structural or processual impacts. The impact of technologies is linked to adoption decisions, according to Davis et al. (1989), and the authors refer to this as observability. Uncovering the impact of novel technologies affects the perception of other organizations that face adoption decisions. A positive impact of a technology is likely to affect the adoption decisions of other organizations positively as well. From the perspective of the organizations that already have adopted DLT-based TSC solutions, a positive impact is important to justify the decision and the associated investment in retrospect. In light of the perceived obstacles outlined in Study 3, a positive impact should outweigh the associated investment. Thus, an impact that leads to reduced costs represents an aspiration of adopters. While cost reductions are certainly not the only positive aspects, a structural or processual impact that can be assessed in terms of cost is of great interest to both academic scholars and supply chain managers. Hence, TCE has been applied as a theoretical lens to assess the impact of novel technologies in the past. Therefore, Study 4 takes a similar approach to address RG 4 and the associated RQ4.1 and RQ4.2 (sub-section 4.4).

An abductive case study approach was chosen to address the RQ4.1 and RQ4.2. Initiated by the trigger that DLT-based TSC solutions affect TCE, a case study design for theory elaboration was applied to discuss the effects of DLT-based TSC solutions on the structures and processes in supply chain transactions. In the study, data was collected relating to five cases from different sources (e.g., interviews, demonstrations, webpages, and press releases) and actors (e.g., DLT users and providers) to gain a detailed understanding of the impact of DLT-based TSC solutions and enable data triangulation. The data was collected and systematically combined with existing literature on TCE in order to identify similarities with and differences from the extant research. The authors identify three types of relationships between the empirical data and the extant literature: confirming, expanding, and refining. These constitute the forms of theory elaboration based on the empirical data of the five cases.

6.4.2 The positive and negative effects of distributed ledger technology-based transparency solutions on supply chain transactions

The findings of Study 4 reveal two significant contributions. First, the empirical data reveal that DLT-based TSC solutions show effects that confirm, refine, and expand the extant literature. The effect of general IT in helping to limit bounded rationality and reduce the chances of hiding opportunism through the use of DLT-based TSC solutions are confirmed. However, the empirical data also indicate expansions and refinements that can be made to the extant literature in terms of IT's impact on TCE. In total, two confirming effects, three expanding effects, and four refining effects are identified in the cases.

Second, DLT-based TSC solutions reveal nine factors that ultimately affect the costs, dependencies, and power in supply chain transactions. The cost effects can be divided into cost reduction and cost avoidance effects, which both constitute positive impacts for adopters of DLT-based TSC solutions. Moreover, a power shift in the role of the third party was revealed, having an impact on the structure and the processes of the supply chain (i.e., giving them less or no involvement). However, another power shift between the transaction partners (a DLT-caused torpedo effect) shows both a positive and negative impact of DLT-based TSC solutions. Given the immutable records of DLT-based TSC solutions, the history of all actions can be ambiguous to the associated supply chain actor with regard to future transactions. Furthermore, the empirical data reveal an increase in dependency, caused by the network effect of deploying DLT-based TSC solutions. Table 17 summarizes the nine effects and highlights the two main contributions of Study 4.

With regard to the overall thesis, Study 4 reveals that the impact of DLT-based TSC solutions can, in fact, be positive (e.g., promoting cost avoidance and reduction), but it also indicates several effects that might be perceived as negative, such as the increasing dependency and power shift between the transaction partners. Overall, the identification of the nine effects helps in understanding the impact of DLT-based TSC solutions, but it also helps to outline the adoption decision in more detail and sheds light on the positive and negative aspects of DLT's adoption and its impact on supply chains.

Table 17: Identified impact of DLT-based TSC solutions[39]

TCE component	Name of effect	Type of effect	Relation to extant TCE literature
TCE assumptions	DLT-enabled assistance effect	Cost avoidance effect due to better decision-making by embanked bounded rationality	Confirming
	DLT-enhanced substitution effect	Cost reduction effect due to DLT-enabled trust as substituting assumption for opportunism	Expanding
Transaction dimension	DLT-enhanced disclosure effect	Cost reduction effect due to better performance evaluation of partners based on DLT data	Confirming
	DLT-caused scale-pan effect	Cost reduction (increase) effect due to equalized (reinforced) information asymmetry	Expanding
	DLT-enabled demonopolization effect	Power shift due to diminished role of third party	Expanding
	DLT-caused network effect	Dependency increasing due to network effect for gapless transparency	Refining
Transaction costs and governance mode	DLT-enabled segregation effect	Cost reduction due to facilitated searching for transaction partners	Expanding
	DLT-enhanced automation effect	Cost reduction due to automated monitoring and enforcement based on verified data	Refining
	DLT-caused torpedo effect	Power shift due to the potential to lose bargaining power	Refining

[39] This table is extracted from Study 4, also found in Appendix D and in Roeck, Sternberg, and Hofmann (2019).

6.5 Integrating the findings of the four studies

Following the presentation of the individual findings of the four studies, this sub-section integrates and reflects on the findings. As such, this sub-section intertwines these findings to present the connecting links between the individual studies in the present thesis.

6.5.1 Setting the groundwork for an application-specific analysis of the adoption and impact of distributed ledger technology applications in supply chains

The classification of Study 1 lays the groundwork for studying the adoption and impact of DLT-based solutions in supply chains in general and in the present thesis. It addresses the heterogeneity of DLT-based solutions in the field of SCM and allows for greater specification in the analysis of technology adoption and impact in this thesis, with a focus on DLT-based TSC solutions (classes 1 and 3 in Study 1). The developed taxonomy enables the disclosure of the configuration of the observed cases in Study 3 and Study 4. The configurations are presented in the Appendix of each of the studies (see Appendix C and Appendix D). For example, the single case studied in Study 3, is a BCT-based TSC solution aiming at enhancing product traceability within the supply chain, based on a private blockchain built on the Hyperledger Fabric (BCT) protocol — including physical (e.g., producers, retailers, and LSPs) and supporting supply chain actors (e.g., hauler associations and transport booking providers).

Moreover, Study 1 identifies the attributes and the value contributions of each class. Both represent potential perceived benefits in the adoption decision of DLT-based TSC solutions. The revealed attributes of DLT-based TSC solutions are further discussed in Study 2, once the TSC determinants have been identified. The attributes that match specific TSC determinants can be perceived as benefits of DLT-based TSC solutions. Thus, Study 1 lays the groundwork for the discussion of the perceived benefits of DLT-based TSC solutions, which is revisited in the conclusion of Study 2 and in the theoretical background of Study 3.

6.5.2 Merging the design of distributed ledger technology-based transparency solutions and the application context

Based on the specification of Study 1, the decomposition of TSC in Study 2 places DLT-based TSC solutions in the context of enhanced TSC. According to Study 2, DLT constitutes an underlying IT, supporting information processing within the focal organization and across organizational boundaries. In this way, Study 2 confirms that DLT is applied as an underlying IOIS in DLT-based TSC solutions. Thus, Study 2 carves out the role of DLT. In addition, Study 2 illustrates that DLT-based TSC solutions are forms of TSC mechanisms, specified by the taxonomy of Study 1. Moreover, Study 2 presents an evaluation framework for assessing the value contributions of DLT-based TSC solutions, based on the exploration of the TSC determinants. Herein, Study 2 reveals that DLT-based TSC solutions can directly address eight TSC determinants as illustrated in Table 18. The table lists the additional technologies as well, which will be revisited later.

Table 18: The overlap of DLT attributes and TSC determinants

Attributes of DLT from Study 1	**Additional technologies required based on Study 1**	**TSC determinants from Study 2**
Decentralized data availability	None	Availability of data
Accessible data	Databases and additional technologies for data input	Accessibility of data
Real-time data distribution	Databases and additional technologies for data input	Timeliness of data
Processable data	None	Processable data
Verifiable data	None	Verifiable data
Real-time and automated data distribution	Databases and additional technologies for data input	Periodic update of data
Automated data distribution	None	Automated data processing
Standardized data formats	Databases and additional technologies for data input	Standardized data exchange

However, the DLT as an underlying IOIS alone does not account for all TSC determinants. As derived in the conclusion of Study 2, DLT helps in attaining eight TSC determinants (see Table 18), yet the TSC mechanisms require between 12 (screening and assessing) and 19 (event watching) TSC determinants. Hence, DLT is a good option for several TSC determinants, yet solely applying DLT does not necessarily enhance TSC. Rather, the DLT-based TSC solution, as a TSC mechanism, must also be configured specifically to attain the other required TSC determinants. In this discussion, Study 2 also reflects on the role of DLT and the factors limiting its significance for enhancing TSC. However, by considering how the attributes of DLT-based TSC solutions match the TSC determinants, these can also be discussed as perceived benefits that affect the adoption decision, as analyzed in Study 3.

6.5.3 Reflecting on the antecedents of adoption decisions

Following the exploration of the TSC determinants and the placement of DLT as an underlying technology and DLT-based TSC solutions in the previous studies, Study 3 sheds light on the decision to adopt a DLT-based TSC solution. Herein, Study 3 widens the discussion on the antecedents of the adoption decision, covering both negative and positive factors. In this way, Study 3 goes beyond the perceived benefits and obstacles derived in Study 1 and Study 2 and studies the organizational readiness or immaturity and the external pressure or resistance, against the backdrop of the adoption decision of a DLT-based TSC solution. In this way, Study 3 refines elaborates on the positive and negative factors revealed in extant literature (see Table 4 and Table 5). The case study reveals that the

In line with Study 1 and Study 2, the single case study confirms the positioning of DLT as an underlying IOIS to enhance TSC. Furthermore, Study 3 reveals enhanced TSC (PB3 in Table 14), improved visibility (PB1 in Table 14), and traceability (PB2 in Table 14) to be perceived benefits of DLT-based solutions. In this way, Study 3 confirms the findings of Study 1 and Study 2, and positive factors in literature concerning the resulting supply chain characteristics (third column in Table 4). However, several other positive aspects that were discussed in literature such scalability and the resulting SCM features were not identified in Study 3 or even denied such as reduced complexity and automation of supply chain processes (see Table 4). Furthermore, Study 3 confirmed most negative factors form literature as well (e.g., privacy issues, garbage-in garbage-out, advanced IT infrastructure required). Yet technical performance issues of DLT as an underlying IOIS were not perceived.

However, with regard to the present thesis, Study 3 also presents a critical reflection on the positioning of DLT to enhance TSC and a discussion of the role of DLT in attaining the TSC determinants. Study 3 emphasizes that DLT is an IT supporting the attainment of the TSC determinants, but it is not sufficient on its own. The study reveals that additional IT, such as sensors, barcode scanners, and an Ethernet/Wi-Fi infrastructure, must be in place as well. This confirms the findings of Study 1 on the additional requirements for class 1 and is also evidenced in Table 18 as four of the eight attributes depend on additional technologies and databases for data input as well. Furthermore, Study 3 underlines the importance of structures and processes that complement IT to attain the TSC determinants. While this confirms the TSC framework of Study 2 (Figure 9), it also limits the role of DLT for enhancing TSC in the case of the tracking and tracing solution in Study 3.

To discuss the role of DLT in the case of Study 3, Table 19 draws on the TSC determinants of tracking and tracing solutions from Study 2 (first column) and the required IT, structures, and processes, as well as the positive and negative factors from Table 14 and Table 15 that are revealed in Study 3. As such, Table 19 illustrates the importance of the interplay between IT, structures, and processes, and it concludes that solely deploying DLT as an underlying IOIS for a TSC mechanism is not enough. This underlines the three elements of the taxonomy in Study 1. In this regard, Table 12 elaborates the importance of databases and additional technologies to enhance TSC in a DLT-based TSC solution. In fact, Study 3 shows that, for example, an immature technological infrastructure (as evidenced by OI2 in Table 15) limits the ability of DLTs to support the availability of data, the timely transfer of data, and the inclusion of relevant data. Furthermore, structures and processes are also important cornerstones, as illustrated in column 2 of Table 19. Thus, a harmonious interplay between IT (including the underlying DLT and other systems), structures, and processes is required.

Table 19: Integration of findings of Study 2 and 3

Required TSC determinants according to Study 2	**Required IT, structures, and process according to Study 3**	**Findings of Study 3**
Availability of data	Sensors, scanners, internet DLT	OR4. Data was available for retailers and booking providers For others: OI2. Required infrastructure beyond DLT that was not in place
Completeness of data	Sensors, scanners, internet	PO1. Required gathering additional data points that lead to decreasing efficiency
Accessibility of data	DLT	Was achieved
Timeliness of data	Internet, DLT	OI2. Required infrastructure beyond DLT that was not in place
Processable data	DLT	Was achieved
Relevant data	Sensors, scanners, internet	OI1., OI2. Required training and infrastructure beyond DLT that was not in place
Clear responsibility	Intra-firm structures	OI1. Required initial training to establish clear responsibilities
Ease of data gathering	Sensors, scanners, internet	PO1., OI2. Due to lack of infrastructure, gathering additional data points led to decreasing efficiency
Integration in processes	Intra-firm and inter-organizational processes	PO1. Was achieved but required additional processes such as scanning that lead to decreasing efficiency
Timely use of TSC mechanism	Intra-firm processes	Was achieved
Collaboration with partner	Inter-organizational structures and processes	Was achieved
Collaboration with third party	Inter-organizational structures and processes	Was achieved
Common understanding	Intra-firm structures	Was achieved

Automated data processing	DLT, intra-firm processes	Was achieved
Standardized data exchange	DLT, intra-firm and inter-organizational processes	OI3. Was achieved but required initial coordination
User acceptance	Intra-firm processes	ER1., OI4. Resistance of worker unions and lack of openness
User friendliness	Intra-firm processes	PO2., PO3. Caused annoying process additions and increased IT handling complexity

Moreover, Study 3 reveals the tensions that supply chain actors face when considering whether to adopt a DLT-based TSC solution. The study shows the complexity of adoption decisions in supply chains and the importance of studying different perspectives and actors. While for some actors, such as retailers, enhanced traceability (e.g., PB1 and PB2 in Table 14) is a perceived benefit, other actors, such as LSPs and producers (e.g., vineyards) worry about the decreased efficiency that is linked to improved traceability (e.g., PO1, PO2, OI2, and OI3 in Table 15); this phenomenon is illustrated by the traceability–efficiency tension outlined in Table 16. In this regard, Study 3 analyzes the adoption decisions of all involved actors and the interdependency of these decisions. In this way, a detailed understanding of adoption in the supply chain was gained, contributing to the overall goal of this thesis.

6.5.4 Bringing the impact of distributed ledger technology-based transparency solutions in the context of adoption

Study 4 uncovers the impact of DLT-based TSC solutions, shedding light on the positive and negative impact of DLT on supply chain transactions. The study reveals the enhanced TSC that can be achieved by deploying a DLT-based TSC solution. However, the study goes beyond just identifying the enhancement of TSC and further illuminates the resulting effects that lead to a structural or processual change in supply chains.

When the nine effects of Study 4 (listed in Table 17) are reflected on in the context of the other three studies, two of them must be discussed with regard to the findings of Study 3 (Table 15 and Table 16). First, the DLT-enhanced substitution effect results in cost reduction due to the presence of greater trust. This effect limits the importance of opportunism as a TCE assumption. However, in consideration of the trust–investment paradox of Study 3, the DLT-enhanced substitution effect has to be refined. Following the findings of Study 3, only if initial trust is established in supply chains will organizations adopt a DLT-based TSC solution. Thus, the assumption that trust lowers the importance of opportunism as an assumption in TCE is limited to long-term, already trusting supply chain relationships.

Second, the DLT-enhanced automation effect represents a cost-reduction effect due to the automated monitoring and enforcing of contracts in supply chain transactions. In light of the findings of Study 3, this effect must also be limited. Study 3 reveals that deploying a DLT-based TSC solution can lead to decreased operational efficiency (PO1 in Table 15). Hence, the DLT-enhanced automation effect will only reduce costs if the associated processes are automized and digitalized and, thus, do not lead to additional effort; this was the case for all the primary supply chain actors observed in Study 3.

7 Overall discussion: Implications on the adoption and impact of distributed ledger technology-based transparency solutions

The aim of the present thesis is to explain the adoption and impact of DLT in supply chains, with a focus on DLT-based TSC solutions. In order to address the overarching goal conclusively, this section presents a synthesis of the various components presented in this thesis to derive an explanatory framework before describing the theoretical and practical implications of the thesis. The thesis concludes with a presentation of its overall limitations and the outlook for future research. As such, it should be noted that this section specifically addresses the overall goal of this thesis, not the research gaps and questions of the individual studies. The conclusions of each study are to be found in each study in the Appendix.

7.1 Summary: The interplay of design, adoption decision, application context and impact

While the findings of the four individual studies and their integration contribute to the explanation of the adoption and impact of DLT-based TSC solutions, a conclusive explanation is necessary to address the overall goal of the present thesis. Drawing on the previous findings of the individual studies and their integration, an explanatory framework in Figure 10 is developed that synthesizes three parts. First, it comprises the design of DLT-based TSC solutions based on Study 1. Second, it includes the application area and deployment of DLT-based TSC solutions based on Study 2. Third, it includes the model of technology adoption and impact, with a focus on IOIS. The second part is based on the findings of Study 3 and Study 4.

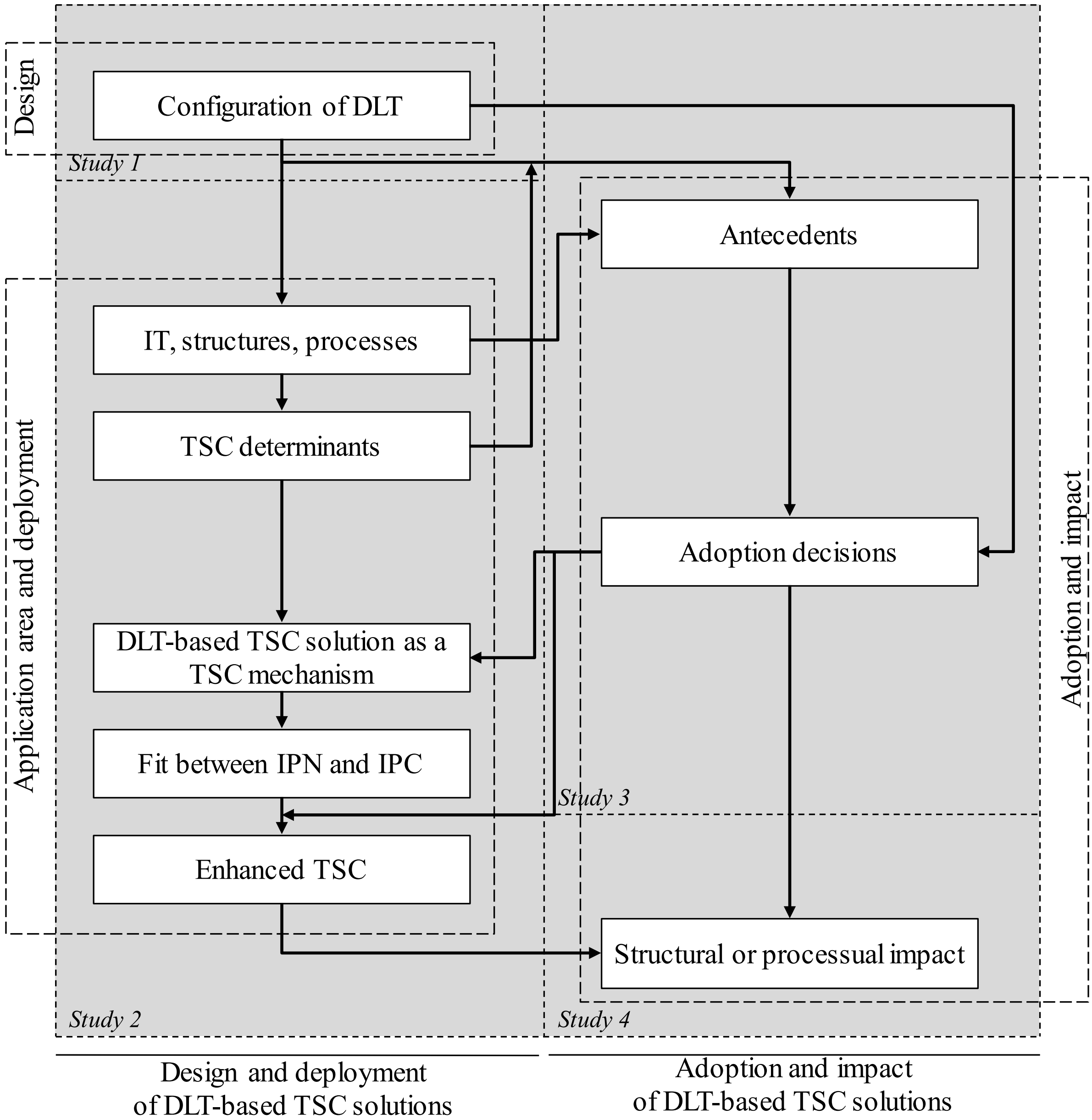


Figure 10: Explanatory framework for studying the adoption and impact of DLT-based TSC solutions

7.1.1 The role of the design in the adoption decision and the deployment of a distributed ledger technology-based transparency solution

Based on Study 1, the thesis uncovers the design options to configure DLT applications (including DLT-based TSC solutions) in supply chains. Herein, the focus is on the design configuration of the DLT as an underlying IOIS for a TSC mechanism. The design component of the upper left part is illuminated in this thesis, which represents a factor influencing both the adoption (right part) and application field of a DLT-based TSC solution. Adoption is affected because the configuration of the DLT largely determines the value contribution of the DLT-based TSC solution (see Table 18). The overlap of value contributions and required TSC determinants lead to perceived benefits, which affect the antecedents to technology adoption. In Figure 10, this is represented by the moderating effect of the TSC determinants.

The extant literature that places the focus on the adoption of DLT (e.g., Kamble et al., 2018; Post et al., 2018) often omits details about the configuration of the DLT-based solutions. However, the heterogeneity of DLT-based solutions requires that the specific configuration be taken into consideration when studying adoption. As such, the present thesis follows previous technology adoption studies—such as those of Chwelos et al. (2001), O'Callaghan, Kaufmann, and Konsynski (1992), and Chau (1996) —that clearly describe and specify the studied technology.

Furthermore, the configuration of DLT affects the adoption decision, as the configuration defines the number of supply chain actors needed (both physical and support actors). As such, the configuration affects the number of adoption decisions, which are required in a supply chain and the interdependency of the adoption decisions of the individual supply chain actors. This is illustrated by the single case in Study 3. In the case, the DLT configuration required the adoption of multiple supply chain actors, leading to a network effect influencing the overall adoption and the interdependency of the adoption decisions on an organizational level. This link represents an addition to extant literature on technology adoption. Previous studies have focused on the link between the technology and the antecedents (including the positive and negative factors), such as those of Iacovou et al. (1995), Zaheer and Venkatraman (1994), and Venkatesh (2000). However, DLT-based TSC solutions entail adoption decisions made by multiple supply chain actors, which show interdependencies. Thus, explaining adoption in detail must take the interdependency of the adoption decisions in supply chains into account.

Moreover, the configuration of DLT affects the IT, structures, and process of a TSC mechanism. The configuration of DLT determines the required additional IT, structures, and processes necessary to deploy the DLT-based TSC solution as a TSC mechanism. Table 19 illustrates this by synthesizing the findings of Study 2 and Study 3. Previous DLT studies have been unclear about the role of DLT; most studies remain at a high level, discussing and mixing various applications of DLT in supply chains, without providing further detail about how DLT is deployed; this is illustrated in the column "Context of study" in Table 6. Only Auinger and Riedl (2018) specify this role, although their study does not focus on SCM. A specification of the role of DLT helps both academic scholars and practitioners understand the influence of this novel technology.

7.1.2 The deployment of distributed ledger technology-based transparency solution and its effect on the antecedents to adoption decisions

Building on the TSC framework of Study 2 (see Figure 9), the deployment of the TSC mechanism is described in Study 2 in detail. Aside from the moderating effect of TSC determinants (described in the previous section), the IT, structures, and processes of the DLT-based TSC solution in question affect the antecedents to adoption, as illustrated in Figure 10. This is revealed in Study 3, especially by the negative factors listed in Table 15. Herein, the influence of IT, structures, and processes is underlined, as organizations may face obstacles to building up and investing in the IT, structures, and processes required to deploy a DLT-based TSC solution as a TSC mechanism. However, a positive effect is possible as well, as a DLT-based TSC solution might include more efficient structures and processes and build on already-established IT. By illuminating this link, the present thesis emphasizes the importance of the additional technologies, structures, and processes crucial to adoption decisions. Previous contributions on the adoption of DLT have omitted this facet, limiting their observations to the DLT itself, such as those by Post et al. (2018), Saberi et al. (2019), and Sadhya and Sadhya (2018). As such, the present thesis expands the comprehensive collection of positive and negative factors (see Table 4 and Table 5) affecting DLT and adds another perspective.

Furthermore, the enhanced level of TSC resulting from the fit between IPN and IPC has a direct effect on the structural and processual impact of DLT adoption, as revealed in Study 4. This study uncovers the positive and negative effects of enhanced TSC, shown in Table 17, which are represented in Figure 10 by the direct effect of enhanced TSC on structures and processes. Several studies, such as that of Swift et al. (2019), have previously studied the impact of TSC on various performance dimensions. In line with and confirming the findings of studies on various IS innovations (e.g., Clemons et al., 1993; Grover & Malhotra, 2003), DLT-enhanced transparency enables structural and processual changes. However, the present thesis is the first to identify this impact on an empirical basis for the application of DLT-based TSC solutions, as only conceptual contributions foreshadow the potential impact of DLT in supply chains (e.g., Kshetri, 2018; Schmidt & Wagner, 2019).

7.1.3 Adoption decisions and their influence on the application context of distributed ledger technology-based transparency solutions

The right part of Figure 10 models the adoption and impact of DLT-based TSC solutions. This half draws on the adoption model of Iacovou et al. (1995), applied throughout this entire thesis and especially in Study 3. Following the logic of scholars that have studied technology adoption, the adoption decision affects the use of the technology (e.g., Davis et al., 1989; Premkumar et al., 1994; Zhu, Kraemer, & Xu, 2003). In the case of the present thesis, the adoption decisions of supply chain actors affect the deployment of a DLT-based TSC solution as a TSC mechanism. As described in Study 3, a positive adoption constitutes a necessary and logical prerequisite for the deployment of a DLT-based TSC solution from the perspective of each individual supply chain actor. Herein, the present thesis confirms the extant research in all the relevant sub-streams discussed in sub-section 3.1.

However, the network effect of such DLT-based TSC solutions, explored in Study 3, leads to an additional effect. Even if a focal company decides to adopt a DLT-based TSC solution, the adoption decision of the corresponding supply chain actors affects the success of the deployment and, thus, the enhancement of TSC. For example, if suppliers decide not to adopt a DLT-based TSC solution aiming to improve product traceability, as in Study 3, the product cannot be traced back through the supply chain. Instead, there will be blind spots. This is illustrated in Figure 10 by the moderating effect of adoption decisions on the enhanced level of TSC.

The moderating effect of the adoption decision of other supply chain actors on the results of the deployment has not been studied previously. Although several studies analyze the post-adoption phase (e.g., Zhu, Dong, Xu, & Kraemer, 2006; Zhu & Kraemer, 2005) and the divide between technology adoption and its use (Lanzolla & Suarez, 2010), the focus remains on the organization, without taking into account the adoption decision of corresponding supply chain actors. As such, academic scholars have omitted to study the moderating effect of external adoption decisions on the results of technology use in the context of supply chains. Against the backdrop of the network effect influencing the adoption of DLT-based TSC solutions, this is a necessary perspective to explain the adoption and impact of such solutions in supply chains.

7.1.4 Adoption and impact of distributed ledger technology-based transparency solutions: Three key elements and their interplay

The overarching goal of the present thesis is to explain the adoption and impact of DLT in supply chains, with a focus on DLT-based TSC solutions. The explanatory framework shown in Figure 10 summarizes the insights of the present thesis. In this, three key elements and their interaction are shown to be the cornerstones in explaining the adoption and impact of DLT-based TSC solutions. First, it is important to understand and specify the design of the DLT-based TSC solution as a form of IOIS, which represents a form of TSC mechanism. Herein, taking into account the specific configuration of the DLT is needed to dive deeper into understanding its adoption and deployment.

Second, the application area and deployment of each DLT-based TSC solution has to be analyzed, including the additional IT, structures, and processes it requires, as well as the TSC determinants. This leads to an understanding of the level of enhanced TSC that can be attained after a positive adoption decision. Third, the antecedents to an adoption decision, the adoption decision itself, and the structural and processual impact of that decision must be investigated in detail. Herein, the practitioner or academic scholar should not only take the perspective of a single organization in the supply chain but also the corresponding supply chain actors. Explaining the adoption and impact of DLT-based TSC solutions requires a careful observation of the interaction of these three key elements, according to Figure 10. Essentially, the practitioner or academic scholar must observe the design, the application area and deployment—as well as the adoption and impact—of DLT applications and in particular DLT-based TSC solutions while also considering the interaction of these elements, with careful consideration of the perspectives of multiple supply chain actors.

7.2 Theoretical implications: A call for empirically focused, multiple perspective, and integrative studies

DLT is a topic of great interest in the field of SCM and IS. Numerous calls for papers (e.g., Koh, Dolgui, & Sarkis, 2018; Kohli & Liang, 2019; Rao, Senthilkumar, Patton, & Rhodes, 2017) have been issued to contribute to the understanding of the emerging technology. Especially in the field of SCM, the adoption of DLT is slowly moving forward, and its impact remains unclear. Thus, this thesis set out to address the gap in explaining the adoption and impact of DLT, with a focus on DLT-based TSC solutions. While all four studies in the present thesis present the theoretical implications in their respective sub-sections (see also the Appendix), this sub-section is designed to present the overall theoretical implications of the entire thesis. Herein, the theoretical implications of the overall thesis are threefold and are discussed in the following sub-sections.

7.2.1 The importance of an integrative adoption study

The present thesis puts an emphasis on the integration of three key elements in studying technology adoption and impact in a supply chain. In addition to the traditional adoption model—which includes the antecedents, adoption decision, and impact (right half of Figure 10)—the present thesis integrates two additional key elements: the technical design and specification of the technology and its application and operationalization in the application area (left half of Figure 10). The thesis underlines the importance of the additional two key elements to aid in understanding and explaining the adoption and impact of a novel technology in supply chains. While some of the extant adoption literature discusses the design of the studied technologies (e.g., Lyytinen & Damsgaard, 2011) and characterizes the respective technologies and their application in detail to study adoption, the application context has received little consideration in adoption studies.

Despite this absence in the literature, the broad applicability of novel technologies such as DLT, artificial intelligence (AI), and IoT in the context of supply chains requires that a detailed illumination of both the technology itself and its application context be outlined when studying technology adoption and impact. Only by providing this can rigorous and relevant contributions be produced that clearly delineate the unit of observation and develop relevant findings for practitioners and academic scholars. The present thesis broadly summarizes this implication in the framework in Figure 11 for use in future studies on the adoption and impact of novel technologies in supply chains.

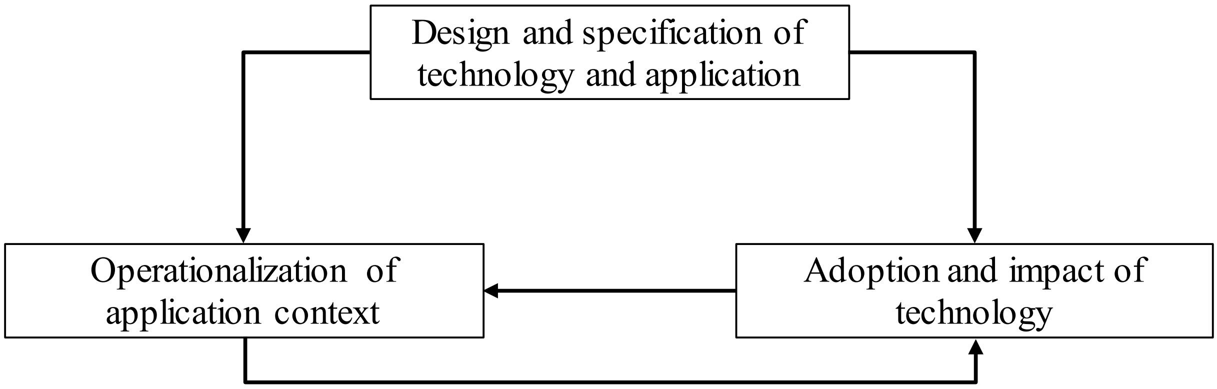


Figure 11: Framework for studying the adoption and impact of technology in supply chains

A clear delineation of the design and specification of the technology in question, its application, and the operationalization of the application context allows for a better understanding of the specific characteristics of the studied technology, application context, and, in turn, of the supply chain. At the level illustrated in Figure 11, the framework poses broad applicability. The following sub-section illuminates a specification that goes along with the studied technology, its application, and the application context, thus representing an exemplary specification of this framework.

7.2.2 The importance of perspective

The present thesis sets out to explain the adoption and impact of DLT-based TSC solutions. Thus, the technology (i.e., DLT), the technology application (i.e., DLT-based TSC solutions), and the application context (i.e., TSC) indicate the importance of studying the adoption and impact in light of the inherent network effect of DLT-based TSC solutions. As Study 1 and Study 3 reveal, DLT-based TSC solutions require the adoption of multiple supply chain actors. Hence, the present thesis underlines the need to take on multiple perspectives to understand the adoption and impact of DLT-based TSC solutions in detail. In line with interpretivist belief, the shift in perspective facilitates the creation of a comprehensive picture of the studied phenomenon. Therefore, studying the adoption of technologies in supply chains that involve multiple supply chain actors requires assuming multiple perspectives. This means that researchers must broaden their observations to various supply chain actors, to enable a multi-angle view of the studied phenomenon. As exemplified in all four of the studies in the present thesis, the focal companies, suppliers, customers, technology providers, LSPs, and supply chain actors should be included to gather data from all relevant angles.

Multi-angle analyses require methods that can capture all relevant views and match them with each other. Their importance in SCM has previously been outlined (e.g., Carter, Meschnig, & Kaufmann, 2015; Choi & Wu, 2009). Hence, the need for a multi-angle analysis is accompanied by the need for adequate methodological approaches. This includes, for example, more qualitative research, such as interview studies, case studies, and action research, that facilitates gathering data from multiple supply chain actors (Holmström et al., 2019). In this, the distance of the researcher from the object of observation is an important aspect, and it includes a trade-off. While engaged scholars are likely to be better able to gain a detailed picture and gather in-depth data, scholars should not be too closely involved with a single party under study, as keeping some distance allows researchers to avoid becoming biased or limiting the data collection from other angles (e.g., due to competition). Aside from capturing multiple perspectives, the present thesis demonstrates the importance of "zooming out" the perspective of individual supply chain actors, which allows for an exploration of the interdependencies of the adoption decisions of different supply chain actors on a network level, as exemplified in Study 3.

7.2.3 The importance of the empirical deep dive

The thesis constitutes a deep dive into DLT-based TSC solutions, the most popular DLT application at the time of this writing.[40] Based on the classification in Study 1, the present thesis delineates the studied DLT application to define and clarify its validity, as previous studies have given a broad understanding of DLT. Due to the heterogeneity of DLT configurations and diverse application contexts, the findings of the extant research have limited generalizability. More often, the

[40] As revealed in an earlier version of Study 1, in Roeck (2020).

lack of detail provided in the study leads to a discussion of topics that are only relevant in certain configurations. For example, the enhanced transparency of transactions does not apply to all DLT applications, as private blockchains do not include this feature per se as described in Study 1. Furthermore, the disadvantages of the technology, such as energy consumption and latency, are also design-specific.

As such, this thesis does not only emphasize the identification and disclosure of design differences of DLT applications but also develops a classification through which to do so. As such, the present thesis can be seen as an example for future studies of how to clearly indicate the unit of observation in use. In addition, the classification enables and guides future researchers to focus their studies on specific DLT applications. The classification helps future researchers to empirically study DLT applications in supply chains in more detail, as it allows them to allocate, compare, and describe the studied applications. In this vein, the thesis fosters a better understanding of the unit of observation and the phenomenon under study itself.

Given the scarcity of empirical studies (Schmidt & Wagner, 2019), the present thesis and the included studies represent the first empirical deep dives in the field of SCM. In this way, the thesis alleviates the scarcity of empirical contributions in the field of SCM and establishes an empirical basis for future studies. While the novelty of the technology limits the options to empirically study DLT in the field of SCM, early-stage empirical contributions help provide a better understanding of the technology and its applicability for both practitioners and academic scholars. As researchers and the media have been enthusiastic about DLT, empirically based studies allow for a grounded reflection that is based on experience. By covering the perspectives of multiple supply chain actors, as previously described in sub-section 7.2.2, a comprehensive and critical analysis can be conducted. This provides an objective picture of the novel and promising technology, helping researchers and practitioners understand it.

7.3 Practical implications: The need for intra-firm and inter-organizational effort

Given not only the large interest of SCM practitioners in DLT (e.g., Pawczuk et al., 2019) but also the slow-moving adoption and fuzzy impact of DLT in supply chains (e.g., Schmahl et al., 2019), the thesis brings to light several practical implications. Congruent with the theoretical implications, each study presents its own individual practical implications. Thus, this sub-section seeks to disclose the implications for practitioners on the level of the entire thesis. Based on the findings of this thesis, a managerial framework is derived to address the various challenges associated with the adoption of DLT-based TSC solutions as revealed in the four studies of this thesis. While the framework in Figure 12 is designed from the perspective of the initiating focal company, it addresses the intra-firm and inter-organizational challenges as well.

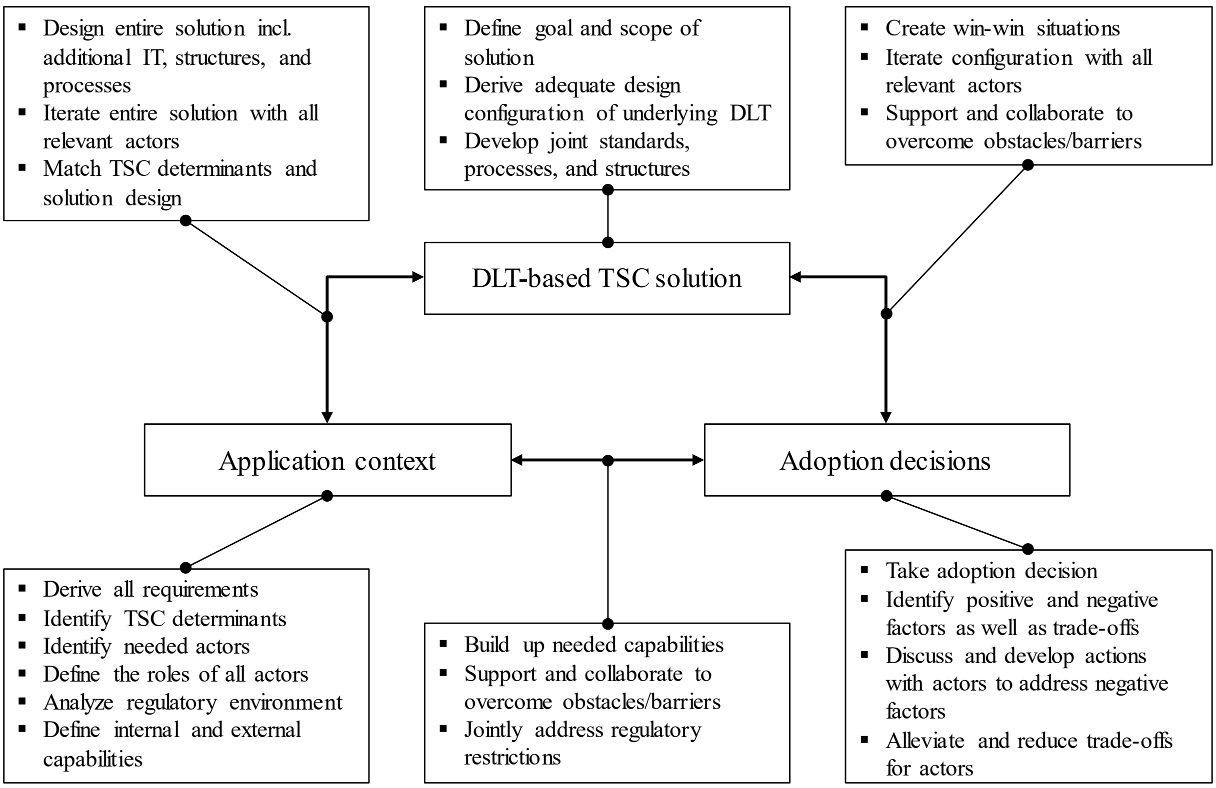


Figure 12: Managerial framework for adoption of DLT-based TSC solutions

The managerial framework contains three elements: the DLT-based TSC solution, the application context, and the adoption decisions that have to be addressed when a focal company aims to adopt a DLT-based TSC solution in its supply chains. While each of the three elements contains several tasks, these three elements share mutual interdependencies as well, illustrated by the arrows. These interdependencies are associated with further tasks. All of the listed tasks are based on the empirical data gathered in the interviews of the four studies and draw on the findings of the four studies on a practical level. The list of tasks is further elaborated in Figure 13.

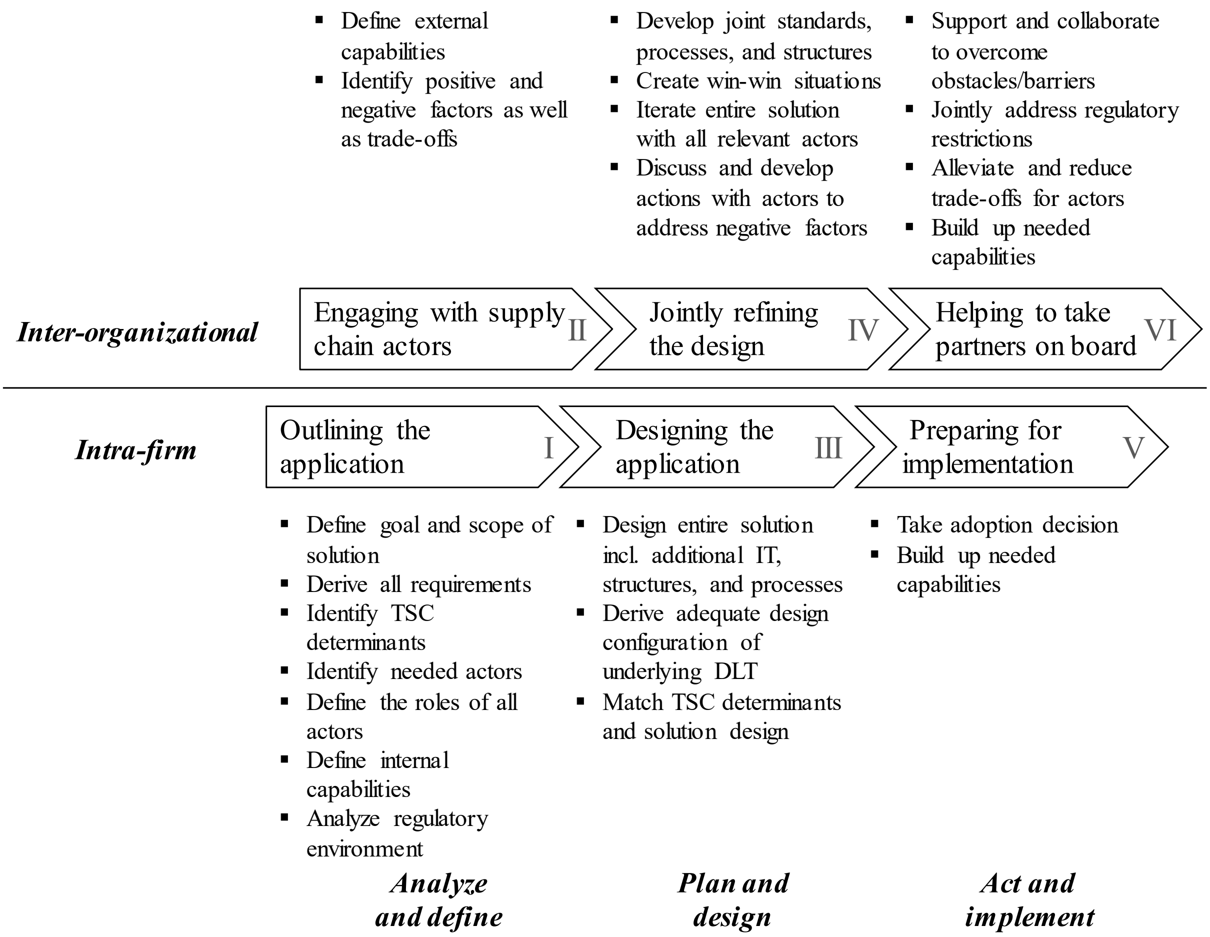


Figure 13: Categorization of tasks for the adoption of DLT-based TSC solutions

Figure 13 categorizes the tasks by the scope (i.e., intra-firm and inter-organizational) and the type of task conducted (i.e., analyze and define, plan and design, and act and implement). Intra-firm tasks are limited to the focal company, without requiring the involvement of external parties. Inter-organizational tasks imply the involvement of at least one other supply chain actor. Furthermore, the tasks can be differentiated into three levels: tasks that require the decision-maker to conduct analysis or define goals, roles, etc.; tasks that, on a more creative level, require the decision-maker to plan and design the DLT-based TSC solution and all its associated elements; and tasks that require action and investment for the DLT-based TSC solution in order to address the challenges to the adoption decisions. Altogether, six phases can be identified that require different approaches and must be addressed successively from the perspective of an initiating focal company.

7.3.1 Outlining the application

The first phase (I), includes tasks to be conducted by the initiating focal company on an intra-firm level. With these tasks, the focal company sets the boundaries and reaches a preliminary definition of the DLT-based TSC solution from its own perspective. The listed tasks help the managers to define the goal, outline the scope, and derive the specific characteristics of the DLT-based TSC solution. Following the insights of Study 2, managers should clearly define their IPN to derive the fitting TSC mechanism. Herein, both the developed taxonomy in Study 1 (see Figure 8) and the TSC framework of Study 2 (see Figure 9) help managers outline an initial DLT-based TSC solution. In this step, a critical reflection on the underlying technology should be conducted. In case a form of DLT is chosen, a preliminary specification and configuration is needed to be able to identify the TSC determinants to be attained, the required supply chain actors, their roles, and the internal capabilities. While these tasks may not be DLT-specific, the results of these tasks, such as the roles of the actors (e.g., the operator of a node and the permissions), are DLT-specific and lead to different implications. For example, an operator of a node will have to invest in a DLT infrastructure and will continuously pay for the maintenance of the DLT.

7.3.2 Engaging with supply chain actors

Following the first tasks, the focal company must engage with the relevant supply chain actors early on to learn more about their perspectives and establish a common understanding in the second phase (II). Herein, the focal company aims to analyze the adoption chances of the initially defined DLT-based TSC solution.

This includes identifying the positive and negative factors of adoption decisions and the antecedents, for each supply chain actor. The supply chain actors should consider the potential trade-offs that may arise, as revealed in Study 3. Engaging early on with the relevant supply chain actors allows the perceived obstacles, organizational immaturities, and external resistance to be identified and, consequently, accounted for at an early stage. Therefore, a collaborative approach is needed, which ultimately requires a certain level of initial trust relationship between the supply chain actors, as Study 3 reveals.

7.3.3 Designing the application

After having identified the positive and negative factors from the perspectives of the corresponding supply chain actors, phase three (III), an internal design phase, should be initiated. The goal of this phase is to develop an initial design for the DLT-based TSC solution, covering the underlying DLT configuration and the additional IT, structures, and processes that will be needed, based on the previous phases. Here again, the taxonomy of Study 1 and the TSC framework of Study 2 help managers. In doing so, the focal company integrates both internal and external prerequisites to design a solution that induces positive factors for all relevant supply chain actors. During this phase, creative methodologies and project management tools, such as design thinking and Scrum, can be used. Furthermore, this might include collaboration with third parties, such as solution providers and research institutes. Although developing extraordinary, funky prototypes[41] can deliver useful input, the designs should match the required TSC determinants according to Study 2. This enables the design of an effective DLT-based TSC solution.

7.3.4 Jointly refining the design

Subsequent to the focal company designing a solution, a second interaction with the relevant supply chain actors is needed to refine the design in phase four (IV). The goal is to adjust the design to the requirements of the supply chain actors to

[41] *Funky prototypes* are prototypes within the macrocycle of design thinking that contain features that are exceptional and do not necessarily address the problem statement. Their purpose is to stimulate creativity and tear down cognitive boundaries (Uebernickel, Brenner, Pukall, Naef, and Schindlholzer, 2015).

reduce the perceived obstacles (PO1, PO2 and PO3 in Table 15), to identify and overcome organizational immaturities (OI1, OI2, and OI3 in Table 15), and to navigate around external resistance (ER1, ER2, and ER3 in Table 15), thus increasing the adoption chances, as emphasized in Study 3. During this phase, certain standards, processes, and structures must be established to enable an efficient deployment of the DLT-based TSC solution. Furthermore, it is helpful to find win-win situations for the supply chain actors, which increases the adoption chances throughout the supply chain.

7.3.5 Preparing for implementation

Once the design is finalized, the adoption decision must be made in phase five (V). Following this decision, the focal company starts building internal capabilities (e.g., establishing trainings for employees) to prepare for the roll-out and implementation of the DLT-based TSC solution in the supply chain. While the initiating focal company is likely to start the roll-out in its own organization, the onboarding of additional supply chain actors will require additional resources as identified in Study 3. Thus, in this phase, the focal company also prepares for the roll-out in its supply chains.

7.3.6 Helping to take partners on board

In a sixth phase (VI), the focal company must support other supply chain actors—for example, SMEs with little technical know-how and limited resources—during the roll-out. By defining collaborative measures, providing training, and conducting introduction workshops, the focal company helps to build up capabilities and alleviate negative factors as revealed in Study 3.[42] Furthermore, the supply chain actors must address specific regulatory issues together, such as those related to data privacy, which presented a substantial obstacle in Study 3 (ER1 in Table 15). Moreover, the focal company can share its implementation experience to foster a more efficient implementation along the supply chain. Precisely defining and committing to such supportive actions prior to

[42] These findings are also based on an additional conference paper by the author. The multi-case study by Roeck and Hofmann (2019) sheds more light on the collaborative support required by the initiating focal company, based on a case study in the diamond industry.

implementation (e.g., in phase IV) will increase the adoption chances along the supply chain.

7.4 Overall limitations and avenues for future research

As is the case for all contributions, the present thesis includes several limitations, which pave the way for future research. These limitations are content-related and methodology-related. This sub-section describes the limitations on the level of the overall thesis. The limitations and corresponding outlook for future research of each study can be found in the respective studies themselves (see Appendix). The present thesis includes three content-related limitations, offering opportunities for future research. Furthermore, two additional methodology-related limitations are included in this thesis, which also present future research opportunities.

7.4.1 Content-related limitations and future research

The present thesis focuses on the adoption and impact of DLT-based TSC solutions. This research focus entails two limitations. First, the thesis discusses the adoption and impact of DLT in supply chains. As such, DLT is studied in an inter-organizational context, with a focus on business-to-business relationships. Although several DLT-based TSC solutions (see the classification framework in Study 1) include an interface to consumers and, thus, also cover the business-to-consumer context in its periphery, the main focus is on business-to-business relationships. As the interface to the consumer does not require the adoption but only the use of a specific mobile application (e.g., by scanning barcodes or quick response codes), the present thesis is limited to inter-organizational, business-to-business supply chains.

Thus, the findings of this thesis are valid for the field of SCM, but they are limited in the trustworthiness in other fields, such as those of finance and banking, insurance, and health care. These fields require an explicit focus on both business-to-consumer and consumer-to-consumer contexts. Herein, the application of another adoption model, such as the DOI model of Rogers (1962) or the TAMs (e.g., Davis et al., 1989; Venkatesh, 2000), might present adequate theoretical foundations to study the adoption of individuals. Future research cannot only study these fields separately but must also consider the transferability of findings from the field of SCM to other fields, and vice versa. However, at this point, it needs to be emphasized that such contributions should be transparent about the studied objects and their field, namely, the specific application. Only though such disclosure can the transferability of findings into other fields be fully evaluated and, thus, the findings used in other fields, as well.

Second, the present thesis lays its focus on DLT-based TSC solutions, which represent specific applications of DLT in the field of SCM. However, these applications are not the only ones discussed in SCM.[43] For instance, SCF applications such as TradeIX, and we.trade constitute different configurations in terms of the underlying DLT and the concrete application. Neither of the mentioned DLT-based SCF solutions require the same degree of adoption as do DLT-based TSC solutions. The underlying DLT is mainly operated by several entities who are not the users of these solutions. This can be compared to online banking applications for companies.

Furthermore, there is no link to the physical flow required, as there is in DLT-based TSC solutions, which implies differences in terms of the antecedents to adoption. For instance, less advanced IT systems and interfaces are required; thus, less investment in the IT infrastructure must be made, eliminating potential arguments about perceived obstacles and organizational immaturity. As this example illustrates, the findings of this thesis are valid for DLT-based TSC solutions. Other DLT-based applications in SCM require additional studies that specifically focus on the design and specification of the specific DLT application, and its operationalization in the application context. For this, the framework in Figure 11 can be applied to help researchers craft their studies. While the approach is applicable to other DLT-based applications, the findings are limited to DLT-based TSC solutions and should only be evaluated as a priori constructs in future studies.

[43] As revealed in an earlier version of Study 1, in Roeck (2020).

Third, the present thesis includes findings focusing on DLT-based TSC solutions but with no specific industry focus. The data of the four studies were gathered in multiple industries (including the pharmaceutical, food, and gemstone industries). However, Study 3, as a single case study, is limited to data from the food industry. In line with the interpretivist stance, taking on multiple perspectives is important. Thus, future studies should illuminate adoption decisions in other industries as well. Although the food industry is the industry with most DLT-based TSC solutions, other industries, such as the automotive and pharmaceutical industries, will follow.[44] Hence, scholars are encouraged to study more industries and to analyze the transferability of research findings on adoption decisions in different industries. To do this, the present thesis, and especially Study 3, can be seen as a blueprint for future studies that aim to explain the adoption decisions of DLT-based TSC solutions. The framework in Figure 11 will help scholars to design their studies and shed light into additional industries.

7.4.2 Methodology-related limitations and future research

As with all contributions, the present thesis has also limitations in terms of its methodological approach. First, the thesis studies the adoption and impact of DLT-based TSC solutions on the level of the organization, and in Study 3 and Study 4 zooms out to the network level, to develop a detailed and multifaceted understanding of the phenomenon under study. In line with the interpretivist belief, the gathering of data from multiple angles was key. However, the present thesis and its findings are limited to these two levels, and mainly to the organization level, as the level of analysis and, accordingly, to the associated perspectives of the organizations. The thesis does not study adoption and impact on the level of individuals. Yet their importance to the adoption decision and the impact DLT-based TSC solutions on these individuals makes studying adoption and impact on the level of individuals also a worthwhile investment. This would require drawing on different theoretical foundations, as the foundation of this study is selected for research on the organizational and network level. For

[44] As revealed in an earlier version of Study 1, in Roeck (2020).

instance, other adoption models such as the TAM (e.g., Davis et al., 1989) would be adequate, and theoretical contributions such as the agency theory would allow for a study of the impact on the level of individuals.

Second, in line with the interpretivist stance, this thesis aims to explain the adoption and impact of DLT-based TSC solutions in detail, based on empirical data. Hence, a methodological approach that includes mainly qualitative research designs is well suited for this research endeavor. However, against the backdrop of a limited number of observable units in the field of SCM, the methodological approach chosen for this thesis is also a result of the limited options at the time of this writing. The use of DLT-based solutions in SCM is just emerging, and more applications will arise over time, though, opening up opportunities for more methodological options to be used in future research. Based on the classification developed in Study 1, quantitative studies based on survey designs will be applicable in the future. This classification can help in selecting appropriate cases and achieving homogeneity in the unit of observation in such studies (and in qualitative studies).

8 References

Abeyrath, S., & Monfared, R. P. (2016). Blockchain ready manufacturing supply chain using distributed ledger. International Journal of Research in Engineering and Technology, 05(09), 1–10.

Agarwal, R., & Prasad, J. (1998). A conceptual and operational definition of personal innovativeness in the domain of information technology. Information Systems Research, 9(2), 204–215.

Aitken, R. (2017). IBM forges blockchain collaboration with Nestlé & Walmart in global food safety. Retrieved from https://www.forbes.com/sites/rogeraitken/2017/08/22/ibm-forges-blockchain-collaboration-with-nestle-walmart-for-global-food-safety/#61d926873d36

Ajzen, H., & Fishbein, M. (1980). Understanding attitudes and predicting social behavior. Englewood Cliffs, NJ: Prentice-Hall.

Alchian, A. A., & Demsetz, H. (1972). Production, information costs, and economic organization. The American Economic Review, 62(5), 777–795.

Andersen, O., & Vogdrup-Schmidt, L. (2018). Rivals reject blockchain solution from Maersk and IBM. Retrieved from https://shippingwatch.com/carriers/Container/article10602520.ece

Annibal, S., Henry, J. Y., & Mark, B. (2019). The social process of big data and predictive analytics use for logistics and supply chain management. International Journal of Physical Distribution & Logistics Management, 49(7), 706–726.

Archer, S. (1988). Qualitative research and the epistemological problems of the management disciplines. In A. Pettigrew (Ed.), Competitiveness and the management process (pp. 265–302). Oxford: Basil Blackwell.

Aron, R., Clemons, E. K., & Reddi, S. (2005). Just right outsourcing: Understanding and managing risk. Journal of Management Information Systems, 22(2), 37–55.

Auinger, A., & Riedl, R. (2018). Blockchain and trust: Refuting some widely-held misconceptions. In Thirty Ninth International Conference on Information Systems, San Francisco, USA.

Autry, C. W., Grawe, S. J., Daugherty, P. J., & Richey, R. J. G. (2010). The effects of technological turbulence and breadth on supply chain technology acceptance and adoption. Journal of Operations Management, 28(6), 522–536.

Babich, V., & Hilary, G. (2019). Distributed ledgers and operations: What operations management researchers should know about blockchain technology. Manufacturing & Service Operations Management, Forthcoming.

Baird, L., Harmon, M., & Madsen, P. (2019). Hedera: A public hashgraph network & governing council: The trust layer of the internet. Retrieved from https://www.hedera.com/whitepaper

Bakos, J. Y., & Brynjolfsson, E. (1993). Information technology, incentives, and the optimal number of suppliers. Journal of Management Information Systems, 10(2), 37–53.

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99–120.

Barratt, M., & Oke, A. (2007). Antecedents of supply chain visibility in retail supply chains: A resource-based theory perspective. Journal of Operations Management, 25(6), 1217–1233.

Basole, R. C., & Bellamy, M. A. (2014). Supply network structure, visibility, and risk diffusion: A computational approach. Decision Sciences, 45(4), 753–789.

Beck, R., Stenum Czepluch, J., Lollike, N., & Malone, S. (2016). Blockchain: The gateway to trust-free cryptographic transactions. In 24th European Conference on Information Systems (ECIS), Istanbul, Turkey.

Blossey, G., Eisenhardt, J., & Hahn, G. (2019). Blockchain technology in supply chain management: An application perspective. In T. Bui (Chair), 52nd Hawaii International Conference on System Sciences, Maui.

Bostrom, R. P., & Heinen, J. S. (1977). MIS problems and failures: A socio-technical perspective. Part I: The causes. MIS Quarterly, 1(3), 17–32.

Brandon-Jones, E., Squire, B., Autry, C. W., & Petersen, K. J. (2014). A contingent resource-based perspective of supply chain resilience and robustness. Journal of Supply Chain Management, 50(3), 55–73.

Bromiley, P., & Rau, D. (2014). Towards a practice-based view of strategy. Strategic Management Journal, 35(8), 1249–1256.

Brown, S. (2020). Supply chain visibility boosts consumer trust, and even sales. Retrieved from https://mitsloan.mit.edu/ideas-made-to-matter/supply-chain-visibility-boosts-consumer-trust-and-even-sales

Brusset, X. (2016). Does supply chain visibility enhance agility? International Journal of Production Economics, 171, 46–59.

Caridi, M., Crippa, L., Perego, A., Sianesi, A., & Tumino, A. (2010). Do virtuality and complexity affect supply chain visibility? International Journal of Production Economics, 127(2), 372–383.

Carson, B., Romanelli, G., Walsh, P., & Zhumaev, A. (2018). Blockchain beyond the hype: What is the strategic business value? Retrieved from https://www.mckinsey.com/business-functions/digit

Carter, C. R., & Easton, L. P. (2011). Sustainable supply chain management: Evolution and future directions. International Journal of Physical Distribution & Logistics Management, 41(1), 46–62.

Carter, C. R., Meschnig, G., & Kaufmann, L. (2015). Moving to the next level: Why our discipline needs more multilevel theorization. Journal of Supply Chain Management, 51(4), 94–102.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. International Journal of Physical Distribution & Logistics Management, 38(5), 360–387.

Carter, C. R., Rogers, D. S., & Choi, T. Y. (2015). Toward the theory of the supply chain. Journal of Supply Chain Management, 51(2), 89–97.

Cartier, L. E., Ali, S. H., & Krzemnicki, M. S. (2018). Blockchain, chain of custody and trace elements: An overview of tracking and traceability opportunities in the gem industry. Journal of Gemmology, 36(3), 212–227.

Casey, M. J., & Wong, P. (2017). Global supply chains are about to get better, thanks to blockchain. Harvard Business Review. Retrieved from https://www.hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain

Catalini, C. (2017a). How blockchain applications will move beyond finance. Harvard Business Review. (2). Retrieved from https://hbr.org/2017/03/how-blockchain-applications-will-move-beyond-finance

Catalini, C. (2017b). Seeing beyond the blockchain hype. MIT Sloan Management Review, 58(4), 17–21. Retrieved from http://sloanreview.mit.edu/article/seeing-beyond-the-blockchain-hype/

Catalini, C., & Gans, J. S. (2016). Some simple economics of the blockchain. Working paper.

Cegielski, C. G., Allison Jones-Farmer, L., wu, Y., & Hazen, B. T. (2012). Adoption of cloud computing technologies in supply chains: An organizational information processing theory approach. The International Journal of Logistics Management, 23(2), 184–211.

Chau, P. Y.K. (1996). An empirical assessment of a modified technology acceptance model. Journal of Management Information Systems, 13(2), 185–204.

Chen, S., Zhang, Q., & Zhou, Y.-P. (2019). Impact of supply chain transparency on sustainability under NGO scrutiny. Production and Operations Management, 28(12), 3002–3022.

Cheng, M. J., & Simmons, J.E.L. (1994). Traceability in manufacturing systems. International Journal of Operations & Production Management, 14(10), 4–16.

Choi, T. Y., & Wu, Z. (2009). Triads in supply networks: Theorizing buyer–supplier–supplier relationships. Journal of Supply Chain Management, 45(1), 8–25.

Chwelos, P., Benbasat, I., & Dexter, A. S. (2001). Research report: Empirical test of an EDI adoption model. Information Systems Research, 12(3), 304–321.

Clegg, C. W. (2000). Sociotechnical principles for system design. Applied Ergonomics, 31(5), 463–477.

Clemons, E. K., Reddi, S. P., & Row, M. C. (1993). The impact of information technology on the organization of economic activity: The "move to the middle" hypothesis. Journal of Management Information Systems, 10(2), 9–35.

Clemons, E. K., & Row, M. C. (1993). Limits to interfirm coordination through information technology: Results of a field study in consumer packaged goods distribution. Journal of Management Information Systems, 10(1), 73–96.

Coase, R. H. (1937). The nature of the firm. Economica, 4(16), 386–405.

Cooper, R. B., & Zmud, R. W. (1990). Information technology implementation research: A technological diffusion approach. Management Science, 36(2), 123–139.

Cosgrove, E. (2019). CMA CGM, MSC join Maersk's TradeLens. Retrieved from https://www.supplychaindive.com/news/cma-cgm-msc-join-maersk-tradelens-blockchain/555635/

Croman, K., Decker, C., Eyal, I., Gencer, A. E., Juels, A., Kosba, A., . . . Wattenhofer, R. (2016). On scaling decentralized blockchains. In J. Clark, S. Meiklejohn, P. Y.A. Ryan, D. Wallach, M. Brenner, & K. Rohloff (Eds.), Financial cryptography and data security (Vol. 9604, pp. 106–125). Berlin, Heidelberg, s.l.: Springer Berlin Heidelberg.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. Management Science, 35(8), 982–1003.

DiMaggio, P. J. (1995). Comments on "What theory is not". Administrative Science Quarterly, 40(3), 391–397.

Dimitrov, B. (2019). Large enterprises are betting on blockchain in 2019. Retrieved from https://www.forbes.com/sites/biserdimitrov/2019/08/13/large-enterprises-are-betting-on-blockchain-in-2019/#25ab02a51bff

Donaldson, L. (2001). The contingency theory of organizations. Foundations for Organizational Science. Thousand Oaks, CA: Sage Publications Inc.

Doorey, D. J. (2011). The transparent supply chain: From resistance to implementation at Nike and Levi-Strauss. Journal of Business Ethics, 103(4), 587–603.

Durach, C. F., Kembro, J., & Wieland, A. (2017). A new paradigm for systematic literature reviews in supply chain management. Journal of Supply Chain Management, 53(4), 67–85.

Easterby-Smith, M., Thorpe, R., Jackson, P. R., & Jaspersen, L. (2018). Management & business research (6th edition). Los Angeles, CA: SAGE.

Egels-Zandén, N., & Hansson, N. (2016). Supply chain transparency as a consumer or corporate tool: The case of Nudie Jeans Co. Journal of Consumer Policy, 39(4), 377–395.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. Academy of Management Review, 14(1), 57–74.

Etherscan. (2020). Ethereum average block size chart. Retrieved from https://etherscan.io/chart/blocksize

Evans, S. (2012). Fire in small German town could curb world car production. Retrieved from https://www.bbc.com/news/business-17769466

Fawcett, S. E., Loeve, L., & Lindeijer, D. (2.) (1996). An investigation of the impact of flexibility on global reach and firm performance. Journal of Business Logistics, 17(2), 167–196.

Galbraith, J. R. (1974). Organization design: An information processing view. Interfaces, 4(3), 28–36.

Gibbons, M. (1994). The new production of knowledge: The dynamics of science and research in contemporary societies. London: SAGE.

Glaser, B. G. (1992). Basics of grounded theory analysis. Mill Valley, CA: Sociology Press.

Gold, S., Seuring, S., & Beske, P. (2010). Sustainable supply chain management and inter-organizational resources: A literature review. Corporate Social Responsibility and Environmental Management, 17(4), 230–245.

Gonzalez-Rodriguez, A. (2019). Warum LVMHs Blockchain die Modeindustrie revolutionieren könnte. Retrieved from https://fashionunited.ch/nachrichten/business/warum-lvmhs-blockchain-die-modeindustrie-revolutionieren-koennte/2019070518724

Grant, R. M. (1996). Toward a knowledge-based theory of the firm. Strategic Management Journal, 17(S2), 109–122.

Gregor, S. (2006). The nature of theory in information systems. MIS Quarterly, 30(3), 611–642.

Grover, V. (1993). An empirically derived model for the adoption of customer-based interorganizational systems. Decision Sciences, 24(3), 603–640.

Grover, V., & Goslar, M. D. (1993). The initiation, adoption, and implementation of telecommunications technologies in U.S. organizations. Journal of Management Information Systems, 10(1), 141–164.

Grover, V., & Malhotra, M. K. (2003). Transaction cost framework in operations and supply chain management research: Theory and measurement. Journal of Operations Management, 21(4), 457–473.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research (Vol. 2, pp. 105–117). Thousand Oaks, CA: SAGE.

Gupta, V. (2017). The promise of blockchain is a world without middlemen. Harvard Business Review. Retrieved from https://hbr.org/2017/03/the-promise-of-blockchain-is-a-world-without-middlemen?referral=03759&cm_vc=rr_item_page.bottom

Haas-Hamannt, R., & Feda, D. (2018). Putting blockchain to the test: Key findings from Germany‘s largest cross-company pilot project. Retrieved from https://www.gs1-germany.de/service/datei-download/?tx_gs1base%5Baction%5D=initDownload&tx_gs1base%5Buid%5D=84791&tx_gs1base%5Bfilename%5D=putting_blockchain_to_the_test.pdf&tx_gs1base%5Bsource%5D=fal

Haensel, M. (2018). Evaluation of standardized and externally procured business services: service types, collaboration, and purchasing integration as determining factors (Ph.D. thesis). University of St.Gallen, St. Gallen.

Hald, K. S., & Kinra, A. (2019). How the blockchain enables and constrains supply chain performance. International Journal of Physical Distribution & Logistics Management, 49(4), 376–397.

Heim, G. R., & Peng, D. X. (2019). Technology management in a global context: From enterprise systems to technology disrupting operations and supply chains: Call for papers: Special issue of the Journal of Operations Management. Journal of Operations Management.

Hevner, A. R. (2007). A three cycle view of design science research. Scandinavian Journal of Information Systems, 19(2), 87–92.

Higginson, M., Nadeau, M.-C., & Rajgopal, K. (2019). Blockchain's occam problem. Retrieved from https://www.mckinsey.com/industries/financial-services/our-insights/blockchains-occam-problem

Hobbs, J. E. (1996). A transaction cost approach to supply chain management. Supply Chain Management, 1(2), 15–27.

Hofmann, E., Omran, Y., Henke, M., & Heines, R. (2017). Blockchain-driven supply chain finance: Towards a conceptual framework from a buyer perspective. In International Purchasing and Supply Education and Research Association (IPSERA) 2017, Budapest - Balatonfüred. Retrieved from https://www.alexandria.unisg.ch/251095/

Hofmann, E., Sternberg, H., Chen, H., Pflaum, A., & Prockl, G. (2019). Supply chain management and Industry 4.0: Conducting research in the digital age. International Journal of Physical Distribution & Logistics Management, 49(10), 945–955.

Hofmann, E., Strewe, U., & Bosia, N. (2018). Supply chain finance and blockchain technology. Cham: Springer International Publishing.

Holmström, J., Holweg, M., Lawson, B., Pil, F. K., & Wagner, S. M. (2019). The digitalization of operations and supply chain management: Theoretical and methodological implications. Journal of Operations Management, 65(8), 728–734.

Holweg, M., Disney, S., Holmström, J., & Småros, J. (2005). Supply chain collaboration: Making sense fo the strategy continuum. European Management Journal, 23(2), 170–181.

Hsu, T. (2019). You know your diamond's cut and carat. But does it have ethical origins? Retrieved from https://www.nytimes.com/2019/01/08/business/diamonds-origin-tiffany-consumers.html

Iacovou, C. L., Benbasat, I., & Dexter, A. S. (1995). Electronic data interchange and small organizations: Adoption and impact of technology. MIS Quarterly, 19(4), 465–485.

IBM (2019). IBM Food Trust: Trust and transparency in our food. Retrieved from https://www.ibm.com/se-en/blockchain/solutions/food-trust

Ireland, R. D., & Webb, J. W. (2007). A multi-theoretic perspective on trust and power in strategic supply chains. Journal of Operations Management, 25(2), 482–497.

Jahanbin, P., Wingreen, S., & Sharma, R. (2019). A blockchain traceability information system for trust improvement in agricultural supply chain. In P. Johannesson, P. Ågerfalk, & R. Helms (Chairs), Proceedings of the 27th European Conference on Information Systems (ECIS), Stockholm & Upsala, Sweden.

Jargon, J. (2015). Chipotle grapples with E. coli outbreak: Some experts point to challenges facing purveyors of fresh food. Wall Street Journal. Retrieved from https://www.wsj.com/articles/chipotle-grapples-with-e-coli-outbreak-1446506975

Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. Journal of Financial Economics, 3(4), 305–360.

Jin, Y. "H.", Williams, B. D., Tokar, T., & Waller, M. A. (2015). Forecasting with temporally aggregated demand signals in a retail supply chain. Journal of Business Logistics, 36(2), 199–211.

Johnson, A., McCurdy, D., Schechter, D., & Loch, K. (2020). Hot or cold…How ready are third party logistics cold storage companies to implement blockchain? In T. X. Bui (Chair), 53rd Hawaii International Conference on System Sciences, Wailea, HI, USA.

Johnston, H. R., & Vitale, M. R. (1988). Creating competitive advantage with interorganizational information systems. MIS Quarterly, 12(2), 153–165.

Jones, E. B., & Bartunek, J. M. (2019). Too close or optimally positioned? The value of personally relevant research. Academy of Management Perspectives. Advance online publication.

Kamble, S., Gunasekaran, A., & Arha, H. (2018). Understanding the blockchain technology adoption in supply chains-Indian context. International Journal of Production Research, 57(7), 2009–2033.

Ketchen, D. J., & Hult, G. T. M. (2007). Bridging organization theory and supply chain management: The case of best value supply chains. Journal of Operations Management, 25(2), 573–580.

Ketokivi, M., & Choi, T. (2014). Renaissance of case research as a scientific method. Journal of Operations Management, 32(5), 232–240.

Kewalram, B. (2019). Blockchain could revolutionize logistics, but is the industry prepared to let it? Retrieved from https://www.forbes.com/sites/forbestechcouncil/2019/12/04/blockchain-could-revolutionize-logistics-but-is-the-industry-prepared-to-let-it/#6b26580c11e2

Kim, S. (2015). Chipotle: Why hundreds of restaurants don’t have pork on the menu. Retrieved from https://abcnews.go.com/Business/chipotle-hundreds-restaurants-pork-menu/story?id=28217932

Klein, H. K., & Myers, M. D. (1999). A set of principles for conducting and evaluating interpretive field studies in information systems. MIS Quarterly, 23(1), 67–93.

Knudsen, C. (2003). Pluralism, scientific progress, and the structure of organization theory. In H. Tsoukas & C. Knudsen (Eds.), The Oxford Handbook of Organization Theory (pp. 262–286). Oxford: Oxford University Press.

Koh, L., Dolgui, A., & Sarkis, J. (2018). Special issue on blockchain in transport and logistics. International Journal of Production Research.

Kohli, R., & Liang, T.-p. (2019). Special issue call for papers: Strategic integration of blockchain technology into organizations. Journal of Management Information Systems.

Korpela, K., Hallikas, J., & Dahlberg, T. (2017). Digital supply chain transformation toward blockchain integration. In T. X. Bui (Chair), Proceedings of the 50th Hawaii International Conference on System Sciences, Hawaii.

Kshetri, N. (2018). Blockchain's roles in meeting key supply chain management objectives. International Journal of Information Management, 39, 80–89.

Kull, T. J., Ellis, S. C., & Narasimhan, R. (2013). Reducing behavioral constraints to supplier integration: A socio-technical systems perspective. Journal of Supply Chain Management, 49(1), 64–86.

Kurpjuweit, S., Schmidt, C. G., Klöckner, M., & Wagner, S. M. (2019). Blockchain in additive manufacturing and its impact on supply chains. Journal of Business Logistics, forthcoming, 1–25.

Labazova, O. (2019). Towards a framework for evaluation of blockchain implementations. In H. Krcmar & J. Fedorowicz (Chairs), International Conference on Information Systems (ICIS) 2019, Munich.

Lacity, M. C. (2018). Addressing key challenges to making enterprise blockchain applications a reality. MIS Quarterly Executive, 17(3), 201–222.

Lanzolla, G., & Suarez, F. F. (2010). Closing the technology adoption–use divide: The role of contiguous user bandwagon. Journal of Management, 38(3), 836–859.

Lee, H. L., Padmanabhan, V., & Whang, S. (1997). Information distortion in a supply chain: The bullwhip effect. Management Science, 43(4), 546–558.

Lee, H. L., & Whang, S. (2005). Higher supply chain security with lower cost: Lessons from total quality management. International Journal of Production Economics, 96(3), 289–300.

Lee, S. (2018). Explaining directed acyclic graph (DAG): The real blockchain 3.0. Retrieved from https://www.forbes.com/sites/shermanlee/2018/01/22/explaining-directed-acylic-graph-dag-the-real-blockchain-3-0/#4fc84b46180b

Lin, C.-H., Shih, H.-Y., & Sher, P. J. (2007). Integrating technology readiness into technology acceptance: The TRAM model. Psychology & Marketing, 24(7), 641–657.

Linch, D. (2014). The path to supply chain transparency: A practical guide to defining, understanding, and building supply chain transparency in a global economy.

Lincoln, Y. S., Lynham, S. A., & Guba, E. G. (2018). Paradigmic controversies, contradictions, and emerging confluences, revisited. In N. K. Denzin & Y. S. Lincoln (Eds.), The SAGE Handbook of qualitative research (5th ed., pp. 108–175). Thousand Oaks, CA: SAGE.

Linnet, M. E. (2019). Major ocean carriers CMA CGM and MSC to join TradeLens blockchain-enabled digital shipping platform. Retrieved from https://www.maersk.com/news/articles/2019/05/28/cma-cgm-and-msc-to-join-tradelens-digital-shipping-platform

Lumineau, F., Wang, W., & Schilke, O. (2020). Blockchain governance - A new way of organizing collaborations. Organization Science, forthcoming.

Lyytinen, K., & Damsgaard, J. (2011). Inter-organizational information systems adoption – a configuration analysis approach. European Journal of Information Systems, 20(5), 496–509.

MacKenzie, B., Ferguson, R. I., & Bellekens, X. (Eds.) (2018). An assessment of blockchain consensus protocols for the internet of things. 2018 International Conference on Internet of Things, Embedded Systems and Communications (IINTEC).

Martyn, P. (2018). Does blockchain provide the new standard for transparency? Retrieved from https://www.forbes.com/sites/paulmartyn/2018/03/28/does-blockchain-provide-the-new-standard-for-transparency/#6ab1122e3921

Mathauer, M., & Hofmann, E. (2020). Dezentrale Technologien in der Supply Chain - Vertiefungsstudie Logistikmarkt Schweiz (Forthcoming). Band 2020.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. Journal of Business Logistics, 22(2), 1–25.

Mentzer, J. T., Min, S., & Michelle Bobbitt, L. (2004). Toward a unified theory of logistics. International Journal of Physical Distribution & Logistics Management, 34(8), 606–627.

Metcalfe, R. (2019). The life story of your supermarket chicken: Food tracking goes high-tech. The Wall Street Journal. Retrieved from https://www.wsj.com/articles/the-life-story-of-your-supermarket-chicken-food-tracking-goes-high-tech-11550761202

Miller, J. W., Fugate, B. S., & Golicic, S. L. (2017). How organizations respond to information disclosure: Testing alternative longitudinal performance trajectories. Academy of Management Journal, 60(3), 1016–1042.

Morgan, T. R., Richey, R. J. G., & Ellinger, A. E. (2018). Supplier transparency: Scale development and validation. International Journal of Logistics Management, 4(1), 959–984.

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system.

New, S. (2010). The transparent supply chain. Harvard Business Review, 88(10), 76–82.

Nickerson, R. C., Varshney, U., & Muntermann, J. (2013). A method for taxonomy development and its application in information systems. European Journal of Information Systems, 22(3), 336–359.

O'Leary, D. E. (2017). Configuring blockchain architectures for transaction information in blockchain consortiums: The case of accounting and supply chain systems. Intelligent Systems in Accounting Finance & Management, 24(4), 138–147.

O'Callaghan, R., Kaufmann, P. J., & Konsynski, B. R. (1992). Adoption correlates and share effects of electronic data interchange systems in marketing channels. Journal of Marketing, 56(2), 45–56.

Oettmeier, K. (2017). Additive manufacturing technology adoption and its impact on supply chain management: an empirical analysis under specific consideration of engineer-to-order production (Ph.D. thesis). University of St.Gallen, St. Gallen.

Orlikowski, W. J., & Baroudi, J. J. (1991). Studying information technology in organizations: Research approaches and assumptions. Information Systems Research, 2(1), 1–28.

Panetta, K. (2018). Gartner top 10 strategic technology trends for 2019. Retrieved from Gartner Group website: https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019/

Pathak, S. D., Day, J. M., Nair, A., Sawaya, W. J., & Kristal, M. M. (2007). Complexity and adaptivity in supply networks: Building supply network theory using a complex adaptive Systems perspective. Decision Sciences, 38(4), 547–580.

Paton, E. (2018). Will blockchain be a boon to the jewelry industry? Retrieved from https://www.nytimes.com/2018/11/30/fashion/jewelry-blockchain-de-beers.html

Pawczuk, L., Massey, R., & Holdowsky, J. (2019). Deloitte's 2019 global blockchain survey: Blockchain gets down to business. Retrieved from https://www2.deloitte.com/us/en/insights/topics/understanding-blockchain-potential/global-blockchain-survey.html

Pawczuk, L., Massey, R., & Schatsky, D. (2018). Breaking blockchain open: Deloitte's 2018 global blockchain survey.

Popov, S. (2018). The tangle. Retrieved from https://www.iota.org/research/academic-papers

Post, R., Smit, K., & Zoet, M. (2018). Identifying factors affecting blockchain technology diffusion. In A. Schwarz, T. Stafford, & R. Hirschheim (Chairs), 24th American Conference on Information Systems, New Orleans, LA.

Premkumar, G., & Ramamurthy, K. (1995). The role of interorganizational and organizational factors on the decision mode for adoption of interorganizational systems. Decision Sciences, 26(3), 303–336.

Premkumar, G., Ramamurthy, K., & Crum, M. R. (1997). Determinants of EDI adoption in the transportation industry. European Journal of Information Systems, 6(2), 107–121.

Premkumar, G., Ramamurthy, K., & Nilakanta, S. (1994). Implementation of electronic data interchange: An innovation diffusion perspective. Journal of Management Information Systems, 11(2), 157–186.

Premkumar, G. P., Ramamurthy, K., & Saunders, C. S. (2005). Information processing view of organizations: An exploratory examination of fit in the context of interorganizational relationships. Journal of Management Information Systems, 22(1), 257–294.

Punj, G., & Stewart, D. W. (1983). Cluster Analysis in Marketing Research: Review and Suggestions for Application. Journal of Marketing Research, 20(2), 134–148.

Rao, S., Senthilkumar, C. P., Patton, J., & Rhodes, Y. E. (2017). Call for papers - Blockchain: Applications and strategies for supply chain research and practice.

Rauchs, M., Blandin, A., Bear, K., & McKeon, S. (2019). 2nd global enterprise blockchain benchmarking study.

Rauer, J., & Kaufmann, L. (2015). Mitigating external barriers to implementing green supply chain management: A grounded theory investigation of green-tech companies' rare earth metals supply chains. Journal of Supply Chain Management, 51(2), 65–88.

Robinson, C. How Brilliant Earth is disrupting the diamond industry and enhancing the customer experience. Forbes. Retrieved from https://www.forbes.com/sites/cherylrobinson/2019/05/07/brilliant-earth/#64b817fe159d

Roeck, D. (2020). The foundation of distributed ledger technology for supply chain management. In T. X. Bui (Chair), 53rd Hawaii International Conference on System Sciences, Wailea, HI, USA.

Roeck, D., & Hofmann, E. (2019). Mastering the onboarding challenge: The case of information processing in distributed ledgers in supply chains. In K. Linderman (Chair), 50th Annual Conference of the Decision Sciences Institute, New Orleans, LA.

Roeck, D., Sternberg, H., & Hofmann, E. (2019). Distributed ledger technology in supply chains: A transaction cost perspective. International Journal of Production Research, 1–18.

Rogers, E. M. (1962). Diffusion of innovations. New York, NY: Free Press.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research, 57(7), 2117–2135.

Sadhya, V., & Sadhya, H. (2018). Barriers to adoption of blockchain technology. In A. Schwarz, T. Stafford, & R. Hirschheim (Chairs), 24th American Conference on Information Systems, New Orleans, LA.

Saunders, M., Lewis, P., Thornhill, A., & Bristow, A. (2019). Understanding research philosophy and approaches to theory development. In M. Saunders, P. Lewis, & A. Thornhill (Eds.), Research methods for business students (pp. 128–171). Pearson.

Schlatt, V., Schweizer, A., Urbach, N., & Fridgen, G. (2016). Blockchain: Grundlagen, Anwendungen und Potenziale. Retrieved from Fraunhofer-Institut für Angewandte Informationstechnik website: http://publica.fraunhofer.de/dokumente/N-452387.html

Schmahl, A., Mohottala, S., Burchardi, K., Egloff, C., Govers, J., Chan, T., & Giakoumelos, M. (2019). Resolving the blockchain paradox in transportation and logistics. Retrieved from https://www.bcg.com/publications/2019/resolving-blockchain-paradox-transportation-logistics.aspx

Schmidt, C. G., & Wagner, S. M. (2019). Blockchain and supply chain relations: A transaction cost theory perspective. Journal of Purchasing and Supply Management, 25(4), 100552.

Schoenherr, T., & Swink, M. (2012). Revisiting the arcs of integration: Cross-validations and extensions. Journal of Operations Management, 30(1), 99–115.

Schueffel, P. (2018). Alternative distributed ledger technologies blockchain vs. tangle vs. hashgraph - A high-level overview and comparison. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3144241

Schwandt, T. A. (1994). Constructivist, interpretivist approaches to human inquiry. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research (Vol. 2, pp. 118–137). Thousand Oaks, CA: SAGE.

Spirakis, P., & Tsigas, P. (Eds.) (2017). International Symposium on Stabilization, Safety, and Security of Distributed Systems: Springer International Publishing.

Srinivasan, R., & Swink, M. (2015). Leveraging supply chain integration through planning comprehensiveness: An organizational information processing theory perspective. Decision Sciences, 46(5), 823–861.

Srinivasan, R., & Swink, M. (2018). An investigation of visibility and flexibility as complements to supply chain analytics: An organizational information processing theory perspective. Production and Operations Management, 27(10), 1849–1867.

Steinfield, C., Markus, M. L., & Wigand, R. T. (2011). Through a glass clearly: Standards, architecture, and process transparency in global supply chains. Journal of Management Information Systems, 28(2), 75–108.

Sternberg, H., & Baruffaldi, G. (2018). Chains in chains: Logic and challenges of blockchains in supply chains. In Proceedings of the 51st Hawaii International Conference on System Sciences, Waikoloa, HI, USA.

Sternberg, H., Hofmann, E., & Roeck, D. (2020). The struggle is real: Insights from a supply chain blockchain case. Journal of Business Logistics, Forthcoming.

Stölzle, W. (1999). Beschaffungs- und Logistik-Management: Industrial Relationships: Oldenbourg.

Sutton, R. I., & Staw, B. M. (1995). What theory is not. Administrative Science Quarterly, 40(3), 371–384.

Swan, M. (2015). Blockchain: Blueprint for a new economy (1. ed.). Safari Tech Books Online. Beijing: O'Reilly.

Swift, C., Guide Jr., V. D. R., & Muthulingam, S. (2019). Does supply chain visibility affect operating performance? Evidence from conflict minerals disclosures. Journal of Operations Management, 65(5), 406–429.

Tapscott, D., & Tapscott, A. (2016). Blockchain revolution: How the technology behind Bitcoin is changing money, business and the world. New York: Penguin.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. Strategic Management Journal, 18(7), 509–533.

Thake, M. (2018). Blockchain vs. DAG technology: A brief comparison. Retrieved from https://medium.com/nakamo-to/blockchain-vs-dag-technology-1a406e6c6242

Thommson, E. (2019). Carrefour says blockchain tracking boosting sales of some products. Retrieved from https://www.reuters.com/article/us-carrefour-blockchain/carrefour-says-blockchain-tracking-boosting-sales-of-some-products-idUSKCN1T42A5

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. In 13th International Conference on Service Systems and Service Management (ICSSSM).

Torcasso, D. (2018). Gübelin präsentiert erste Blockchain für Farbedelsteine. Retrieved from https://www.handelszeitung.ch/unternehmen/gubelin-prasentiert-erste-blockchain-fur-farbedelsteine

Tosh, D. K., Shetty, S., Liang, X., Kamhoua, C., & Njilla, L. (Eds.) (2017). Consensus protocols for blockchain-based data provenance: Challenges and opportunities. 2017 IEEE 8th Annual Ubiquitous Computing, Electronics and Mobile Communication Conference (UEMCON).

Tushman, M. L., & Nadler, D. A. (1978). Information processing as an integrating concept in organizational design. Academy of Management Review, 3(3), 613–624.

Uebernickel, F., Brenner, W., Pukall, B., Naef, T., & Schindlholzer, B. (2015). Design thinking: Das Handbuch. Frankfurt: Frankfurter Allgemeine Buch.

Urquhart, C. (2013). Grounded theory for qualitative research. a practical guide. Cathy Urquhart. London: SAGE.

Van De Ven, Andrew H. (1989). Nothing is quite so practical as a good theory. Academy of Management Review, 14(4), 486–489.

Vanoye, M. (2018). Food traceability: After successful tests in Vietnam, Auchan Retail is launching blockchain technology internationally. Retrieved from https://www.auchan-retail.com/en/food-traceability-auchan-retail-launch-blockchain-technology-internationally/

Venkatesh, V. (2000). Determinants of perceived ease of use: Integrating control, intrinsic motivation, and emotion into the technology acceptance model. Information Systems Research, 11(4), 342–365.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. Management Science, 46(2), 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425–478.

Walker, R., & Merkley, G. (2017). Chipotle Mexican Grill: Food with integrity? (Case KEL979). Evanston, IL: Kellogg School of Management, Northwestern University.

Walsham, G. (1995a). Interpretive case studies in IS research: Nature and method. European Journal of Information Systems, 4(2), 74–81.

Walsham, G. (1995b). The emergence of interpretivism in IS research. Information Systems Research, 6(4), 376–394.

Wang, E. T. G., & Wei, H.-L. (2007). Interorganizational governance value creation: Coordinating for information visibility and flexibility in supply chains. Decision Sciences, 38(4), 647–674.

Wang, Y., Han, J. H., & Beynon-Davies, P. (2018). Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. Supply Chain Management: An International Journal, 24(1), 62–84.

Wang, Y., Singgih, M., Wang, J., & Rit, M. (2019). Making sense of blockchain technology: How will it transform supply chains? International Journal of Production Economics, 211, 221–236.

Weick, K. E. (1995). What theory is not, theorizing is. Administrative Science Quarterly, 40(3), 385–390.

Weisenberger, F., & de Knegt, F. (2019). DAG - A potential game changer in the field of M2M communication. Retrieved from https://www.bearingpoint.com/files/DAG_Technology.pdf?download=0&itemId=562844

Weking, J., Mandalenakis, M., Hein, A., Hermes, S., Böhm, M., & Krcmar, H. (2019). The impact of blockchain technology on business models – a taxonomy and archetypal patterns. Electronic Markets. Advance online publication.

Wheeler, M. (2017). The woman whose mum inspired her to track ethical food. Retrieved from http://www.bbc.com/news/business-38773878

Wieland, A., Handfield, R. B., & Durach, C. F. (2016). Mapping the landscape of future research themes in supply chain management. Journal of Business Logistics, 37(3), 205–212.

Wilhelm, M. M., Blome, C., Bhakoo, V., & Paulraj, A. (2016). Sustainability in multi-tier supply chains: Understanding the double agency role of the first-tier supplier. Journal of Operations Management, 41, 42–60.

Williams, B. D., Roh, J., Tokar, T., & Swink, M. (2013). Leveraging supply chain visibility for responsiveness: The moderating role of internal integration. Journal of Operations Management, 31(7-8), 543–554.

Williamson, O. E. (1985). The economic institutions of capitalism: Firms, markets, relational contracting (2. print). New York NY u.a.: Free Press.

Williamson, O. E. (2008). Outsourcing: Transaction cost economics and supply chain management. Journal of Supply Chain Management, 44(2), 5–16.

Wowak, K. D., & Boone, C. A. (2015). So many recalls, so little research: A review of the literature and road map for future research. Journal of Supply Chain Management, 51(4), 54–72.

Yan, T., Choi, T. Y., Kim, Y., & Yang, Y. (2015). A theory of the nexus supplier: A critical supplier from a network perspective. Journal of Supply Chain Management, 51(1), 52–66.

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where is current research on blockchain technology? A systematic review. PloS One, 11(10), e0163477.

Zaheer, A., & Venkatraman, N. (1994). Determinants of electronic integration in the insurance industry: An empirical test. Management Science, 40(5), 549–566.

Zhou, H., & Benton Jr., W.C. (2007). Supply chain practice and information sharing. Journal of Operations Management, 25(6), 1348–1365.

Zhu, K., Dong, S., Xu, S. X., & Kraemer, K. L. (2006). Innovation diffusion in global contexts: Determinants of post-adoption digital transformation of European companies. European Journal of Information Systems, 15(6), 601–616.

Zhu, K., & Kraemer, K. L. (2005). Post-adoption variations in usage and value of e-business by organizations: Cross-country evidence from the retail industry. Information Systems Research, 16(1), 61–84.

Zhu, K., Kraemer, K. L., & Xu, S. (2003). Electronic business adoption by european firms: A cross-country assessment of the facilitators and inhibitors. European Journal of Information Systems, 12(4), 251–268.

Zhu, K., Kraemer, K. L., & Xu, S. (2006). The process of innovation assimilation by firms in different countries: A technology diffusion perspective on e-business. Management Science, 52(10), 1557–1576.

Zhu, S., Song, J., Hazen, B. T., Lee, K., & Cegielski, C. (2018). How supply chain analytics enables operational supply chain transparency. International Journal of Physical Distribution & Logistics Management, 48(1), 47–68.

Zsidisin, G. A., & Ellram, L. M. (2003). An Agency Theory Investigation of Supply Risk Management. Journal of Supply Chain Management, 39(3), 15–27.

Zu, X., & Kaynak, H. (2012). An agency theory perspective on supply chain quality management. International Journal of Operations & Production Management, 32(4), 423–446.

Appendix

Note: In the following all four studies are presented according to their status on March 31, 2020. Accordingly, the citation styles are kept as in the respective journals.

Appendix A Roeck, D.

Distributed ledger technologies in supply chains: A taxonomy of applications

Present version:

As submitted to *Journal of Business Logistics*[45]

Published in former or amended versions:

Roeck, D. (2020). "The foundation of distributed ledger technology for supply chain management", Proceedings of the 53rd Hawaii International Conference on System Sciences,[46] Wailea, USA

Presented in a former version at:

53rd Hawaii International Conference on System Sciences, Wailea, USA

January 9, 2020

Best Paper Nomination

[45] VHB-JOURQUAL3: B; 2019 ABDC Journal Quality List: A; SJR: 2.49
[46] VHB-JOURQUAL3: C; SJR 2018: 0.25

Appendix B Roeck, D., Hofmann, E., & Rogers D.S.

Decomposition of transparency in supply chains: An information processing perspective

Present version:

As submitted to *Journal of Supply Chain Management*.[47]

Published in former or amended versions:

Roeck, D., Hofmann, E., & Rogers D.S. (2020). "Determinants of transparency in supply chains: A frame to assess the influence of digital technologies on transparency", Proceedings of the 29th IPSERA, Knoxville, USA

Roeck, D., Hofmann, E., & Rogers D.S. (2020). "Enhancing transparency in the supply chain: An information processing perspective", Proceedings of the 80th Annual Meeting of the Academy of Management, Vancouver, Canada – *Accepted.*

[47] VHB-JOURQUAL3: B; 2019 ABDC Journal Quality List: A; SJR 2018: 6.44

Appendix C Sternberg, H., Hofmann E., & Roeck, D.

The struggle is real: Insights from a supply chain blockchain case

Present version:

As accepted and published online in *Journal of Business Logisitcs*[48]

Published in former or amended version:

Sternberg S., & Baruffaldi. (2018). "Chains in chains: Logic and challenges of blockchains in supply chains", Proceedings of the 51st Hawaii International Conference on System Sciences,[49] Waikoloa, USA

Presented in a former version at:

51st Hawaii International Conference on System Sciences, Waikoloa, USA

January 11, 2018

[48] VHB-JOURQUAL3: B; 2019 ABDC Journal Quality List: A; SJR 2018: 2.49
[49] VHB-JOURQUAL3: C; SJR 2018: 0.25

Appendix D Roeck, D., Sternberg, H., & Hofmann E.

Distributed ledger technology in supply chains: A transaction cost perspective

Present version:

As accepted and published online in *International Journal of Production Research*.[50]

Published in former or amended version:

Roeck, D., & Hofmann E. (2018). "Theorizing distributed ledger technology - A supply chain management perspective", Proceedings of the 30th Annual Conference of the Nordic Logistics Research Network (NOFOMA), Kolding, Denmark

Presented in a former versions at:

CSCMP Edge Academic Research Symposium, Nashville, USA

October 3, 2018

30th Annual Conference of the Nordic Logistics Research Network (NOFOMA), Kolding, Denmark

June 14, 2018

[50] VHB-JOURQUAL3: B; 2019 ABDC Journal Quality List: A; SJR 2018: 1.59

Appendix A – Study 1

Distributed Ledger Technologies in Supply Chains: A Taxonomy of Applications

Dominik Roeck

Institute of Supply Chain Management, University of St.Gallen, Switzerland

Submitted to Journal of Business Logistics

Abstract

A wide range of promising applications of distributed ledger technology (DLT) are being tested in supply chains. This study sheds light on the diversity of existing DLT applications in supply chains. By combining design science research (DSR) and the qualitative data analysis of interviews and secondary data, the study develops a taxonomy of DLT applications in supply chains. The taxonomy draws on socio-technical systems and allows the characterization of DLT applications in supply chains based on the underlying technology used, the participation structure, and the targeted task. Furthermore, the study identifies the four predominant classes of DLT applications in supply chains. It then identifies the relevant DLT attributes of the predominant classes and derives the specific value contributions of these classes. The study culminates in a framework that illustrates the relationship between the characteristics of a DLT application and its value contributions. In this way, this research enables both practitioners and academic scholars to understand DLT applications in supply chains in more detail and—in contrast to existing studies, which focus on DLT in supply chains in general—provides an analysis at the level of specific applications.

Keywords: *taxonomy, design science research, blockchain technology, distributed ledger technology, supply chain management; socio-technical systems*

Introduction

In the course of the digitalization of supply chain management (SCM), managers see great potential in distributed ledger technologies (DLTs) (Casey and Wong 2017; Wang et al. 2019; Schmahl et al. 2019). In 2018 and 2019, two global DLT surveys conducted by Deloitte underlined the importance of DLT for SCM practitioners, as the majority of respondents identified DLT as one of their top five strategic priorities and stated that they were working on use cases related to DLT in SCM (Pawczuk, Massey and Schatsky 2018; Pawczuk, Massey and Holdowsky 2019). *DLT* is an umbrella term that includes technologies such as blockchain technologies (BCTs) and directed acyclic graphs (DAGs) (Kurpjuweit et al. 2019). In the field of SCM, DLTs are deployed as underlying computing protocols that orchestrate the storage, distribution, and integrity of data in a distributed network.

In this way, DLT is used as a protocol layer for diverse applications in supply chains. These DLT applications aim to enhance product traceability, digitalize processes, and build secure financing ecosystems (Wang, Han and Beynon-Davies 2018). Numerous academic studies (e.g., Babich and Hilary 2019; Kim and Laskowski 2018; White 2017) and practitioner contributions (e.g., Casey and Wong 2017; Harbert 2020; Tapscott and Tapscott 2016) have described a wide range of applications in supply chains that build on DLT protocols. Thus, the value contributions of these DLT applications can vary, spanning from enhancing traceability to ensuring secure financing ecosystems.

However, despite the great interest of SCM practitioners in DLT, they are still facing uncertainty regarding its applications. As SCM experts stated, in a study by Wang et al. (2019): “[M]any organizations are still unsure of blockchain technicalities, functions or benefits.” and “the concept of the technology is complex, and difficult to grasp” (231). Hence, supply chain managers need help to understand the technology, its applications and the resulting value contributions of these applications. Extant research on DLT has started the discussion on DLT’s strengths and weaknesses (e.g., Wang et al. 2019; Babich and Hilary 2019), application potential (e.g., Kim and Laskowski 2018; Saberi et al. 2019), and adoption benefits and barriers in supply chains (e.g., Kurpjuweit et al. 2019; Sternberg, Hofmann and Roeck 2020) on a general level. While these contributions help develop practitioners' understanding of DLT, more distinct research focusing on specific DLT applications is needed to help practitioners understand the applicability of DLT in supply chains.

Given the wide range of DLT applications, the complexity of the novel technology, and the diversity of the technological configurations and designs of DLT applications (e.g., private or public DLTs, and additional technologies), more specific research on the level of DLT applications is needed. More application-specific research will not only help practitioners to better understand DLT as a technology and the diversity of DLT applications but also to guide the design of future DLT applications in supply chains. However, to conduct application-specific research, a guiding framework that classifies DLT applications and elaborates on their distinct characteristics is needed. This study aims to address this need. By shedding light on the diverse configurations of DLT applications, a classification can be created that paves the way for more application-specific research. This leads to the first research question (RQ):

RQ1: How can DLT applications in supply chains be classified?

Following this classification, a clustering of a sample of existing DLT applications into homogenous classes can be derived to identify the different types of DLT applications prevalent in supply chains. Based on the identification of these classes, the different value contributions of each class are to be derived to understand the diverse benefits of these applications. This leads to the second RQ:

RQ2: What are the value contributions of the resulting classes of DLT applications in supply chains?

The existing literature on DLT in supply chains provides a general understanding of the potentials, barriers, and effects of DLT, yet more empirical research is needed (Kurpjuweit et al. 2019). Therefore, this study applies a mixed-methods approach. As such, design science research (DSR) is applied to develop the taxonomy and derive the classes. Following the method of Nickerson, Varshney and Muntermann (2013), and in line with the three cycles of DSR (Hevner 2007), a literature review and the gathering of empirical data from 48 DLT projects that represent 48 different DLT applications in supply chains are used to develop a taxonomy and derive homogenous classes of DLT applications. In this way, the first RQ is addressed. Furthermore, the qualitative data analysis of interviews and secondary data related to the 48 DLT applications is applied to address the second RQ.

The findings of this study provide a taxonomy, visualized in a morphological box, that helps improve the overview and the understanding of the different characteristics of distinct DLT applications in supply chains. Furthermore, the study supports practitioners in designing configurations of DLT applications and guides future research to characterize the DLT applications under study. The derived classes help researchers to identify homogeneous units of observation for empirical studies and dive deeper into DLT applications. Furthermore, the identified value contributions facilitate a more detailed discussion of DLT applications, both for practitioners and academic scholars.

Literature background

Distributed ledger technologies

While having emerged as the underlying technology behind Bitcoin, DLT has found its way into fields other than finance. Among others, the field of SCM is a promising field for DLT applications, as the technology could be used to resolve long-standing challenges, such as the lack of trust and transparency, issues with inter-organizational information flow, and the need for third parties (Wang et al. 2019; Schmidt and Wagner 2019; Zhao, Fan and Zheng 2018). *DLT* is an umbrella term that includes a set of technologies that are characterized by distributed ledgers of data that are shared and agreed upon by a peer-to-peer network (Christidis and Devetsikiotis 2016; Hofmann et al. 2017). In a DLT network, all participants (e.g., an organization in a supply chain) have identical ledgers of data (Swan 2015). By constantly updating and verifying the correctness of all ledgers in the DLT network, each participant holds an updated ledger (Yli-Huumo et al. 2016). Among such technologies, BCT is the most commonly known and applied representation of DLT in the field of SCM (Kurpjuweit et al. 2019). However, lately, DAGs—a different form of DLT—are attracting more attention from both practitioners and academic scholars. Among the more popular examples of DAGs are IOTA and Hedera. Both types of DLTs (i.e., BCTs and DAGs) are introduced in the following sections.

Blockchain technologies

BCTs allow the storage of transactions in data chained blocks and distribute these blocks within a peer-to-peer network (Beck et al. 2016). The BCT protocols orchestrate the storage and distribution of data and define the consensus mechanism in the BCT network. In the field of SCM, most DLT applications are built on BCT protocols, such as Hyperledger Fabric, MultiChain, and Ethereum (Rauchs et al. 2019). Before new transaction data is stored and distributed in the network, the protocol validates the correctness of a transaction record that is issued for storage. Afterward, the data is verified by a consensus mechanism. An example of an early BCT protocol is the proof-of-work (PoW) consensus mechanism, which requires a large number of network participants to solve mathematical puzzles at the same time (i.e., mining). As this type of consensus mechanism leads to a significant amount of energy consumption and time delays to establish new blocks, more advanced BCT protocols make use of permissioned voting–based and permissioned notary–based consensus mechanisms (Cao et al. 2020).[51] In a permissioned voting–based consensus, only a few pre-defined network participants can verify new transactions as they are the only ones to vote on correctness. In case the majority (a pre-defined ratio or a lottery-selected participant) confirms a new transaction, verification is conducted. In a permissioned notary–based consensus, a small, fixed number of entities in the network is assigned to verify new transactions and maintain the integrity of the

[51] More details on the different consensus mechanisms can be found in: Cao et al. (2020), The Linux Foundation (2020), and Ganne (2018)

ledger. Depending on the protocol, new transactions can even be verified by a single notary.

Once both validation and verification are achieved, the new transaction data is encrypted in a block and distributed among the network (Swan 2015). Consequently, each network member chains the new data block automatically to the previous blocks using a header that points to the previous block (Blossey, Eisenhardt and Hahn 2019). Hence, each network participant holds the same ledger in the form of a linear chain of data blocks (Hofmann, Strewe and Bosia 2018). Therefore, if a single ledger within a network is not congruent with the others, it has clearly been manipulated and can be detected immediately (Yli-Huumo et al. 2016). Moreover, the distribution of data in near real-time allows for the steady accessibility of data without a single point of failure (Kshetri 2018).

Directed acyclic graphs

*DAG*s are directed graphs (including nodes and edges), without cycles, that are used to store data records. Within these graphs, it is impossible to reach a specific node within the graph again. The edges in the graph constitute the links between the nodes—more precisely, they constitute the parent–child relationship between the data nodes (Lerner 2015). Like the header in blockchains, the incoming directed edges carry out the typological ordering of the data graph. However, unlike in blockchains, the data is not stored in blocks that are chained together but rather in the nodes within the graph. One advantage of DAGs in comparison to BCTs is that DAGs do not rely on mined blocks and so are not limited by data storage size or the speed of the miners (Benčić and Žarko 2018). Instead, new transactions are individually stored in graphs, without having to be aggregated with others into a block. This also leads to reduced energy consumption, as the typical mining operations of BCTs are energy-consuming (Lee 2018). Another advantage of DAGs is that the improved transaction volume that can be processed enhances scalability, which is particularly important for applications that require both high volume and velocity (Benčić and Žarko 2018). This is the result of the consensus mechanism used within DAGs; while the entire chain of blocks—that is, the longest chain—must be verified in a blockchain, DAG consensus mechanisms only verify a pre-defined number of nodes (e.g., IOTA verifies the last two transactions), reducing the verification time (Thake 2018).

Participation in distributed ledger technologies

BCTs and DAGs have different permission rights. Permission rights determine the permission granted to an entity (e.g., supply chain actors) to participate in a DLT network and to enter (i.e., write) and see (i.e., read) transactions. In this way, the degree of transparency in relation to transactions within a DLT network is defined (Swan 2015). Public DLTs allow all individuals and organizations to join the DLT network and provide full transparency for all transactions in the network, while the entities themselves remain anonymous via pseudonyms. In this way, every entity has read and write access, yet the content of a transaction is only revealed to the corresponding, yet anonymous, transaction partners. In a supply chain setting, the anonymity will just be formality, as buyers will know their transaction partner (e.g., the names of their suppliers) despite the pseudonyms.

Private DLTs are restricted to a permissioned selection of network participants that are invited to join the network (Yli-Huumo et al. 2016). In the case of DLT applications in supply chains, no pseudonyms are applied in this case, as the participants will already know most or even all of the other participants due to the invitation. As in public DLTs, only the corresponding partners of a transaction can see its contents. For all others, the transaction content is concealed via encryption, yet its occurrence is visible to all. Last, in consortium DLTs, permission is as again pre-defined. In contrast to private DLTs, however, a consortium DLT enables the establishment of private channels for transactions between network participants, which are not visible to the other network participants.

Characterization of distributed ledger technology applications in supply chains

Research on DLT applications in supply chains is just emerging. However, early contributions have discussed a wide range of applications, different scopes and industries, and additional technologies. Furthermore, the diversity of supply chain actors in DLT participation and of the involvement of end customers have been highlighted in these early contributions. As such, a review of the extant literature provides a first glance of the different types of DLT applications and the distinct characteristics of these applications.

In their expert study, Wang et al. (2019) explore potential DLT applications in supply chains. The authors reveal that DLT applications can aim to provide visibility and traceability, to enable simplification and digitalization, to allow shipment and multi-agent validations, and to monitor fair funding for humanitarian and ethical-critical supply chains (e.g., diamonds). Moreover, Kshetri (2018) discusses potential DLT applications related to enhancing traceability for food, pharmaceuticals, and raw materials, as well as enabling visibility to monitor temperature-controlled pharmaceuticals. In addition, Durach et al. (2020) identify a list of 13 DLT applications; while they are all related to transactions in supply chains, 5 of the applications target core supply chain topics in particular: escrow service, document-signing processes, transparent performance-management systems, product-quality certification, and logistics and delivery systems.

Saberi et al. (2019) and Manupati et al. (2019) discuss the broad application of DLTs for sustainable SCM. Nærland et al. (2017) develop design principles for digitalizing processes and shipping documents. Moreover, Babich and Hilary (2019) present product traceability, data aggregation, and the automation of contracts as potential DLT applications in their research agenda, while Wang, Han and Beynon-Davies (2018) list traceability, digitalizing processes, the visibility of processes, and financial services as the primary objectives of the 17 DLT projects observed in their study. In conclusion, the existing contributions reveal a wide range of objectives of DLT applications in supply chains, which constitutes the basis for further characterizing DLT applications in supply chains.

In addition to the different objectives, SCM scholars have illuminated diverse application scopes. Blossey, Eisenhardt and Hahn (2019) discuss DLT applications for procurement tasks, while Nærland et al. (2017) focus on transportation and logistics tasks (i.e., processing the bill of lading). The interviews and Delphi study conducted by Kurpjuweit et al. (2019) explore the potential to apply DLT for additive manufacturing (that is, in production). Moreover, Wang, Han and Beynon-Davies (2018) discuss DLT applications in distribution, transportation and logistics, and supply chain finance (SCF). As such, multiple scopes of DLT applications in supply chains have been discovered, prompting the further characterization of the scope of DLT applications in supply chains. Scholars have also revealed DLT applications in different industries, including aviation (Kurpjuweit et al. 2019), textile (Wang, Han and Beynon-Davies 2018), food (Tian 2016), and pharmaceutical supply chains (Weking et al. 2019). As the different industries entail specific characteristics, such as regulations, the industry in which DLT applications are deployed will affect its characterization as well.

Aside from the different objectives, scopes, and industries of DLT applications in supply chains, several scholars pave the way to a more detailed characterization of these DLT applications. First, Tian (2016), Sternberg, Hofmann and Roeck (2020), and Babich and Hilary (2019) elaborate on the need for additional technologies to support DLT applications in supply chains. These studies emphasize the need for radio-frequency identification (RFID) tags, internet of things (IoT)–based sensors, and Ethernet connections, as the studies discuss DLT applications to improve product traceability in supply chains. Moreover, the studies by Sternberg, Hofmann and Roeck (2020) and Kurpjuweit et al. (2019), which focus on the adoption of DLTs in supply chains, point out that the participation of supply chain actors may vary in different DLT applications. Furthermore, the DLT applications presented by Wang, Han and Beynon-Davies (2018) demonstrate that some applications aim to involve end customers (e.g., Provenance) while others do not (e.g., Maersk).

To summarize the existing literature on DLT applications in supply chains, the identified characteristics of the applications can be classified into three topics: (1) the technological aspects of DLT applications, which include the underlying DLT, permission rights, consensus mechanisms, and additional technologies deployed in DLT applications in supply chains; (2) the task-related aspects of DLT applications, such as the objective, the scope, and the industry of the applications; and (3) the structural, network-related aspects of DLT applications in supply chains, which include the scope of the participants in the supply chains and the end customer involvement.

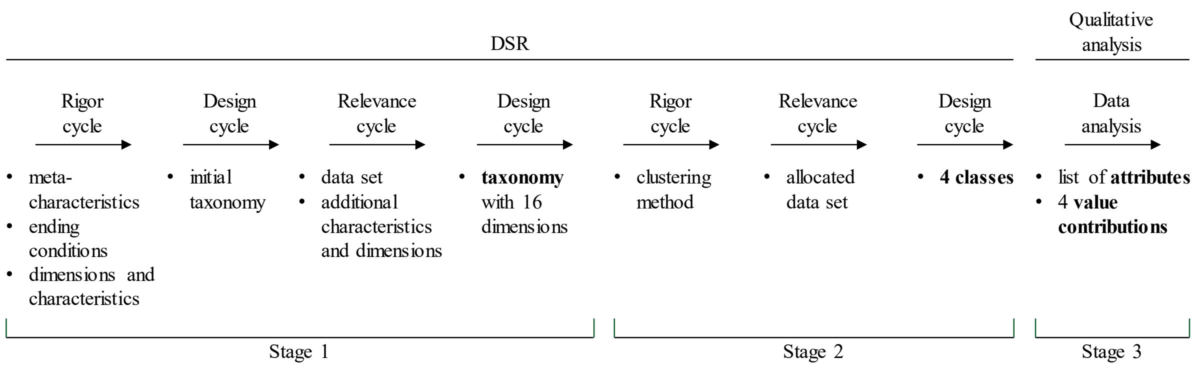
These three topics constitute three of the four elements of socio-technical systems (STS; Bostrom and Heinen 1977a), with people being the fourth. STS elaborates on the interplay of technical and social systems to help in understanding the use of technology in organizations. While the idea emerged from behavioral and organizational sciences, only a few SCM scholars (e.g., Kull, Ellis and Narasimhan 2013) draw on STS to explore the interplay of technology and social systems such as supply chains. However, in his seminal work on system design principles for information systems (IS), Clegg (2000) emphasizes the applicability of STS in inter-organizational contexts such as supply chains. In addition, Fawcett, Waller and Bowersox (2011) suggest the application of STS as a theoretical lens through which to explore the deployment of technologies in supply chains.

The present study follows this call and applies STS as a structural guidance for the development of a classification of DLT applications in supply chains. As shown by Bostrom and Heinen (1977b), DLT applications represent a form of STS, and viewing them as such helps in exploring their technical sub-system (i.e., the technological topic and task-related topic) and social ecosystems (i.e., the structural topic, related to the user network of DLT applications). As the RQs set out to classify DLT applications and carve out their value contributions rather than to explore the actual deployment of the applications, this study focuses solely on these three elements.

Methodology

To address the RQs, a three-stage research process was followed that combines DSR and the qualitative data analysis of interview and secondary data. By deploying this mixed-methods approach, an in-depth analysis of DLT applications in the field of SCM was conducted, leading to the development of a taxonomy of DLT applications in supply chains and the derivation of the attributes and value contributions of the underlying DLT. The first and second stages draw on DSR, while the third stage is based on qualitative data analysis.

In line with Hevner (2007), the first two stages include the rigor cycle, the relevance cycle, and the design cycle. First, the rigor cycle ensures the taxonomy will be built on a foundation of well-established methods, theoretical contributions, and the latest research on DLT to guide and structure the development of the taxonomy (stage 1) and the classes (stage 2). In this way, the research draws on the established knowledge base. Second, the relevance cycle both enables the integration of empirical insights from real-world DLT projects in supply chains that represent distinct DLT applications and guides the development of the taxonomy and classes for practical relevance and applicability. Third, the design cycle allows the development and evaluation of the taxonomy in an iterative fashion. Stage 1 and stage 2 follow the approach of Nickerson, Varshney and Muntermann (2013) to develop the taxonomy and the classes, while stage 3 involves qualitative data analysis. In the following sections, the three stages are described in detail. A-Figure 1 illustrates the methodological approach used in this study.



A-Figure 1: Methodological approach

Developing the taxonomy

In stage 1, the rigor cycle marks the starting point. During this stage, extant IS and SCM research was analyzed to identify the characterizations of DLT applications in supply chains. Both peer-reviewed scientific journals and academic conference proceedings were reviewed in the fields of IS and SCM. The literature review led to the definition of meta-characteristics, which is step 1 in Nickerson, Varshney and Muntermann (2013). The contributions related to DLT applications in supply chains (e.g., Wang et al. 2019; Babich and Hilary 2019)—guided by the seminal work Bostrom and Heinen (1977a) on STS to identify the meta-characteristics—revealed three meta-characteristics: underlying technology, participation structure, and targeted task. The fourth element of STS according to Bostrom and Heinen (1977a), people, was excluded due to the focus of this study on the characterization of DLT applications themselves rather than on their deployment or use. Furthermore, both the subjective and objective ending conditions were defined, in line with step 2 of Nickerson, Varshney and Muntermann (2013).

In a literature review the dimensions and characteristics to develop an initial taxonomy were derived. Several authors, including Bottone, Raimondi and Primiero (2018), Benčić and Žarko (2018), and Cao et al. (2020), discuss the different underlying protocols of DLT, permission rights of DLT, and consensus mechanisms of DLT. Further, Sternberg, Hofmann and Roeck (2020) identify the additional technologies for data gathering deployed in DLT applications. These dimensions enable a refined characterization of the underlying technology of DLT applications in general and in supply chains in particular. The required participating supply chain actors and usage by end customers—dimensions that allow for a specification of the meta-characteristic participation structure—are also discussed by Sternberg, Hofmann and Roeck (2020) and Kurpjuweit et al. (2019).

Moreover, scholars such as Babich and Hilary (2019) and Wang et al. (2019) illuminate the main objectives of DLT applications, as the section literature background condenses. Wang, Han and Beynon-Davies (2018), Nærland et al. (2017), Kurpjuweit et al. (2019), and Blossey, Eisenhardt and Hahn (2019) analyze the scope of DLT applications, while Weking et al. (2019) present the underlying assets as dimension to characterize DLT applications. As such, the main objective of an application, the scope of an application, and the industry in which a DLT is applied also constitute dimensions to further elaborate on the targeted tasks of DLT applications in supply chains. Based on these findings, an initial taxonomy with nine dimensions was designed (i.e., the first design cycle). As the ending conditions were not met (i.e., evaluation), this led to the relevance cycle.

For the relevance cycle, a database was created with DLT applications in supply chains, and a list of search terms to identify DLT applications in SCM was defined. This list contained two word sets representing both the technology (i.e., DLT) and the specified field of usage (i.e., SCM), as presented in A-Table 1. After the definition of the sets, both word sets were combined to start the search process.

A-Table 1: List of search terms

Word sets	Search terms
DLT	"distributed ledger technology" OR "shared ledger" OR "decentralized ledger" OR "blockchain technology" OR "block directed acyclic graph" OR "transaction-based directed acyclic graph"
	AND
SCM	"supply chain" OR "supply chain management" OR "supplier networks" OR "value chain" OR "inter-organizational"

The following selection criteria were then defined to allow for proper data analysis:

- The use of DLT in SCM, based on an understanding of the supply chain operations reference (SCOR) model
- The availability of multiple data sources to allow for data triangulation and to reduce biases
- The availability of data in English to enable data analysis

Next, the databases CrunchBase, GitHub, Factiva, and LexisNexis were screened for relevant entries using the search terms, which included press releases, blogs, conference and event programs, and webpages. Initially, 87 DLT projects in supply chains, constituting different DLT applications, were identified in the screening phase; this was conducted between September 2019 and December 2019. Subsequently, the selection criteria were applied to the 87 projects, leading to a reduction in the identified initiatives, particularly as a result of the last criterion, as several projects were identified that did not provide sufficient data in English for further analysis. As such, the list was reduced to 59 DLT projects. After this identification step, data collection from the selected sources began, and a new database for this research was created. For six projects, insufficient data was available to apply the initial taxonomy or to refine it further, and an additional five projects were merged or abandoned during the four months in which data collection occurred. Thus, the final set comprised 48 DLT applications for further analysis to refine the taxonomy.

Following this relevance cycle, another design cycle was conducted. In line with the empirical-to-conceptual approach (step 3 of Nickerson, Varshney and Muntermann (2013)), the database of 48 DLT applications was used to refine the previous development. The 48 DLT applications were classified according to the taxonomy (step 4e), new dimensions were derived (step 5e), and thereby, the taxonomy was refined (step 6e). In this way, the dimensions *database as a source for data input* and *tag with physical product* were added to the meta-characteristics underlying the technology, while the additional characteristics were added to the dimensions *permission rights* and *consensus mechanism*. Furthermore, the dimensions *scope of the participation network* and *role as* *operator of nodes* were added to the meta-characteristic participation structure. This iteration also included the identification of the dimension *direction of the information flow* in DLT applications in supply chains. Thus, a refined taxonomy was developed that comprised 16 dimensions (second design cycle).

Based on this development, the ending conditions were evaluated (step 7). All 48 DLT applications of the dataset could be classified in a meaningful way (comprehensive and concise) according to the taxonomy, without further refining the dimensions or their distinct characteristics (i.e., showing robustness). Moreover, the taxonomy was revealed to be extendable and explanatory, as no new dimensions or characteristics could be found and those identified showed explanatory power to characterize DLT applications in supply chains. Furthermore, the objective ending conditions of Nickerson, Varshney and Muntermann (2013) were fulfilled. In this way, the first stage was completed, and a taxonomy was developed.

Developing the classes

Until now, SCM scholars have underlined different objectives of DLT applications in this field of study and have outlined the scope of DLT applications regarding various SCM tasks. In this way, facilitating traceability of products (e.g., Sternberg, Hofmann and Roeck 2020; Tian 2016), visibility of actors and processes (e.g., Wang et al. 2019; Korpela, Hallikas and Dahlberg 2017), authenticity of products (e.g., Tian 2016; Kim and Laskowski 2018), digitalization of processes (e.g., Nærland et al. 2017; Kolb et al. 2019), and financing and escrow (e.g., Durach et al. 2020; Hofmann et al. 2017) were identified as the main objectives of DLT applications in supply chains. These characteristics are included in the developed taxonomy. Moreover, procurement (e.g., Kolb et al. 2019), transportation and logistics (e.g., Nærland et al. 2017), distribution (e.g., Sternberg, Hofmann and Roeck 2020), SCF (e.g., Hofmann et al. 2017), and SCM in general (e.g., Babich and Hilary 2019) were identified as primary objectives. These constitute the distinct characteristics of the dimension scope of DLT applications in the taxonomy. As such, the characteristics of both the main objective and the scope of DLT applications allow for the a priori characterization of DLT applications. In line with Hevner (2007), this insight from another rigor cycle was used to identify initial patterns in the data set of 48 DLT applications.

Based on the established sample of 48 DLT applications and the developed taxonomy, a cluster analysis was conducted, combining both relevance and design cycles. This allowed for a refinement of the initial patterns of DLT applications, which were limited to the characterization of the main objective and the scope of the applications. As the characteristics were nominally scaled, a transformation was required. Each distinct characteristic of the taxonomy was transformed into dichotomous dummy variables to allow the measurement of distances. Consequently, 53 binary variables were established to characterize each DLT application in the sample. Based on this transformation, the Ward method (Kaufman and Rousseeuw 2009) was applied to cluster the DLT applications. In this vein, a hierarchical, agglomerative cluster analysis was performed. To determine the number of clusters, a quantitative analysis of different numbers of clusters (between three and six) was used to find the best homogeneity within the clusters (i.e., intra-homogeneity) and the highest heterogeneity between the clusters (i.e., inter-heterogeneity). For each number of clusters, the mean squared Euclidean distance to the center of each cluster was compared to identify the best number of clusters in terms of intra-homogeneity. Furthermore, for each number of clusters, the mean squared Euclidean distance between each cluster was compared to measure the inter-heterogeneity. The analysis revealed that the use of four clusters is the optimal solution. These are referred to as the "four archetypal classes of DLT applications in supply chains" in the remainder of this study

Identifying the attributes

In stage 3, qualitative data analysis was conducted to dive deeper into the identified classes of DLT applications and explore the attributes of DLT as an underlying technology of these classes. Therefore, data from interviews and secondary data, including websites, press releases, blog posts, conference presentations, and video demonstrations were collected. For the interviews, multiple representatives of each of the 48 DLT applications were contacted via email. At this time, both representatives who were supply chain actors using the DLT applications and who were technology providers were asked to participate in an interview. In this way, a multi-angle perspective was assumed to study DLT applications from different angles and to allow an interpretive analysis. For conducting the interviews, a semi-structured interview instrument (see Appendix A) was crafted. The interview instrument is guided by both the second RQ and the dimensions within the taxonomy to identify the characteristics that lead to the distinct attributes of DLT within DLT applications in SCM. In total, interviews with representatives from 16 of the 48 DLT applications in the data set were conducted. Between three (in class 4) and five (in class 1) DLT applications of each class were covered in the interviews. In total, 24 interviews were conducted, between October 2019 and March 2020. A list of interviewees can be found in Appendix B.

For secondary data, the data in the previously established data set were used for the further triangulation of data and to enhance trustworthiness. Secondary data on all 48 of the DLT applications were collected.

Following the process of data gathering, a coding procedure was conducted, following the steps of analytical, selective, and theoretical coding outlined by Glaser (1992). As the data collection and analysis were influenced by the literature and the established taxonomy, the grounded theory method was only applied as guidance for coding rather than as an overall approach (Urquhart 2013). First, the interview transcripts and notes, as well as the secondary data, were coded by assigning analytical codes in Atlas.ti. These codes go beyond descriptive codes and include an interpretation of the statements. Second, the developed analytical codes were transferred into selective codes, limiting the focus to the research problem (Urquhart 2013). Third, the relationships between the remaining codes were identified and characterized in order to achieve theoretical codes.

Results

Following the DSR approach, a taxonomy of DLT applications in supply chains was developed that contains the following three categories: underlying technology, participation structure, and targeted task. In total, these three categories contain 16 dimensions, with each dimension containing between 2 to 8 distinct characteristics. The developed taxonomy is depicted as a morphological box, illustrated in A-Figure 2. Each DLT application in a supply chain can be characterized according to this taxonomy, thus enabling an in-depth analysis of specific DLT applications.

Underlying technology	Underlying protocols [UP]	BCT	DAG				
Underlying technology	Permission right [PR]	Public	Private	Consortium			
Underlying technology	Consensus mechanisms [CM]	Proof-of-work	Permissioned voting	Permissioned notary	DAG consensus		
Underlying technology	Databases as sources for data input [DI]	Single	Multiple				
Underlying technology	Additional technologies for data gathering [AT]	Required	Not required				
Underlying technology	Tag with physical product [TP]	Required	Not required				
Underlying technology	Transaction space [TS]	Only on-ledger	Off-ledger				
Participation structure	Scope of participation network [SP]	Supply chain	Industry	Open			
Participation structure	Participating supply chain actors [PA]	Physical actors	Physical and support actors				
Participation structure	Usage by end customer [UE]	Yes	No				
Participation structure	Role as operator of nodes [RO]	Not required	Operated as a service	Operated by individual actors			
Targeted task	Underlying asset [UA]	Physical product	Information	Financial resources			
Targeted task	Main objective [MO]	Traceability of products	Visibility of actors and processes	Authenticity of products	Digitalization of processes	Financing and escrow	
Targeted task	Industry [IN]	Automotive	Aviation	Chemicals	Food		
Targeted task	Industry [IN]	Minerals	Pharmaceuticals	Textile	Multiple industries		
Targeted task	Scope of the application [SA]	Transport and logistics	Procurement	Production	Distribution	SCF	SCM
Targeted task	Direction of objective [DO]	Downstream supply chain actors	Upstream and downstream actors	End customers	All		

A-Figure 2: Taxonomy of DLT applications in supply chains

Following the presentation of the taxonomy, visualized by the morphological box in A-Figure 2, the 16 dimensions are described in greater detail in A-Table 2. In this way, the 53 characteristics are further specified in terms of the application of DLT in supply chains (shown in italics in A-Table 2).

A-Table 2: Description of the dimensions and characteristics

Dimension	Description
Underlying protocol	This dimension specifies the applied protocol of the DLT application and, thus, the orchestration of the data storage, distribution, and volume of processed transactions. While *BCTs* aggregate multiple transactions and store these in chained blocks, different protocols of BCTs—such as Hyperledger Fabric, Corda, and MultiChain—exist. *DAGs* store each transaction by itself in a node, connected to a specified number of parent nodes; these include Tangle and Hashgraph.
Permission right	This dimension specifies the ability to participate in the DLT application and read and write transactions in the ledger. *Public* DLTs are unrestricted in terms of participation, read access, and write access, allowing for a high visibility of transactions but also anonymity. *Private* DLTs require permission to participate, while read and write access is given to all permissioned participants. In *Consortium* DLTs, as in private DLTs, permission is required, but only several pre-assigned participants have read and write access, maintaining the consensus of the ledger
Consensus mechanism	This dimension specifies the procedure for reaching a consensus on new and inconsistent data in the ledger. A *permissioned voting* consensus is restricted to a defined number of participants. In *permissioned notary* consensus, one or multiple entities are assigned the right to reach consensus. *DAG*

	consensus mechanisms require participants to verify other transactions before entering their new transactions. By cross-proofing individual transactions, integrity is established.
Databases as sources for data input	This dimension specifies the number (i.e., *single/multiple*) of different databases required by a participating supply chain actor to enter data into the DLT application. In this way, the number of interfaces and required application programming interfaces (APIs) are defined.
Additional technologies for data gathering	This dimension specifies the requirement (i.e., *required/not required*) to deploy additional technologies to gather the required data for the DLT application. This can include not only basic technologies such as Wi-Fi connection or global positioning system (GPS) but also advanced technologies such as sensors.
Tag with physical product	This dimension specifies the requirement (i.e., *required/not required*) to deploy a product identifier such as quick response (QR) codes, barcodes, or RFIDs to match the transaction in the ledger with a corresponding physical product.
Transaction space	This dimension specifies whether or not transactions are only performed in the distributed ledger. Several DLTs allow *only on-ledger* transactions, in which the ledger is only limited to transactions that are verified via a consensus mechanism, which restricts the capacity of transactions. Other DLTs allow *off-ledger* storage, which enables the storing of data in, for example, cloud systems, that are referenced with identifiers in the ledger. This can make sense for transactions that require more storage space (e.g., images or computer-aided designs).

Scope of participation network	This dimension specifies the range of participants aspiring to use the DLT application. The participation can be limited to actors in the *supply chains* of an initiating focal company, in an entire *industry* (e.g., pharmaceutical), or spanning multiple or all industries (i.e., *open*).
Participating supply chain actors	This dimension specifies the type of actors that deploy the DLT application. In line with the definition of Carter, Rogers and Choi (2015), this can either include only *physical actors* or *both* physical and support actors.
Usage by end customer	This dimension specifies the aspired usage of end customers. While some DLT applications aim to be used by end customers (*yes*) others do not (*no*).
Role as operator of nodes	This dimension specifies the need for supply chain actors to operate and maintain a node in the DLT network. Some DLT applications draw on external services to operate nodes and, thus, do *not require* supply chain actors to achieve this task. Other DLT applications require the supply chain actors to invest in nodes (i.e., *operated as a service*). Furthermore, several network nodes are *operated by individual actors* in the supply chain.
Underlying asset	This dimension specifies the asset, which is replicated or present in the ledger. This describes the focus of information, as the focus can be on a *physical product*, supply chain *information,* or *financial resources*.

Main objective	This dimension specifies the aim of the DLT application, prominently represented in the vision and mission of a DLT application or a project description. This can include providing the *traceability of products*, *visibility of actors and processes* in the supply chain, information on the *authenticity of products*, the *digitalization of processes*, or *financing and escrow* services in the supply chain.
Industry	This dimension specifies the industry in which the DLT applications are used. The observed DLT applications are deployed in *automotive*, *aviation, food, mineral* (including raw materials)*, pharmaceutical, shipping,* and *textile* supply chains. Furthermore, several DLT applications are deployed in *multiple industries* and are not industry specific.
Scope of the application	This dimension specifies the range of applications with regard to SCM tasks. DLT applications can be applied in *transport and logistics*, *procurement*, *production* (including additive manufacturing) *distribution*, or *SCF* (i.e., trade finance and working capital management), or they can cover the management of supply chain operations with multiple *SCM* tasks.
Direction of objective	This dimension specifies the user of the DLT application in terms of the direction of information flow. The DLT application can provide information for *downstream supply chain actors*, *upstream and downstream supply chain actors*, *end customers* only, or both supply chain actors and end customers (i.e., *all*).

Archetypal classes of DLT applications in supply chains

Based on the taxonomy, four salient archetypal classes of DLT applications in supply chains were identified. These four classes cover all 48 DLT applications in the sample. Each of the four archetypal classes contains between 7 (class 3) and 21 (class 1) DLT applications. A-Table 3 gives a brief description of each of the four classes, with their respective emphasis in terms of characteristics. Furthermore, A-Table 4 summarizes the specific characteristics of each archetypal class. Thereby, A-Table 4 lists the center of the classes. The table illustrates the characteristics, based on their frequency within each class (i.e., the cluster center), which does not necessarily indicate that all DLT applications in each class obtain these characteristics.

A-Table 3: Overview of DLT application classes

Class (C)	**Definition**	**Number of DLT applications**
C1: The product traces	Enhancing product traceability in the supply chain	21
C2: The transportation ecosystem	Enabling an ecosystem to digitalize information flow in global transportation	9
C3: The supply chain supervision	Enhancing actor and process visibility in the upstream supply chain	7
C4: The SCF ecosystem	Enabling a financing ecosystem for supply chains	11

Class 1: The product traces

This class includes DLT applications that aim to facilitate the traceability of products by deploying DLT as an underlying IS. These DLT applications provide solutions for tracing the journey of products back along the supply chain. For these applications, the supply chain actors—mainly the physical actors such as producers, manufacturers, and retailers—store different data points for each product (e.g., production data, origin). The granularity of the term *product* may vary here. For instance, in the diamond and gemstone industry (e.g., Provenance Proof [52]), each stone is entered separately in the DLT application, while for solutions in the food or pharmaceutical industries (e.g., IBM Food Trust [53]), the information is mostly stored on a batch level. Therefore, the DLT applications require data from multiple databases (e.g., enterprise resource planning [ERP] systems) of the supply chain actors to be entered via APIs. Moreover, the applications require additional data gathering along the supply chains in order to build the basis for traceability. These data points are entered in the DLT, often stored off-ledger (e.g., in cloud systems), thereby allowing traceability at a later time.

Furthermore, a link between the physical product in the supply chain and the associated transactions in the distributed ledger is required. Thus, unique identifiers such as barcodes, QR codes, or RFID tags are used. For high-value goods such as diamonds, gemstones, and clothing, several DLT applications make use of advanced technologies such as nanoparticles with deoxyribonucleic acid (DNA) markers.[54] The combination of DLT-stored data and physical goods allows for the history of the product to be traced back and helps in case of recalls. In this way, DLT applications allow supply chain actors to know more about the product, react timely to recalls, and identify quality or sustainability issues. An interface to the end customer, often in the form of a mobile application, allows the provision of more information about a product's history, as well as sustainability and quality information at the point of sale. In this way, more transparency and trust are established.

In contrast to the other classes, traceability applications are characterized by the need for additional technology, product tags, end-customer interfaces, and the

[52] See https://www.provenanceproof.io/
[53] See https://www.ibm.com/blockchain/solutions/food-trust
[54] See https://www.provenanceproof.io/ and https://www.gubelingemlab.com/en/provenanceproof/emerald-paternity-test

product itself as underlying assets. The DLT applications are deployed mainly by physical supply chain actors and are limited to supply chains or industries, as they provide specific solutions, addressing the requirements of products (e.g., product tags) and the industry regulations (e.g., serialization in the pharmaceutical industry).

Class 2: The transportation ecosystem

This class clusters DLT applications that aim to digitalize processes of SCM, initially and mainly in transportation and logistics, by deploying DLT as an underlying IS. These DLT applications leverage the ability of DLT to be an immutable and distributed ledger for multiple organizations in the supply chain at the same time and at low cost. These DLT applications digitalize information and the associated rights that were previously available only physically, such as freight documents for different transportation modes (e.g., the bill of lading or airway bill). By digitizing these documents, associated processes can be carried out digitally, thereby speeding up these processes. For instance, TradeLens[55] allows the timely availability of customs documents to prepare inspections and approvals before shipments have arrived at the port of destination. These documents are uploaded in the distributed ledger and distributed to the respective stakeholders (e.g., trading partners, shippers, port operators, and customs authorities). The digital paper flow also enables the virtual transition of the ownership of the cargo.

In contrast to the other classes, digital transport ecosystems are designed to be ecosystems with a large number of diverse stakeholders and are not limited to the supply chains of a single company or industry. This is evidenced by the applications requiring the participation of both physical and support members as well as by the bidirectional information flow of the applications. Furthermore, the consortium permission right favored in such applications aim to balance transparency for the involved stakeholders and privacy from parties outside the transaction. While these DLT applications require little to no additional

[55] See https://www.tradelens.com/

technology, these applications build on the input of data from multiple systems of the different stakeholders. Moreover, the emergence of DAG applications in this class illustrates the need for an efficient way to process a large volume of transactions in near real-time on a large-scale network.

Class 3: The supply chain supervision

This class centers around the aim of making external supply chain actors and their processes visible by deploying DLT as an underlying IS. These DLT applications leverage the ability of DLT to provide data integrity, immutability, and traceability to the transaction data. In this way, the users of these DLT applications can rely on the data in the ledger to monitor, surveil, or evaluate their supply chain partners. The solutions enable the diverse processes of external supply chain partners to be visible. For instance, modum.io provides a DLT-based monitoring solution for the pharmaceutical industry to monitor the distribution process (mainly temperature compliance) of pharmaceuticals.[56] Specifically, these DLT applications promote the visibility of the transportation process. The solution implemented by modum.io includes the use of a sensor device (MODsense) to gather data points (i.e., temperature data) to evaluate compliance to regulations and quality procedures. Other DLT applications, such as Volvo's responsible sourcing application, provide visibility of suppliers' adherence to sustainability and corporate social responsibility practices.[57]

In contrast to other DLT applications, this class comprises applications that address the information need of downstream supply chain actors—mostly, buying companies. As the DLT applications enable visibility of diverse supply chain processes of external actors, multiple data sources are connected to the DLT applications. Therefore, the wide range of data points must be stored on off-ledger databases, such as cloud systems, while only the identifiers of actors and individual shipments are stored in the distributed ledger. The applications in this class and those of *the product trac*es (i.e., class 1) do certainly overlap, as they

[56] See https://modum.io/
[57] See https://www.rcsglobal.com/blockchain-traceability/

both provide visibility of upstream actors and, thus, also provide a minimum level of traceability. However, the difference lays in the focus on information related to the actors' practices and processes, as opposed to information about the products themselves. Therefore, no product tags are used in these DLT applications.

Class 4: The SCF ecosystem

This class includes DLT applications that aim to provide financial solutions (e.g., trade finance and working capital) using a DLT infrastructure. These applications leverage the security of data, data immutability, and the integrity of DLT to provide cost-efficient financing options for supply chain actors. Solutions providers such as we.trade enable their customers to digitally manage trade processes (including undertaking and financing) and payments.[58] Herein, the buyer and supplier, as well as their banks, are part of the ecosystem, which enables faster processes, such as bank verifications and undertakings. Especially for small and medium-sized enterprises, a lack of trust in new and foreign trading partners is a barrier for international transactions. Because the DLT ecosystem is used by all involved stakeholders, both trade partners can be provided with the undertaking, financing, and request payment easily and at a low cost.

In contrast to the other classes, SCF ecosystems require little investment on behalf of the users, as no additional technology is needed, no product tags are required, and, in most cases, data from a single database, the ERP system, is sufficient. As in the *transportation ecosystems* class, this class establishes an ecosystem with a large number of stakeholders (e.g., banks, insurances, suppliers, and buyers) in order to provide financing solutions. The stakeholders can interact in bilateral relations in the entire ecosystem, spanning different industries.

[58] See https://we-trade.com/

A-Table 4: Characteristics of DLT application classes

Dimension	**The product traces**	**The transportation ecosystem**	**The supply chain supervision**	**The SCF ecosystem**
Underlying protocols	BCT	BCT	BCT	BCT
Permission rights	Private	Consortium	Private	Private
Consensus mechanisms	Permissioned voting-based	Permissioned voting-based	Permissioned voting-based	Permissioned notary-based
Databases as sources for data input	Multiple	Multiple	Multiple	Single
Additional technologies for data gathering	Required	Not required	Not required	Not required
Tag with physical product	Required	Not required	Not required	Not required
Transaction space	Off-ledger	Off-ledger	Off-ledger	Off-ledger
Scope of participation network	Supply chain	Open	Industry	Open
Participating supply chain actors	Physical actors	Physical and support actors	Physical actors	Physical and support actors
Usage by end customer	Yes	No	No	No

Role as operator of nodes	Operated by individual actors	Operated by individual actors	Operated as a service	Not required
Underlying asset	Physical product	Information	Information	Financial resources
Main objective	Traceability of products	Digitalization of processes	Visibility of actors and processes	Financing and escrow
Industry	Food	Shipping	Automotive	Multiple industries
Scope of the application	Distribution	Transport and logistics	Procurement	SCF
Direction of objective	All	Upstream and downstream actors	Downstream supply chain actors	Upstream and downstream actors

Attributes of DLT as an underlying protocol

Based on the qualitative data analysis, the attributes resulting from DLT as an underlying IS for DLT applications were identified. A-Table 5 presents the attributes relevant for each class, briefly describes them, and allocates them to the six dimensions of the meta-characteristic *underlying technology* of the taxonomy that enable these attributes. While the focus is on DLT (the first three dimensions of the taxonomy in A-Figure 2), most attributes can only be achieved in combination with databases, additional technology, or product tags. However, the data analysis revealed that not all attributes are valid by default. In fact, the configuration of the underlying technology (with the six dimensions) is only decisive for the realization of several attributes. Thus, several attributes are conditional, depending on the configuration; in A-Table 5, these attributes are written in italics. Furthermore, in the last column of A-Table 5, the italic font characterizes the dimensions that affect the attribute. These dimensions constitute the corresponding dependable dimension to a specific attribute. The acronyms used in the last column are defined in A-Figure 2, above.

A-Table 5: Attributes based on DLT

Attributes	**Description**	**Classes**	**Enabling dimension**
Accessible data	Once data is entered in the distributed ledger (by databases or additional technology), it is accessible to all associated supply chain actors.	All	UP, PR, DI, AT
Integrity of data	Before data is entered correctly in the distributed ledger by databases or additional technology, it is checked for consistency and validated by the consensus mechanism to ensure integrity.	All	UP, *CM, DI, AT*
Immutable data	Once data is entered in the distributed ledger, it cannot be altered without approval via the consensus mechanism.	All	UP, *CM*
Decentralized data availability	Data in the ledger is available to all participating supply chain actors.	All	UP, PR
Automated data distribution	Depending on the permission rights, data is entered in the distributed ledger; it is distributed to all participating supply chain	All	UP, *PR*

	actors automatically via peer-to-peer communication.		
Standardized data formats	Data entered by databases and additional technologies must be in standardized formats, which are pre-defined and maintained in the distributed ledger.	All	UP, DI, AT
Processable data	Following the standardized formats, data in the distributed ledger can be transferred and processed in other applications of the supply chain actors.	All	UP
Traceable data	Transaction data in the DLT can always be traced by going back in the chain or graph, for all supply chain actors.	All	UP
Secure data	Data in the ledger and its transfer between participants in the distributed ledger is cryptographically encrypted and, thus, secured from the access of others.	All	UP, CM
Verifiable data	Only verified transactions (by consensus mechanism) are entered.	All	UP, CM

Scalable application (participants, data volume)	Depending on the underlying protocol, permission rights, consensus mechanisms, and transaction space, DLT applications enable the onboarding of more participating supply chain actors and process a greater transaction volume in the supply chain.	1, 2, 4	*UP, PR, CM*, *TS*, DI, AT
Integrable data	DLT enables the integration of various data points from different sources of supply chain actors and link these to a specific transaction in the ledger.	1, 2, 3	UT, DI, AT,
Expandable application (objectives, functions)	Depending on the underlying protocol, permission rights, consensus mechanism, and transaction space, more functions of DLT applications can be added to expand their applicability for other supply chain tasks.	1, 2, 4	*UT, PR, CM, TS,* DI, AT

Real-time data distribution	Once data are entered in the distributed ledger by databases or additional technology, they are directly distributed to the participating supply chain actors, enabling the option for near real-time data distribution.	2	UP, *DI, AT*

Next, a closer look at the conditional attributes is presented. Based on the qualitative data analysis, the specific characteristics that affect the attributes are revealed. The attribute *integrity of data* depends on the concrete realization of the consensus mechanism, the databases (as sources for data input), and the additional technologies (for data gathering). First, for permissioned voting–based and permissioned notary–based consensus, not all network participants can ensure data integrity. Instead, pre-defined network members (for permissioned voting) or assigned notaries (permissioned notary) ensure integrity. However, individual supply chain actors hand over the power to these representatives. In a proof-of-work or DAG consensus, each network participant ensures data integrity when confirming previous transactions as the network participant enters new transactions. Second, the integrity of the input data depends on the integrity of the databases and additional technologies of the corresponding supply chain actors; this is what one interviewee referred to as the "garbage in, garbage out" problem.

The attribute *immutable data* depends on the consensus mechanism as well. As described above, the handover of the power to pre-defined network members or assigned notaries affects immutability as well. New transactions can be added that change previous transactions, based on the consensus of these members or notaries. Thus, the supply chain actors that do not participate in the consensus mechanism have no control over the immutability of data in the distributed ledger.

The attribute *automated data distribution* depends on the permission rights within the DLT network. As the permission rights determine the scope of participants that have read and write access, they also define the distribution of data. In public DLTs, transactions are automatically communicated to the entire network. In private or consortium DLTs, this is not the case by default. Instead, only the stakeholders in a transaction and the stakeholders that perform the consensus (i.e., pre-defined participants or assigned notaries) get the transaction update. Thus, the data distribution is restricted in these DLTs. As one interviewee stated, “Only the involved parties will see these transactions; these are communicated in a private channel” (BCT specialist of class 2).

The attribute *scalable application* depends on the configuration of the underlying protocol, permission rights, consensus mechanism, and transaction space. The distinct underlying protocol and the consensus mechanism define the number of transactions per second and, thus, the latency. For example, the Bitcoin blockchain has a capacity of 7 transactions per second, while IOTA’s Tangle allows between 500 and 800 transactions per second. Furthermore, DLTs that are limited to on-ledger transactions are limited in terms of storage capacity and, as such, allow a smaller number of transactions per second; this is because the size of a transaction increases if all the data is stored in the ledger. Moreover, it is easy to onboard new supply chain actors in public DLTs, while consortium and private DLTs require the agreement of the established network in the form of a permission for such onboarding.

The attribute *expandable application* depends on the configuration of the underlying protocol, permission rights, consensus mechanism, and transaction space. As A-Table 4 illustrates, DLTs in the *transportation ecosystems* class are built on consortiums, and those in the *SCF ecosystems* class favor permissioned notary–based consensus; as such, the dimensions permission rights and consensus mechanism have to be designed to enable expendability. Furthermore, the underlying protocol defines the transaction volume, as described above. Thus, the expandability, which leads to additional transaction volumes, depends on the underlying protocol as well. This volume must be processed, which favors DLTs that enable off-ledger transactions. As several interviewees in classes 1, 2, and 4 disclosed, the configuration of the underlying technology in their DLT applications was driven by the plan to expand the applications in the future.

The attribute *real-time data distribution*—or, more accurately, near real-time data distribution[59]—is only applicable if the databases (as sources for data input) and the additional technologies (for data gathering of the corresponding supply chain actors) enable this feature. If this technical infrastructure is not established or not supported, neither the *product tracing* nor *transportation ecosystems* class can leverage this attribute, and they must instead have only limited traceability and availability of digital documents. One interviewee summarized this dependency as follows: "The blockchain enables an immediate communication of transactions to the partners. […]. However, we and our partners have to ensure that our technical infrastructure is in place. We worked with several interfaces to upload the relevant data" (supply chain coordinator of class 1).

Discussion

A-Table 5 is not merely an unrelated accumulation of attributes; instead, the attributes jointly enable specific value contributions of DLT applications. The participation structure and the targeted task moderate the enabling effect of the attributes. The following sub-sections discuss the results of the connection of these attributes in specific classes of DLT applications and the moderating role of the structure and task.

Enhancing transparency

The ability of DLT to enhance *data accessibility* and to enable *automated data distribution* leads to *decentralized data availability*. The combination of these three attributes results in DLT, as an underlying technology for SCM applications, enabling supply chain actors to gain visibility in supply chains. Moreover, as represented in the *traceability of data* dimension, the application of DLT enables traceability in supply chains. All four classes draw on these characteristics and, thus, build on visibility and traceability. Furthermore, *real-time data distribution*

[59] Transferring and entering data into a distributed ledger results in a time lag of multiple seconds or minutes.

allows ledgers to be kept constantly up to date, which, in turn, facilitates real-time visibility and traceability, used in class 2.

In their studies, Babich and Hilary (2019), Hald and Kinra (2019), and Wang et al. (2019) identify BCT's improvement of visibility and traceability. In line with Morgan, Richey and Ellinger (2018), visibility and traceability represent enablers for TSC. Furthermore, previous SCM scholars such as Williams et al. (2013) and Srinivasan and Swink (2018) indicate that, in general, data availability and data accessibility are antecedents to TSC, thus suggesting that DLT enhances TSC

However, A-Table 5 emphasizes that *automated data distribution* is a conditional attribute. For all four classes, this is a relevant attribute for the associated DLT applications, as illustrated in A-Table 5. Using this logic, visibility and traceability are not value contributions of all DLT applications, per se; only public DLTs lead to this value contribution by default. For consortium and private DLTs, visibility is limited to specific stakeholders. When revisiting the characteristics of the classes in A-Table 4, not all the classes lead to enhanced visibility and traceability, as the representative of these classes are mostly private or consortium DLTs. In particular, the *product traces* and *supply chain supervision* classes, which aim to enhance TSC, must be designed properly to achieve TSC through the use of DLT. Thus, a closer look at the distribution of data must be taken to evaluate a DLT application regarding the value contributions of traceability, visibility, and transparency. *Real-time data distribution* is also a conditional attribute. With regard to class 2, the value contribution of real-time traceability and visibility depends on the databases and additional technologies in the supply chains as well.

Enabling authenticity and trust

The *integrity of data*, *immutability of data*, *verifiability of data*, and *security of data* are attributes that are relevant to all classes. SCM and IS scholars have, in particular, elaborated on the immutability, verifiability, and integrity of data in distributed ledgers (e.g., Beck et al. 2016; Abeyrath and Monfared 2016; Wang et al. 2019). The combination of these attributes enables authenticity, another value contribution of DLTs. However, both the *integrity of data* and *immutability of data* are conditional attributes, as both depend on the deployed consensus mechanism of the DLT. In permissioned voting–based and permission notary–based consensus mechanisms, immutability and integrity depend on individual stakeholders (i.e., the voting stakeholders or notaries). Moreover, the integrity of data is also dependent on the databases and additional technologies, illustrated by the "garbage-in, garbage-out" problem. Kshetri (2018) and Babich and Hilary (2019) point out this problem as well.

When combining transparency and authenticity, trust can be reached as an additional value contribution of DLT applications. While transparency reveals information about actors, processes, and products in the supply chain, authenticity helps in building confidence in this information. As trust is an important topic in SCM (e.g., Ireland and Webb 2007; Kwon and Suh 2004; Schnackenberg and Tomlinson 2014), the fact DLT can foster trust is another value contribution, which all four classes of DLT applications in supply chains build on. However, the conditional attributes indicate that a detailed analysis of the consensus mechanism, the input databases, and the additional technologies of specific DLT applications are required.

Building an inter-organizational information system

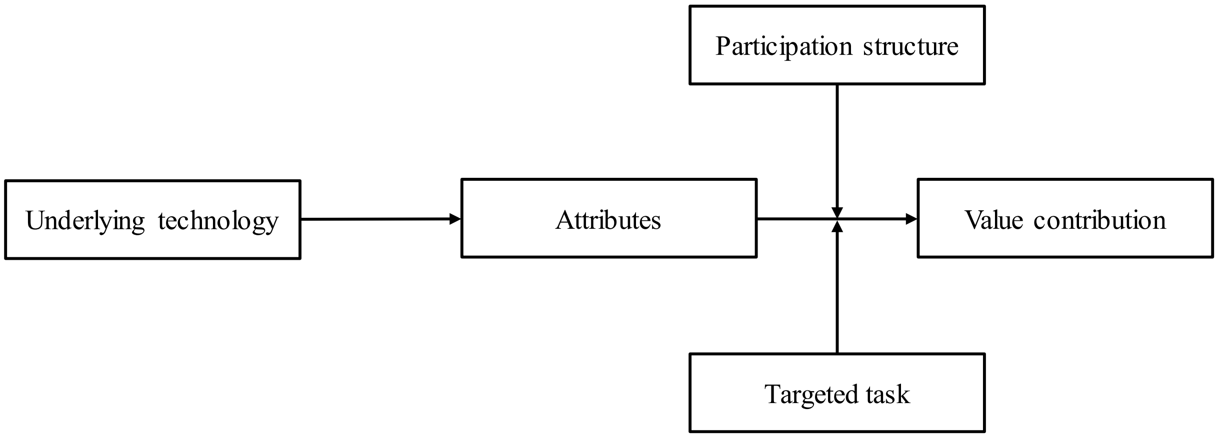
While the attributes *standardized data formats* and *processable data* are relevant for all classes, *integrable data* is relevant only for classes 1, 2, and 3. These attributes have been overlooked in the existing literature on DLT in supply chains. Only a few contributions, such as Kurpjuweit et al. (2019) and Babich and Hilary (2019), discuss standardization in DLT. However, the combination of the three attributes illuminates the nature of DLT in supply chains. In line with the definitions of *IOIS* by Johnston and Vitale (1988) and Lyytinen and Damsgaard (2011), the DLTs in classes 1, 2, and 3 are forms of IS that are jointly used by multiple supply chain actors with shared functionalities, to store and distribute information across organizations. In this way, the supply chain actors make use of standardized data formats, processable data, and integrable data to process information in the supply chain. Hence, these DLTs in classes 1, 2, and 3 are IOIS, building the basis for the applications and ecosystems. By revisiting A-Table 4, classes 1, 2, and 3 underline the nature of DLT as IOIS. While class 4 does not require the ecosystem participants to operate nodes, classes 1, 2, and 3 have nodes operated by several supply chain actors via services or directly by individual supply chain actors.

Establishing ecosystems

The attributes *scalable application* and *expendable application* are relevant for classes 1, 2, and 4. In combination, these attributes illustrate the nature of these classes to deploy DLT as an underlying technology to build a scalable and expendable ecosystem, with an increasing number of participants and a growing variety of functions. While classes 2 and 4 represent DLT applications that are already ecosystems for transportation and SCF, the DLT applications in class 1 are aspiring to build on existing functionalities by developing more functionalities. However, both scalability and expandability depend on the adequate protocol, permission right and consensus mechanism to cope with a larger number of participants, transactions, and diverse functionalities. This aspect must be addressed in future research in SCM.

The role of participation structure and targeted task on the four value contributions

A-Table 5 illustrated the relationship between the underlying technology, the first meta-characteristic of the taxonomy, and the attributes. Furthermore, in this section, the relationship between these attributes and the value contributions was derived. However, the participation structure and the targeted task, the second and third meta-characteristics of the taxonomy affect the chain of effects as well. Both the participation structure and the targeted task moderate the relationship between the attributes and the value contributions. First, the participation structure defines the range of value contributions. The dimensions scope of participation network, participating supply chain actors, and usage by end customer define the actors that will benefit from the value contributions. For instance, the dimension participating supply chain actors is decisive whether transparency (visibility or traceability) on products, actors and processes regarding physical or also support actors is enhanced. In the same way, the scope of participation network and the usage of end customers moderate the value contributions and define the scope of their validity. Moreover, the meta-characteristic targeted task moderates the relationship between attributes and value contributions concerning the underlying assets, main objective, industry, scope of application, and direction of objective. For instance, the direction of objective defines the scope of DLT as an IOIS. In conclusion, the following framework in A-Figure 3 is developed that illustrates the identified relationships in this study.



A-Figure 3: Framework of DLT applications and their chain of effects

Conclusion

Following a DSR approach, a taxonomy of DLT applications in the supply chain was developed, based on 48 DLT projects in the field of SCM. Furthermore, the study identified four distinct classes of current DLT applications in SCM. These homogenous classes were further characterized by the inherent attributes in these applications. Based on these attributes, the value contributions of DLT in terms of transparency, authenticity, trust, enabling ecosystems, and IOIS infrastructure were discussed on the level of the distinct DLT applications. Moreover, the study sheds light into the chain of effects of DLT applications in supply chains, by developing A-Figure 3 as explanatory framework.

Managerial implications

The study has two managerial implications. First, the taxonomy of DLT applications—visualized in a morphological box—allows supply chain managers to gain a deeper understanding of the emerging technology and its application in SCM. The meta-characteristics of the taxonomy guide practitioners to divide DLT applications into three elements: underlying technology, participation structure, and targeted task. Furthermore, the taxonomy illustrates the existing diversity in terms of potential configurations, and, in this way, helps in evaluating specific DLT configurations in a more detailed fashion.

Second, the taxonomy, attributes, and value contributions enable managers to design tailored DLT applications. In so doing, each of the three meta-characteristics must be addressed, and managers must design and assess different technology configurations in terms of the fit for their application. To help managers achieve this, this study guides them to select the appropriate protocol, consensus mechanism, etc. to cope with the number of transactions, their complexity, and nature of the tasks. Furthermore, the characterization of the participation network helps to identify important partners early on and launch collaborative measurements. The third meta-characteristics guides managers to precisely define the characteristics of the targeted task.

Theoretical implications

Aside from the managerial implications, the study reveals three theoretical implications. First, the taxonomy and the identified classes allow researchers to conduct empirical studies with homogenous units of observations. Given the relative scarcity of DLT projects in the field of SCM, this will help to design qualitative studies, such as case studies. Furthermore, the characterization helps in interviews with experts and in allowing the precise definition of relevant DLT applications. In this way, the study paves the way for more empirical research on the level of specific DLT applications. Second, the study helps in discussing DLT applications in detail. For example, the taxonomy, attributes, and value contributions facilitate a discussion of the adoption decisions of specific DLT applications. As evidenced by the archetypal characteristics in A-Table 4, the four classes reveal different characteristics that lead to different adoption contexts. Third, the study develops a framework that illustrates the chain of effects of DLT applications. The framework in A-Figure 3 enables future research to focus on specific relationships in this framework.

Limitations and future research

The study has three limitations. First, the data on the majority of the 48 DLT applications were collected from secondary sources. Although interviews were also used to triangulate the data, not all data from webpages, conference presentations, etc. related to the 48 DLT applications could be verified by triangulation. Furthermore, several characteristics are subject to change. For instance, the Ethereum blockchain changed its consensus mechanism from PoW to permissioned voting, which was taken into account here, but as the technology will mature and future developments will arise, new characteristics within these dimensions will be required. Thus, future research should take this dynamic into account and should validate the characteristics within the taxonomy when applying it.

Second, although the attributes and value contributions were derived from multiple interviews and secondary data, they were not measured or quantified. As more DLT applications will be implemented, future research should strive to measure and quantify these attributes and the resulting value contributions. However, the developed taxonomy can help researchers to identify appropriate cases in which to analyze the attributes and value contributions.

Third, the framework in A-Figure 3 illuminates the effects of the three elements of STS on the attributes and value contributions of DLT applications in supply chains. Following the notion of STS, the relations between these three elements, which was not studied and should be addressed in future studies. While the dimensions in the taxonomy are interdepend per definition of a taxonomy, the four classes in the cluster analysis reveal cluster centers that represent the frequent configurations. Future research can study why these frequencies occur.

Appendix

A. Interview instrument

General information:

- Introduction, position and job description.
- Company information, supply chain overview.

Description of DLT application:

- Please describe the DLT application.
- What is the main objective of the DLT application?
- Please describe the underlying DLT (Protocol, consensus mechanism, permission right).
- Please also describe the additional technologies deployed in the DLT application.
- Who is participating in the DLT application and who will participate in the future?
- Please describe the roles of the individual actors that participate?

Exploration of attributes:

- Please describe the relevant attributes of the DLT application in regard to the underlying DLT.
- What are the technological sources of these attributes?
- Are additional technologies needed to attain these attributes?
- Please reflect if the attributes are related?

B. Interview overview

Class	Sample number	Position of interviewees	Type of actor
1	1	Managing Director, Head of Research and Development	User
		Vice President, Head of Communications	Provider
	12	Supply Chain Coordinator	User
		Business Architect	Provider

	14	Business Developer	Provider
	23	Supply Chain and Logistics Manager	User
	26	Head of Outbound Distribution	User
		Supply Chain Specialist	Provider
2	3	Business Developer	Provider
	9	Supply Chain Solution Architect	Provider
	24	Vice President Supply Chain Management, Logistics Officer	User
		Solution Architect	Provider
	42	Project Leader	User
3	5	Supply Chain Innovation Specialist	User
	6	Head of Quality Management	User
		Business Architect	Provider
	34	CEO, COO	Provider
		Head of Supply Chain Management	User
	46	COO	Provider
4	8	CFO	User
	17	Project Manager, Trade Expert	User
	31	Export Manager	User
		CMO	Provider
	38	Project Leader	User

Note: The sample number indicates the number of interviews on an individual DLT application. Multiple positions of interviewees reflect that the interviews were conducted with two interviewees from the same actor. The last column describes whether the interviewees were employed by a technical solution provider (Provider) or a supply chain actor using the DLT application (User).

References

Abeyrath, S., and Monfared, R. P. 2016. Blockchain ready manufacturing supply chain using distributed ledger. *International Journal of Research in Engineering and Technology* 05 (09): 1–10.

Babich, V., and Hilary, G. 2019. Distributed ledgers and operations: What operations management researchers should know about blockchain technology. *Manufacturing & Service Operations Management* Forthcoming.

Beck, R., Stenum Czepluch, J., Lollike, N., and Malone, S. 2016. Blockchain: The gateway to trust-free cryptographic transactions. In *Proceedings of the 24th European Conference on Information Systems (ECIS)*, 1–14. 24th European Conference on Information Systems (ECIS), Istanbul, Turkey. June 12 - 15, 2016.

Benčić, F. M., and Žarko, I. P. 2018. Distributed ledger technology: Blockchain compared to directed acyclic graph. In *Proceedings of 2018 IEEE 38th International Conference on Distributed Computing Systems*, 1569–1570. IEEE 38th International Conference on Distributed Computing Systems (ICDCS), Vienna, Austria. 2 - 5 July, 2018.

Blossey, G., Eisenhardt, J., and Hahn, G. 2019. Blockchain technology in supply chain management: An application perspective. In *Proceedings of the 52nd Hawaii International Conference on System Sciences.* 52nd Hawaii International Conference on System Sciences, Maui. January 8-11.

Bostrom, R. P., and Heinen, J. S. 1977a. MIS problems and failures: A socio-technical perspective. Part I: The causes. *MIS Quarterly* 1 (3): 17–32.

Bostrom, R. P., and Heinen, J. S. 1977b. MIS Problems and Failures: A Socio-Technical Perspective, Part II: The Application of Socio-Technical Theory. *MIS Quarterly* 1 (4): 11–28.

Bottone, M., Raimondi, F., and Primiero, G. 2018. Multi-agent based simulations of block-free distributed ledgers. In *Proceedings of the 32nd International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, 585–590. 32nd International Conference on Advanced Information Networking and Applications Workshops (WAINA), Krakow, Poland. 16 - 18 May, 2018.

Cao, B., Zhang, Z., Feng, D., Zhang, S., Zhang, L., Peng, M., and Li, Y. 2020. Performance analysis and comparison of PoW, PoS and DAG based blockchains. *Digital Communications and Networks* forthcoming.

Carter, C. R., Rogers, D. S., and Choi, T. Y. 2015. Toward the theory of the supply chain. *Journal of Supply Chain Management* 51 (2): 89–97.

Casey, M. J., and Wong, P. 2017. Global supply chains are about to get better, thanks to blockchain. *Harvard Business Review*.

Christidis, K., and Devetsikiotis, M. 2016. Blockchains and smart contracts for the internet of things. *IEEE Access* 4:2292–2303.

Clegg, C. W. 2000. Sociotechnical principles for system design. *Applied Ergonomics* 31 (5): 463–477.

Durach, C. F., Blesik, T., Düring, M. von, and Bick, M. 2020. Blockchain applications in supply chain transactions. *Journal of Business Logistics* forthcoming.

Fawcett, S. E., Waller, M. A., and Bowersox, D. J. 2011. Cinderella in the c-suite: Conducting influential research to advance the logistics and supply chain disciplines. *Journal of Business Logistics* 32 (2): 115–121.

Ganne, E. 2018. Can blockchain revolutionize international trade? https://www.wto.org/english/res_e/publications_e/blockchainrev18_e.htm. Accessed 24 March 2020.

Glaser, B. G. 1992. *Basics of grounded theory analysis.* Mill Valley, CA: Sociology Press.

Hald, K. S., and Kinra, A. 2019. How the blockchain enables and constrains supply chain performance. *International Journal of Physical Distribution & Logistics Management* 49 (4): 376–397.

Harbert, T. 2020. Blockchain for business starts in the supply chain. https://mitsloan.mit.edu/ideas-made-to-matter/blockchain-business-starts-supply-chain. Accessed 6 February 2020.

Hevner, A. R. 2007. A three cycle view of design science research. *Scandinavian Journal of Information Systems* 19 (2): 87–92.

Hofmann, E., Omran, Y., Henke, M., and Heines, R. 2017. Blockchain-driven supply chain finance: Towards a conceptual framework from a buyer perspective. In *International Purchasing and Supply Education and Research Association (IPSERA) 2017*, 1–15, Budapest - Balatonfüred. April 09-12.

Hofmann, E., Strewe, U., and Bosia, N. 2018. *Supply chain finance and blockchain technology.* Cham: Springer International Publishing.

Ireland, R. D., and Webb, J. W. 2007. A multi-theoretic perspective on trust and power in strategic supply chains. *Journal of Operations Management* 25 (2): 482–497.

Johnston, H. R., and Vitale, M. R. 1988. Creating competitive advantage with interorganizational information systems. *MIS Quarterly* 12 (2): 153–165.

Kaufman, L., and Rousseeuw, P. J. 2009. *Finding groups in data: An introduction to cluster analysis:* John Wiley & Sons.

Kim, H. M., and Laskowski, M. 2018. Toward an ontology-driven blockchain design for supply-chain provenance. *Intelligent Systems in Accounting, Finance and Management* 25 (1): 18–27.

Kolb, J., Becker, L., Fischer, M., and Winkelmann, A. 2019. The role of blockchain in enterprise procurement. In *Proceedings of the 52nd Hawaii International Conference on System Sciences*, 4575–4584. 52nd Hawaii International Conference on System Sciences, Maui. January 8-11.

Korpela, K., Hallikas, J., and Dahlberg, T. 2017. Digital supply chain transformation toward blockchain integration. In *Proceedings of the 50th Hawaii International Conference on System Sciences*, 4182–4191, Hawaii.

Kshetri, N. 2018. Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management* 39:80–89.

Kull, T. J., Ellis, S. C., and Narasimhan, R. 2013. Reducing behavioral constraints to supplier integration: A socio-technical systems perspective. *Journal of Supply Chain Management* 49 (1): 64–86.

Kurpjuweit, S., Schmidt, C. G., Klöckner, M., and Wagner, S. M. 2019. Blockchain in additive manufacturing and its impact on supply chains. *Journal of Business Logistics* forthcoming:1–25.

Kwon, I.-W. G., and Suh, T. 2004. Factors affecting the level of trust and commitment in supply chain relationships. *Journal of Supply Chain Management* 40 (1): 4–15.

Lee, S. 2018. Explaining directed acyclic graph (DAG): The real blockchain 3.0. https://www.forbes.com/sites/shermanlee/2018/01/22/explaining-directed-acylic-graph-dag-the-real-blockchain-3-0/#4fc84b46180b. Accessed 9 June 2019.

Lerner, S. D. 2015. DagCoin Draft. https://bitslog.files.wordpress.com/2015/09/dagcoin-v41.pdf. Accessed 9 June 2019.

Lyytinen, K., and Damsgaard, J. 2011. Inter-organizational information systems adoption – a configuration analysis approach. *European Journal of Information Systems* 20 (5): 496–509.

Manupati, V. K., Schoenherr, T., Ramkumar, M., Wagner, S. M., Pabba, S. K., and Inder Raj Singh, R. 2019. A blockchain-based approach for a multi-echelon sustainable supply chain. *International Journal of Production Research* 1–20.

Morgan, T. R., Richey, R. J. G., and Ellinger, A. E. 2018. Supplier transparency: Scale development and validation. *International Journal of Logistics Management* 4 (1): 959–984.

Nærland, K., Müller-Bloch, C., Beck, R., and Palmund, S. 2017. Blockchain to rule the waves: Nascent design principles for reducing risk and uncertainty in decentralized environments. *Proceedings of the International Conference on Information Systems (ICIS) 2017*.

Nickerson, R. C., Varshney, U., and Muntermann, J. 2013. A method for taxonomy development and its application in information systems. *European Journal of Information Systems* 22 (3): 336–359.

Pawczuk, L., Massey, R., and Schatsky, D. 2018. Breaking blockchain open: Deloitte's 2018 global blockchain survey. Accessed 19 April 2019.

Pawczuk, L., Massey, R., and Holdowsky, J. 2019. Deloitte's 2019 global blockchain survey: Blockchain gets down to business. https://www2.deloitte.com/us/en/insights/topics/understanding-blockchain-potential/global-blockchain-survey.html. Accessed 27 January 2020.

Rauchs, M., Blandin, A., Bear, K., and McKeon, S. 2019. 2nd global enterprise blockchain benchmarking study.

Saberi, S., Kouhizadeh, M., Sarkis, J., and Shen, L. 2019. Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research* 57 (7): 2117–2135.

Schmahl, A., Mohottala, S., Burchardi, K., Egloff, C., Govers, J., Chan, T., and Giakoumelos, M. 2019. Resolving the blockchain paradox in transportation and logistics. https://www.bcg.com/publications/2019/resolving-blockchain-paradox-transportation-logistics.aspx. Accessed 21 August 2019.

Schmidt, C. G., and Wagner, S. M. 2019. Blockchain and supply chain relations: A transaction cost theory perspective. *Journal of Purchasing and Supply Management* 25 (4): 100552.

Schnackenberg, A. K., and Tomlinson, E. C. 2014. Organizational transparency: A new perspective on managing trust in organization-stakeholder relationships. *Journal of Management* 42 (7): 1784–1810.

Srinivasan, R., and Swink, M. 2018. An investigation of visibility and flexibility as complements to supply chain analytics: An organizational information processing theory perspective. *Production and Operations Management* 27 (10): 1849–1867.

Sternberg, H., Hofmann, E., and Roeck, D. 2020. The struggle is real: Insights from a supply chain blockchain case. *Journal of Business Logistics* Forthcoming.

Swan, M. 2015. *Blockchain: Blueprint for a new economy.* Beijing: O'Reilly.

Tapscott, D., and Tapscott, A. 2016. The Impact of the blockchain goes beyond financial services. *Harvard Business Review*.

Thake, M. 2018. Blockchain vs. DAG technology: A brief comparison. https://medium.com/nakamo-to/blockchain-vs-dag-technology-1a406e6c6242. Accessed 9 June 2019.

The Linux Foundation. 2020. Hyperledger architecture: Volume 1. https://www.hyperledger.org/resources/publications. Accessed 20 March 2020.

Tian, F. 2016. An agri-food supply chain traceability system for China based on RFID & blockchain technology. In *13th International Conference on Service Systems and Service Management (ICSSSM).* 13th International Conference on Service Systems and Service Management (ICSSSM).

Urquhart, C. 2013. *Grounded theory for qualitative research. a practical guide. Cathy Urquhart.* London: SAGE.

Wang, Y., Han, J. H., and Beynon-Davies, P. 2018. Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. *Supply Chain Management: An International Journal* 24 (1): 62–84.

Wang, Y., Singgih, M., Wang, J., and Rit, M. 2019. Making sense of blockchain technology: How will it transform supply chains? *International Journal of Production Economics* 211:221–236.

Weking, J., Mandalenakis, M., Hein, A., Hermes, S., Böhm, M., and Krcmar, H. 2019. The impact of blockchain technology on business models – a taxonomy and archetypal patterns. *Electronic Markets*.

White, G. R. T. 2017. Future applications of blockchain in business and management: A Delphi study. *Strategic Change* 26 (5, SI): 439–451.

Williams, B. D., Roh, J., Tokar, T., and Swink, M. 2013. Leveraging supply chain visibility for responsiveness: The moderating role of internal integration. *Journal of Operations Management* 31 (7-8): 543–554.

Yli-Huumo, J., Ko, D., Choi, S., Park, S., and Smolander, K. 2016. Where is current research on blockchain technology? A systematic review. *PloS one* 11 (10): e0163477.

Zhao, J. L., Fan, S., and Zheng, E. 2018. Blockchain-enabled trust: The case of inter-firm dataflow. In *AMCIS 2018 Proceedings.* 24th American Conference on Information Systems, New Orleans, LA. August 16 - 18, 2018.

Appendix B – Study 2

Decomposition of transparency in supply chains: An information processing perspective

Dominik Roeck[a], Erik Hofmann[a] and Dale S. Rogers[b]

[a] Institute of Supply Chain Management, University of St.Gallen, Switzerland

[b] W.P. Carey Business School, Arizona State University, USA

Submitted to Journal of Supply Chain Management

Abstract

Focal companies are trying to enhance transparency in the supply chain (TSC), as the phenomenon gains importance. However, research lacks to provide an integrative view on TSC that elucidates how focal companies can enhance TSC. To address this gap, we apply a multiple-case study design to build an integrative framework of TSC that draws on information processing theory as a theoretical lens, which allows elucidating both the capabilities and process to enhance TSC. The findings of our case study reveal a deep dive into the common ground of 24 award-winning and industry-wide best practice solutions for enhanced TSC. We find that, to enhance TSC, the focal company needs to establish a fit between its needs and its capabilities by deploying tailored TSC mechanisms. Furthermore, the deployment of these TSC mechanisms requires between 12 and 19 TSC determinants, which have to be attained by the focal company and the corresponding supply chain actors. We reveal that the focal company and the corresponding supply chain actors must therefore build up information technology, structures, and processes to enable these determinants. In addition, we find that multiple context factors affect the deployment of TSC mechanisms. By synthesizing these findings, we explore how focal companies can enhance TSC and elaborate on information processing theory in the context of TSC.

Keywords: *transparency; visibility; traceability; information processing theory; sustainability; supplier management; case study research*

Introduction

Transparency in the supply chain (TSC) has become an important topic in both research and industry (Kim & Davis, 2016; Morgan, Richey, & Ellinger, 2018). The ability to enhance transparency on supply chain operations becomes more and more important due to globalization, international division of labor and outsourcing decisions by firms from around the world (Min, Zacharia, & Smith, 2019; Swift, Guide Jr., & Muthulingam, 2019). The negative impacts of a lack of transparency have been emphasized in recent examples such as Evonik's explosion in 2012[60] (Yan, Choi, Kim, & Yang, 2015) and Chipotle's E. coli outbreak in 2015[61] (Saberi, Kouhizadeh, Sarkis, & Shen, 2019). As a result, decision-makers are seeking to enhance transparency in processes outside of their organizational boundaries, while end-consumers and investors are demanding more traceability on a product's journey through the supply chain (Gross, 2019). This forces organizations to identify critical suppliers and sub-suppliers (actors) in their supply chain to avoid poor brand awareness. An example is the case of Cargill, an agricultural heavyweight, that earned the dubious honor of being "the worst company in the world" (Mighty Earth, 2019) after quickly turning from a company with laudable standards into the "devil's advocate" (Yaffe-Bellany, 2019). Given the footprint of Cargill, food retailers and restaurants such as McDonald's are affected and endangered by the practices of their supplier or even sub-supplier and thus seeking to enhance TSC to identify problems in their supply chain. Thus, the goal of this study is to explore TSC based on a multiple-case study to help organizations enhance TSC.

Despite its relevance, the phenomenon of TSC is still understudied in the field of operations management (OM) and supply chain management (SCM) (Wieland, Handfield, & Durach, 2016). Those authors rank TSC as the fourth most relevant but understudied topic in OM and SCM, as the number of contributions on TSC

[60] In 2012, an explosion at an Evonik Industries site disrupted the entire automotive industry, as Evonik produced 50% of all PA 12 worldwide. The dependency was not known to most original equipment manufacturers.

[61] In 2015, two E. coli outbreaks infected 58 customers of Chipotle Mexican Grill Restaurants. The chain was unable to monitor its suppliers and withdraw the infected products from its restaurants.

is increasing but fragmented. To date, contributions have focused on selected facets of the phenomenon, such as conflict mineral disclosure (Swift et al., 2019), supplier transparency (Morgan et al., 2018), or visibility and flexibility as complements to analytics in the supply chain (Srinivasan & Swink, 2018). Thus, the overall picture of TSC remains fragmented. Moreover, the phenomenon lacks clear operationalization, which leads to misuse and makes it ill-defined, according to Williams, Roh, Tokar, and Swink (2013). Newly emerging digital technologies, such as distributed ledger technologies (DLT), the internet of things (IoT), artificial intelligence (AI), and digital twins, hold promise to impact and improve TSC (Hofmann, Sternberg, Chen, Pflaum, & Prockl, 2019). For example, some DLT pilot projects appear to be weak applications of DLT, aiming to enhance TSC (Wang, Han, & Beynon-Davies, 2018). These weak applications may also be due to the fact that academic scholars have come short of providing practitioners with an understanding of what it takes to enhance TSC and present a framework to assess the contribution of digital technologies such as DLT, IoT or AI to enhance TSC. Swift et al. (2019) outline this lack of an integrative framework as a research gap: "[…] we did not directly observe how firms improved their SCV [supply chain visibility]. It would be interesting to understand what specific steps firms take to improve SCV and analyze how each contributes to improved operating performance" (p. 426). Hence, we are lacking transparency on the enhancement of TSC, as visibility can be understood as a part of TSC (Morgan et al., 2018). The current research aims to fill this void by answering the following research question (RQ):

RQ: How can focal companies enhance transparency in the supply chain?

In order to address the RQ, it is necessary to gain a clear picture of the TSC phenomenon by examining focal companies' motivation to enhance TSC, the deployment of solutions to enhance TSC, and the resulting level of TSC. The RQ leads to the exploration of the TSC determinants, which represent attributes to be fulfilled in order to enhance TSC from the perspective of the focal company. As the phenomenon of TSC is complex and lacks an integrative view, we apply an inductive multiple-case study to answer the RQ based on in-depth data. Specifically, we study 24 different cases that were identified as award-winning or industry-wide good practice solutions for enhancing TSC to explore the common ground on the TSC determinants to enhance TSC for the focal company. We mainly apply information processing theory (IPT) as a theoretical lens to dive deep and explain how organizations can enhance TSC. After reviewing the literature and describing our research approach, we present the mechanisms for enhancing TSC and identify the relevant TSC determinants for each TSC mechanism. Then, we use abductive reasoning by drawing on extant literature to develop a framework of TSC from the perspective of the focal company to answer our RQ. Herein, we derive five propositions regarding the relationships between the core elements of TSC. Thereby, we contribute a mid-range theory on the phenomenon of TSC. We conclude by summarizing our findings and providing suggestions for future research.

Literature Background

Transparency research in supply chains

Physically, transparency can be defined as an optical property of an object (i) that can be seen through and that allows the appearance of a second object (ii) behind the first object (i). Practitioners and academic scholars in the field of SCM apply this definition in a metaphorical way. Our field of study defines the organizational boundary as object (i), given the state that a focal company is generally unable to see through the organizational boundary of external supply chain actors (e.g., suppliers, sub-suppliers, or logistics service providers), revealing their key characteristics, the affiliated processes and the products as object (ii). From this perspective, TSC refers to a state of an inter-organizational supply chain network or part of a network that enables an element behind the organizational boundary to be visible from the perspective of a focal company. SCM scholars (e.g., Williams et al., 2013) tend to agree on the inter-organizational nature of TSC, which means that the object of interest is situated outside of the sphere of the focal company in another node (e.g., an organization including its characteristics) or along an edge (e.g., in transit). However, SCM scholars vary their focus, as they study TSC in upstream (e.g., Morgan et al., 2018) and downstream directions (e.g., Jin, Williams, Tokar, & Waller, 2015), with the focus on products (e.g., Aung & Chang, 2014) or processes (e.g., Steinfield, Markus, & Wigand, 2011) within the supply chain. In addition, they discuss TSC in various contexts, including improvement of decision-making (Kent & Mentzer, 2003), risk mitigation (Basole & Bellamy, 2014), responsiveness (Williams et al., 2013), product safety (Costa, Antonucci, Pallottino, Aguzzi, Sarriá, & Menesatti, 2013), collaboration (Holweg, Disney, Holmström, & Småros, 2005), and sustainability (Carter & Rogers, 2008).

The broadness of foci and contexts in prior literature are reflected in the variety of definitions of TSC proposed by SCM scholars (Egels-Zandén, Hulthén, & Wulff, 2015). For instance, some authors, like Cramer (2008) and Miller, Fugate, and Golicic (2017), focus on the disclosure of sustainability information about supply chain actors to the end-consumer in their definitions. Others, such as Doorey (2011), define TSC as the ability to track a product in a supply chain, thus placing traceability and transparency at the same level. In addition, the term "visibility," as an enabler of TSC, is used interchangeably with "information sharing" (Barratt & Oke, 2007). However, information sharing is an activity that is required to enable visibility. Therefore, information sharing can be regarded as an antecedent of TSC (Barratt & Oke, 2007). We rely on Carter and Easton (2011), define TSC as "proactively engaging and communicating with key stakeholders and having traceability and visibility into upstream and downstream supply chain operations" (p. 49). Herein, visibility is defined as the ability to "access to high-quality information that describes various factors of demand and supply" (Williams et al., 2013, p. 545), while traceability can be understood as "the ability of a system to indicate the current or historical state of activities" (Cheng & Simmons, 1994, p. 4). We draw on the definition of Carter and Easton (2011).

In addition to a variety of foci, contexts, and definitions, the literature addresses a broad range of motivations that lead to the decision to enhance TSC, and target effects, which describe the intended goals of an enhanced level of TSC. Research presents the need for supply chain actors to reduce demand and supply uncertainties as a motivation for enhancing TSC (Oliva & Watson, 2009), while other contributions identify the need to reduce uncertainty about the quality and sustainability of products (Costa et al., 2013) or the corporate social responsibility (CSR) of upstream supply chain actors (Gold, Seuring, & Beske, 2010; Rauer & Kaufmann, 2015) as motivations. Reducing the operational uncertainties stemming from supply chain disruptions and poor operational performance of suppliers (Ivanov & Dolgui, 2018; Tomlin, 2006) have also been identified as motivations to enhance TSC. According to Holweg et al. (2005), supply chain actors enhance TSC when seeking to reduce uncertainty that prevents them from achieving a high level of supply chain performance. In these situations, they aim to achieve specific effects, such as improved planning and replenishment (Jin et al., 2015; Wadhwa, Mishra, Chan, & Ducq, 2010), resilience (Brandon-Jones, Squire, Autry, & Petersen, 2014; Gunasekaran, Subramanian, & Rahman, 2015), or avoidance of quality (Costa et al., 2013) and CSR issues (Zhu, Song, Hazen, Lee, & Cegielski, 2018), which are discussed as target effects of enhanced TSC.

Mechanisms of transparency in the supply chain

Given the variety of different motivations and target effects, the literature reveals that different TSC mechanisms are deployed to enhance TSC. These TSC mechanisms describe solutions that are composed of technologies, structures, and processes to enable TSC. Predominantly, seven types of TSC mechanisms have been differentiated[62]:

- *Screening and assessing (S&A):* Enhancing the visibility of specific characteristics (e.g., capabilities) of external organizations (e.g., potential

[62] SCM scholars use slightly different expressions (e.g., “event watching” is also referred to as “supply chain disruption management”), but we will use the following terms consistently throughout this paper.

suppliers) and their processes to enable an evaluation before engaging with them and signing a contract (e.g., Wan & Beil, 2009).

- *Forecasting (Fo):* Enhancing the visibility of the future product demand of customers or supply of external suppliers to improve planning and production decisions (e.g., Oliva & Watson, 2009).
- *Monitoring (Mo):* Enhancing the visibility of the performance of external supply chain actors to maintain surveillance over their operations (e.g., McFarlane & Sheffi, 2003).
- *Tracking and tracing (T&T):* Enhancing the visibility of a product's current position in the supply chain and condition as well as gaining traceability of products' history in retrospect to identify problems or deviations at the product level (e.g., Kärkkäinen, Ala-Risku, & Främling, 2004).
- *Mapping (Ma):* Enhancing the visibility of the involved supply chain partners and their locations, value contributions, and processes within the supply chain in order to identify dependencies, inefficiencies and mitigate risks (e.g., Gardner & Cooper, 2011).
- *Event watching (Ew):* Enhancing the visibility of the involved supply chain partners and the flow of products and money to identify and react to incidents and disruptions (e.g., Tomlin, 2006).
- *Auditing (Au):* Enhancing the visibility of specific characteristics (e.g., value contributions) of direct supply chain partners (e.g., suppliers) during established, contractual relationships (e.g., Kovács, 2008).

All seven TSC mechanisms rely on technology that supports the deployment of the TSC mechanism, mostly information technology (IT) (Zhu et al., 2018). To manage the volume, variety, and velocity of data in supply chains currently, state-of-the-art TSC mechanisms employ cloud computing, big data analytics and machine learning algorithms (Wang, Gunasekaran, Ngai, & Papadopoulos, 2016). Moreover, TSC mechanisms may also include image analysis, sensors, radio frequency identifiers, geo-fencing, and global positioning systems (Cegielski, Allison Jones-Farmer, wu, & Hazen, 2012; Oliveira, Cardoso, Barbosa, da Costa, & Prado, 2015; Visich, Li, Khumawala, & Reyes, 2009). Furthermore, several blockchain and DLT pilots indicate the potential of the novel technologies to enhance products' traceability and processes' visibility (Wang, Singgih, Wang, & Rit, 2019). Overall, the literature emphasizes the importance of technology as an enabler of TSC mechanisms. However, as Zhu et al. (2018) note, the use of technology does not imply successful TSC per se. Technology is one element that enables TSC mechanisms, but it is not the only one.

In addition to technologies, the literature has revealed data-related antecedents of TSC, including data accessibility, accuracy, availability, and timeliness (Srinivasan & Swink, 2018; Williams et al., 2013; Zhu et al., 2018), which would qualify as TSC determinants. These data antecedents are necessary, but they are not sufficient for enhancing TSC alone; Cegielski et al. (2012), Morgan et al. (2018), and Zhu et al. (2018) underline the importance of collaboration between supply chain partners and communication for enhancing TSC and thus suggest to go beyond these data-related antecedents. Thus, prior research has been dominated by a technology-centric perspective, which does not sufficiently account for the complexity of TSC. Moreover, not all TSC mechanisms are affected by technologies in the same way, and their motivations and target effects are quite different. Thus, generalizing the few known antecedents for all TSC mechanisms does not sufficiently account for the heterogeneity of the TSC mechanisms. In general, elucidating the determinants to deploy the TSC mechanisms successfully, can be understand as a missing element in extant literature to understand how focal companies can enhance TSC. This goes along with investigating the required capabilities and processes to carve out entireness of the determinants. Therefore, a deep dive into TSC requires applying an adequate theoretical lens to explain entire effect mechanism with a focus on both capabilities and processes in the focal company and corresponding supply chain actors.

Theoretical lenses on transparency in supply chains

SCM scholars draw on the resource-based view, dynamic capabilities, contingency theory, and IPT when studying TSC. The resource-based view has been applied to explore the sources of competitive advantage in the context of TSC. Enabling visibility in supply chains is seen as an antecedent of sustainability implementation (Dubey, Gunasekaran, Childe, Papadopoulos, Luo, & Roubaud, 2017; Pagell & Wu, 2009) and supply chain resilience (Brandon-Jones et al., 2014). Barratt and Oke (2007) apply the resource-based view to identify the linkage between antecedents of visibility and achieving competitive advantage, and Wang and Wei (2007) as well as Steinfield et al. (2011) use the resource-based view to study competitive advantage as a result of achieved TSC. While these authors focus on competitive advantage, the role of TSC and its enabler visibility as well as the corresponding antecedents vary in their contributions. While the resource-based view allows to put focus on the required resources, the process of deploying TSC mechanism in the focal company and across its organizational boundaries remains in the shadow of this theoretical lens. Moreover, the emphasis on the competitive advantage requires to carefully observe the resulting effect of enhanced TSC on performance dimensions that constitute competitive advantages. This constitutes a strong assumption. Similar to the resource-based view, the theory of dynamic capabilities has been applied by SCM scholars focusing on the capabilities required to achieve a competitive advantage and herein discuss TSC. Brusset (2016) identifies visibility as one of the three capabilities needed to enhance agility in supply chains as a competitive advantage, while Liu, Ke, Wei, and Hua (2013) describe visibility as one of four second-order constructs of agility in supply chains. Moreover, contingency theory has been applied to study the context of phenomena related to TSC. For example, Brandon-Jones et al. (2014) examine the contingencies of supply chain resilience, including connectivity and information sharing as predictors of visibility. Moreover, the authors identify visibility as an antecedent of resilience. Caridi, Crippa, Perego, Sianesi, and Tumino (2010) explore the effect of supply chain configurations on visibility, while Wamba and Chatfield (2009) apply contingency theory to identify contingency factors affecting TSC as a result of radio frequency identification (RFID) use. In addition, SCM scholars have applied IPT to focus on adequate information processing and required capabilities in the context of TSC. Srinivasan and Swink (2018) draw on IPT to examine the role of visibility as an enabler of supply chain analytics, and Williams et al. (2013) use IPT to examine the impact of visibility on responsiveness of supply chains. Furthermore, Zhu et al. (2018) apply IPT to explore analytics-enabled TSC.

B-Table 1 summarizes the applied theoretical lenses, the roles of TSC, and the foci of previous related research. It also includes additional contributions that discuss these theories indirectly (shown in italics).

B-Table 1: Overview of theoretical lenses applied to examine TSC

Focus of study	**Applied theoretical lens**	**Role of TSC in study**		
		TSC as an antecedent for another phenomenon	TSC as the focus	TSC as a result of another phenomenon
Competitive advantage	Resource-based view	Dubey et al. (2017), Brandon-Jones et al. (2014), *Holweg et al. (2005), Gunasekaran et al. (2015)*	Barratt and Oke (2007), *Doorey (2011)*	Wang and Wei (2007), Steinfield et al. (2011)
Capabilities to achieve a competitive advantage	Theory of dynamic capabilities	Brusset (2016), Liu et al. (2013), *Aung and Chang (2014), Jin et al. (2015)*	*Egels-Zandén et al. (2015)*	*Costa et al. (2013), Rauer and Kaufmann (2015)*
Context factors of the phenomenon under study	Contingency theory	Brandon-Jones et al. (2014), *Gold et al. (2010)*	Caridi et al. (2010)	Wamba and Chatfield (2009)
Elements to enable information processing	Information processing theory	Srinivasan and Swink (2018), Williams et al. (2013)	*Morgan et al. (2018)*	Zhu et al. (2018)

Our RQ positions TSC as the focus of the study as it aims to understand how focal companies can enhance TSC, which includes diving into the need to enhance TSC, the required capabilities and the process of deploying TSC mechanisms within the focal company and corresponding supply chain actors. Thereby, we can study the necessary element of the determinants of enhanced TSC. Given the described inter-organizational scope of TSC, addressing the RQ requires the understanding of information processing across organizational boundaries in the supply chain. Thus, the RQ is best explored through the lens of IPT as it allows to explain intra-firm and inter-organizational capabilities and processes.

Moreover, Williams et al. (2013) stated that IPT can help researchers understand the bigger picture, which fits well to the aspiration to gain an integrative picture on TSC to address the RQ. Furthermore, the extant SCM literature illustrates that focal companies seek to reduce different types of uncertainties in their supply chains via TSC mechanisms. This aligns with the logic of IPT, meaning that IPT is well-suited for use as a theoretical lens to study how firms can enhance TSC and gain an integrative picture of this phenomenon.

Information processing theory and transparency in supply chains

IPT emerged from organizational research that aimed to explore intra-firm information processing (i.e., between different sub-units within an organization). Following Galbraith (1974) and Tushman and Nadler (1978), IPT characterizes organizations as open social systems that aim to mitigate uncertainty in order to increase their performance. The theory consists of three elements: information processing need (IPN), information processing capability (IPC), and the fit between IPN and IPC (Bensaou & Venkatraman, 1995; Tushman & Nadler, 1978). Herein, an IPN stems from uncertainty. In the intra-firm context, three types of uncertainties have been identified: sub-unit task characteristics, sub-unit task environment, and inter-unit task interdependence (Tushman & Nadler, 1978). According to Galbraith (1974), an organization can address uncertainty-triggered IPN in two ways: (i) by reducing the IPN or (ii) by increasing the IPC and thus achieve a fit. In the intra-firm context, the first option requires building up slack or enabling self-contained tasks, and the second option requires investment in vertical and cross-functional IT (e.g., enterprise resource planning (ERP) systems) or extension of lateral relationships (e.g., direct contact, task force). The fit between IPN and IPC marks the pivotal role to improve performance in general, as unfulfilled IPN leads to reduced performance, while overachieved IPC leads to inefficiency (Galbraith, 1974). Hence the fit is defined by matching the characteristics of the IPN with the obtained IPC.

Premkumar, Ramamurthy, and Saunders (2005) were the first to apply IPT in an inter-organizational context. In their contribution, they developed a taxonomy for

IPNs and IPCs. In the inter-organizational context, different types of uncertainties, such as demand uncertainty, supply uncertainty, and product criticality, trigger IPNs for supply chain actors, increasing the focal company's need to enhance TSC (Premkumar et al., 2005). Accordingly, the focal company can either (i) reduce IPN by building up slack (e.g., inventory) and thereby avoid enhancing TSC or (ii) increase IPC by deploying a TSC mechanism. By deploying a TSC mechanism, the focal company invests in vertical IT that fosters information processing across organizational boundaries (e.g., collaborative EDI-based forecasts) and extends lateral relations, including joint structures, processes, and meetings with external supply chain partners (e.g., supplier days). The degree of investment in inter-organizational vertical IT also referred to as inter-organizational information systems (IOIS), and extension of cross-company lateral relations depends on the TSC mechanism that is deployed. As prior illustrated by the role of IT for auditing, the TSC mechanisms vary in their dependence on IT, structures and processes, as Bensaou and Venkatraman (1995) found in general for information processing. By deploying TSC mechanisms in the supply chain, focal companies can increase their IPC and thus establish a fit with their IPN. This, in turn, leads to enhanced TSC, ultimately achieving the target effect. However, this fit can be achieved only if IPCs can be successfully built up in the supply chain and match the focal company's IPN. Thus, IPCs require cross-company deployment of the specific TSC mechanism. For each TSC mechanism, there are a set of specific determinants that define the success of deployment, which take effect at the intra-firm and inter-organizational level. However, extant research on IPT has focused only on the intra-firm perspective, without illuminating inter-organizational information processing. Hence, when exploring TSC, it is necessary to elaborate on IPT within the inter-organizational setting of supply chains. Our study addresses this gap.

Research Design

Extant research has identified motivations to enhance TSC and the target effects of doing so. However, how firms can enhance TSC and the determinants that should be attained to enhance TSC remain largely unexplored. This requires an integrative study on a rather novel phenomenon, given the fragmented and specific literature on TSC. Hence, we adopt an inductive, multiple-case study research design with abductive reasoning to develop a mid-range theory concerning the determinants of TSC (Ketokivi & Choi, 2014), which sheds light on an unexplored phenomenon and lays the groundwork for future research (Edmonson & McManus, 2007; Meredith, 1998). An inductive case study enables us to gain both a deep and comprehensive understanding of the phenomenon under study, which is needed to answer the RQ and identify the common ground of the TSC determinants that play a pivotal role in enhancing TSC from the perspective of the focal company (Eisenhardt, 1989; Gerring, 2004). Abductive reasoning was chosen because our research aim is to exploit IPT in the inter-organizational context of TSC. Given the diversity of TSC mechanisms, our case study adopts a holistic, multiple-case design in which the determinants are the unit of analysis and the TSC mechanisms form the units of observation (Yin, 2017).

Sampling of cases

To identify the TSC determinants, we studied applied and leading solutions that represent the seven TSC mechanisms. Our RQ required applied TSC solutions, as we aim to study functioning real-world applications. Moreover, we decided to observe only leading solutions in order to study the phenomenon of TSC based on a successful deployment of the observed TSC mechanism. To identify the leading solutions, we applied two selection criteria. Each of our cases adheres to one of the criteria:

1. Independently awarded solutions: The TSC solution received a competitive award (among multiple nominees) from an independent jury in the field of operations and supply chain management. Examples of such awards are the Supply Chain Innovation Award awarded by the Council of Supply Chain Management Professionals (CSCMP) or the Automotive Logistics Award awarded by the German Association of the Automotive Industry.
2. Industry-wide good practice solutions: The TSC solution resulted in enhanced TSC compared to the initial level and the supply chains of

competitors. The initial level was typically identified as a problem, leading to motivation to improve the level of TSC. At best, this improved level of TSC was indicated by key performance indicators (e.g., on-time delivery, lead time).

We applied theoretical sampling in accordance with Glaser and Strauss (2009) to build our mid-range theory, which stipulates to add new cases to expand the emerging theory until saturation was achieved, as no novel findings could be generated (Eisenhardt, 1989). This implied to carry out data collection and analysis in parallel. As there are seven TSC mechanisms, we required at least 14 cases, assuming that saturation would be achieved after two cases[63]. While at first, we only defined the first criterion, this led us to define the second selection criterion, as we realized that the number of cases from awarded TSC solutions would be insufficient to cover all TSC mechanisms.

Based on the selection criteria, we started to identify potential cases. First, we identified a number of SCM awards and sought potential case candidates. In this step, we identified 37 award-winning companies (selection criterion 1) and approached all of them via email and telephone. We described our research initiative and asked if they were willing to participate in our study. Five candidates were willing. Second, via email or telephone, we contacted 135 companies in different industries to identify additional case candidates that deployed industry-wide good practice solutions (selection criterion 2). We asked them to indicate whether they deployed a promising solution to enhance TSC and whether they would be willing to participate in our study. In total, we acquired 27 additional cases and arranged interview appointments.

Data collection

Before conducting the interviews, we crafted our case study protocol based on the seminal work of Yin (2017), building on extant TSC research to ensure construct validity. The interview protocol contained an interview instrument in two versions (one for the focal company, the other for the corresponding supply chain actors

[63] As shown in B-Table 2, saturation was achieved after three to four cases.

and the solution providers) that constituted the line of inquiry during the interviews. After conducting the first four interviews, the interview instrument was reflected and revised. The instrument for the focal company consisted of four parts[64] and can be found in Appendix A:

1. General information
2. Questions about the general understanding of TSC and its importance.
3. Questions about the usage and the success of each of the seven TSC mechanisms.
4. Questions about the selected TSC mechanisms.

The third part was applied only in cases with industry-wide good practice solutions (selection criterion 2). The questions of the third part took the form of a self-assessment, enabling us to study applied and leading solutions according to selection criterion 2. Eight of the 27 additional cases did not reveal sufficient evidence in the interviews to justify selection. Thus, we acquired five award-winning solution cases and 19 industry-wide good practice cases—a total of 24 cases—at which point saturation was achieved.

The interview instrument contained questions that focused on strategic and operational levels. If the interviewees did not cover both levels, we conducted additional interviews. In some cases, there was a need to interview external partners (e.g., corresponding supply chain actors, solution providers) to obtain a complete picture of the studied TSC solution. Thus, the second version for the interview instrument was crafted to gain additional insights from their perspective, to complement the insights of the focal company. In these cases, we asked the interviewee to introduce us to additional internal or external stakeholders in order to achieve saturation within the cases. The number of interviews required for each case varied between one and six. The duration of the interviews varied as well depending on the complexity and number of interviewees required (see B-Table 2). Most of the case interviews were

[64] The instrument for the corresponding supply chain actors and solution providers contained only part 1 and part 4 as illustrated in Appendix A.

conducted on-site, which allowed us to see live demonstrations of the TSC solutions (incl., software tools) or verbal introductions (e.g., in videos) and study additional data, such as process maps, auditing templates, and tracking devices. In addition, we collected secondary data from web sites, press releases, and newspaper articles to enable data triangulation. This allowed us to alleviate interviewer bias and increase reliability and construct validity (Jick, 1979; Yin, 2017). In total, we conducted 46 interviews, with interviewees from different positions and organizations (see B-Table 2), with over 49 hours of total duration, collected 1,046 additional pages of internal documents and researched 78 different web pages to enable data triangulation. 44 of 46 interviews were audio-recorded and subsequently transcribed. In addition, the researchers took extensive notes during the interviews. The transcripts were sent to the interviewees for review to ensure accuracy. Afterward, all data was collected in a case database to enhance reliability and enable subsequent data analysis.

B-Table 2: Case overview and description of data sources

Case ID	Industry	Studied mechanism	Selection criteria	Case interviews				Additional data sources	
				Position of interviewees	**Number of inter-views**	**Total duration in minutes**	**Demonstration of applied TSC mechanism**	**Pages of internal documents (incl. manual, templates, presentation, project descriptions, etc.)**	**Number of different public sources (incl. webpages, press releases, etc.)**
1	Automotive	Ew	Award winner	Head of Automotive SCM, FC Vice President SCM, FC Global Risk Manager, FC	3	124	ld	54	7
2	Semiconductor	Fo	Award winner	Principal SCM. FC	1	75	vi	57	4
3	Pharmaceutical	Mo	Self-assessment	Head Global Supply Chain, FC Export Coordinator, FC Logistics Coordinator, FC Supply & Demand Specialist, FC Quality Control, FC Product Owner, SP Board Member, LSP	6	429	ld	186	3
4	Food	Ma	Self-assessment	Head of Quality Management, FC SCM Specialist, FC Head of Quality Management, S Business Architect, SP	4	267	ld	31	2
5	Food	Mo	Self-assessment	Head of Strategic Procurement Service/SCM, FC Head of SCM Projects, FC	2	100	ld	29	2
6	Machinery	Au	Self-assessment	Head of Supply Chain Management, FC	2	70	vi	49	2
7	Machinery	Fo	Self-assessment	Head of Sales, FC	1	74	ld	36	5
8	Machinery	S&A	Self-assessment	SCM Specialist, FC	1	88	ld	81	4
9	Machinery	Fo	Self-assessment	Value Chain Planning Manager, FC SCM Specialist, FC	1	84	ld	24	1
10	Machinery	Au	Self-assessment	Lead Supplier Auditor, FC SCM Specialist, FC	1	71	ld	36	2
11	Automotive	T&T	Award winner	Director Logistics Services, FC	1	79	vi	26	6
12	Pharmaceutical	Mo	Self-assessment	Global Head Environmental Supply Chain, FC	2	84	ld	72	3
13	Sanitation	Fo	Self-assessment	Head of Global Supply Chain Management, FC Head of Supply Management, FC	1	131	vi	18	0
14	Food	T&T	Self-assessment	Head of Supply Chain Information Solutions, FC Head of IT	3	166	ld	59	4
15	Transportation	S&A	Self-assessment	Strategic Purchasing Manager, FC Category Manager IT, FC	1	81	ld	0	3
16	Transportation	Au	Self-assessment	Strategic Purchasing Manager, FC Category Manager IT, FC	1	75	ld	0	4
17	Machinery	Ma	Self-assessment	Head of SCM, FC	2	140	ld	45	2
18	Automotive	T&T	Award winner	Product Supply Chain Solutions, FC Senior Manager Material Control , FC	1	105	ld	12	3
19	Automotive	Ew	Self-assessment	Corporate Supply Chain Manager, FC Business Developer, SP	2	116	ld	21	4
20	Automotive	T&T	Award winner	Project Manager, FC	1	79	vi	42	5
21	Machinery	Ma	Self-assessment	Head of Sourcing Excellence, FC Head of Corporate Risk, FC Project Manager Sourcing Excellence, FC	3	146	vi	51	3
22	Pharmaceutical	S&A	Self-assessment	Head of Global Supply Chain, FC Purchasing Manager, FC	2	96	ld	81	2
23	Cosmetics	S&A	Self-assessment	Head of Raw Material Sourcing, FC Vice President SCM, FC	2	89	vi	0	4
24	Precision mechanics	Ew	Self-assessment	Vice President SCM, FC Managing Director, SP	2	214	ld	32	3
				Total	46	49 h		1,042	78

S	Supplier company	ld	Live demonstration
SP	Service provider	vi	Verbal introduction

Data analysis

For our data analysis, we followed the three-stage coding procedure described by Glaser (1992), which includes open coding, selective coding, and theoretical coding. Throughout the three stages, we moved from our inductive cases to abductive reasoning, enabling us to further exploit and combine existing theory on IPT with empirical data from our 24 cases (Alvesson & Kärreman, 2007). We applied a mid-range coding approach that allowed us to derive codes from our empirical data and the literature (Urquhart, 2013). We also drew on the aforementioned literature on TSC, the a priori constructs and theoretical lenses that have been applied in relation to this phenomenon. The three-stage grounded theory procedures described by Glaser (1992) were used as a method for data analysis. To ensure consistent coding and analysis, we used Atlas.ti.

In the first stage of our coding procedure, we created open codes. Herein, we made use of first- and second-order codes. In our first open coding run, we created interviewee-centric first-order codes that used the terminology of the interviewees to account for organization- or industry-specific terms as suggested by Gioia, Corley, and Hamilton (2013). As these first-order codes were descriptive in nature, we generated analytical second-order codes to synthesize specific terms and move from descriptive to analytical codes in the second run. Using the rich data set obtained for all cases, we developed detailed case descriptions, which enabled us to comprehend the big picture regarding the unit of observation. Specifically, we understood the motivations to enhance TSC, the specific TSC mechanisms, the TSC determinants, and the target effects. Only by analyzing all four elements could we understand the interrelationships in depth.

In the second stage of our coding procedure, we performed selective coding to identify the codes that help answer our RQ. We identified the emerging codes and synthesized them into core categories for our RQ. Different colors were applied to the codes in Atlas.ti to continuously focus our attention on the RQ and avoid digressing. For example, after merging the codes, we identified a total of 29 codes that described the TSC determinants. An exemplary illustration of the quotes, the first-order codes and the second-order codes can be found in Appendix B.

In the third stage of our coding procedure, we applied theoretical coding, identifying and describing the relationships between the selected codes. We followed an abductive approach, drawing on ideas about the relationships described in the SCM literature.

Findings

Results regarding TSC mechanisms

We summarize three to four cases for each of the seven TSC mechanisms, outlining the initial uncertainty, motivation to enhance TSC, the TSC mechanism itself, the fit between IPN and IPC, the level to which TSC was enhanced, the applied technologies and the context factors that affect the deployment of the TSC mechanism.

Screening and assessing: The focal companies in Cases 8, 15, 22, and 23 reported uncertainty regarding different performance dimensions - including operational performance, financial stability, sustainability performance, communication capabilities, and the innovativeness of potential new suppliers - as a motivation to enhance TSC. The uncertainty created an IPN for greater transparency in different dimensions of the performance of potential suppliers before the focal companies engaged in a long-term business relationship. By deploying screening and assessing as a TSC mechanism, the focal companies sought to ensure successful business relationships and identify risks or areas for improvement before establishing supply chain relationships. All cases feature a comprehensive IPN that includes all of the aforementioned performance dimensions. Thus, the observed solutions in these cases enable transparency in multiple dimensions, which requires aggregating information from multiple parties, including the supplier, providers of external testimonials, third-party data providers (e.g., EcoVadis, RapidRatings), and different departments from the focal company (e.g., procurement, R&D, quality). Moreover, the observed solutions are anchored in an established, obligatory process of supplier selection. By aggregating and combining information from different angles and stakeholders and by embedding the TSC mechanism in an internal business process, the focal companies could enhance TSC regarding potential suppliers, ultimately leading to a reduction in quality issues and risk exposure in the observed cases. For screening and assessing, the focal companies used standardized databases, which enabled easy data entry via web portals or several upload interfaces. In all four cases, trust and mutual interest between the focal company and potential supplier were found to be context factors that positively affect the deployment of the TSC mechanism.

Forecasting: In Cases 2, 7, 9, and 13, the focal companies faced uncertainty regarding future demand and supply. On the customer side, the focal companies needed more accurate and timely information about future demand, while on the supplier side, they needed timely, accurate, and comprehensive information about future production capacity and the current inventory levels of their suppliers. This IPN led the companies to establish advanced forecasting solutions as a TSC mechanism to enhance transparency regarding future demand and supply. The analyzed solutions are characterized by timely distribution and diffusion of information, matching demand and supply forecasts, and application of state-of-the-art technologies and forecasting methods. First, advanced technologies, including big data analytics (BDA) and artificial intelligence (AI), are used to aggregate and analyze customer data, economic data, and internal estimations. This allows forecast data for several time horizons to be generated and continuously updated at the product level for the focal company. Then, the forecast data are automatically broken down into individual product components. The required future supply is derived by automatically matching these numbers with the inventory level of the focal company and the suppliers (only in Cases 7 and 13). Electronic data interchange (EDI) and customized web portals enable timely information processing from the customer to the supplier, providing automated and timely forecasts for the customer, focal company, and supplier. Thereby, the observed forecasting solutions address the need for accurate and timely information processing to address the demand and supply uncertainty. As a consequence, the lead time and inventory level were reduced in all of the observed cases. Power and trust between supply chain partners, as context factors, affect the deployment of the TSC mechanism since they lead to sharing of data on supply and demand. While the cases showed that power enables to force the relevant upstream or downstream supply chain actors to share data, it can also be counterproductive as customers fear to disclose their future demand and thus showcase their dependencies. Trust enhances data sharing without power.

Monitoring: In Cases 3, 5, and 12, the focal companies faced uncertainty within various performance dimensions, such as delivery reliability, service level, product quality, and sustainability of their direct supply chain partners, including suppliers and logistics service providers (LSPs). Given that the associated processes were outside of the focal companies' power, the uncertainty led to an IPN to increase transparency regarding external supply chain processes. While the scope in all three cases varied, all focal companies established a monitoring mechanism that included three steps: data gathering, data analysis, and reactive measures. Data gathering solutions combined traditional data sources, such as EDI data transfer and ERP systems, with state-of-the-art sensors, image analysis, and machine learning algorithms. Then, the data was processed and analyzed by the focal company and deviations were identified. Third, the focal companies initiated a dialogue with their supply chain partners based on the severity of the deviations. In these dialogues, additional data was exchanged to identify the root causes of deviations and develop countermeasures. By deploying monitoring as a TSC mechanism, the focal company enhanced TSC, which led to significant improvements in different performance dimensions. For example, after the monitoring solution was introduced in Case 5, the replenishment time for most projects was reduced from 120 days to 30 days and the focal company and its suppliers increased delivery reliability to well over 95%. In Cases 3 and 12, the number of quality and sustainability incidents was reduced by a low double-digit percentage. All three cases show that the monitoring and especially the process of data sharing with the focal company is based on a contract between the focal company, its suppliers (Cases 5, and 12) and its LSPs (Case 3). Hence, the power to establish these contracts is positively affecting the deployment of the TSC mechanism.

Tracking and tracing: In Cases 11, 14, 18, and 20, the focal companies faced uncertainty regarding the timely delivery of products and components that are in transit after being consigned at the partner's site (mostly supplier or LSP). Thus, the focal companies face the IPN to enhance transparency regarding products in transit to ensure they could react to unplanned deviations and reduce the risk of production stops due to delayed deliveries. To achieve this transparency, the focal companies established tracking and tracing solutions in collaboration with their suppliers and the associated LSPs. These tracking and tracing solutions enabled them to gather and process data in almost real-time using positioning data (e.g., GPS) from telematics systems, third-party data providers (e.g., VesselFinder), or smartphones' GPS to track shipments for smaller supply chain partners and LSPs. In Cases 14 and 18, the solutions were built on an integrative IT layer that enables aggregation of data points from different sources and transfer formats (e.g., JSON, REST, HTML) to achieve carrier- and modality-independent visibility of all relevant shipments. This data is combined with schedules to identify deviations, which are visualized in a dashboard. Thereby, uncertainty is addressing by enhancing transparency with timely data processing and detection of deviations. Consequently, the focal companies were able to reduce the number of production stops and costs for express deliveries. All three cases demonstrate that the tracking and tracing solutions and its usage are defined in the contract between the focal company, its suppliers (Cases 14, 18, and 20) or its LSPs (all cases). Hence, the power to establish these contracts is positively affecting the deployment of the TSC mechanism.

Mapping: Cases 4, 17, and 21 are examples of focal companies in different industries that addressed uncertainty regarding supply chain actors that cause quality issues, inadequate behavior of their upstream supply chain partners or the inherent operational risks of these partners. While operational risks might stem from natural hazards (e.g., earthquakes) or incidents (e.g., fire), inadequate behavior is caused by process, quality, sustainability, or CSR issues. Thus, the focal companies identified an IPN to gain transparency regarding upstream supply chain actors and make the involvement of actors visible. In the aforementioned cases, the focal companies applied mapping solutions to address this IPN. These solutions comprise three steps. First, the focal companies defined the scope (i.e., the information of interest), which varies based on processes (Case 17), adherence to sustainability practices (Cases 4, 17, and 21), and quality practices (Cases 4, 17, and 21). Second, the focal companies engaged with their tier-1 suppliers, sometimes with the support of a third-party (Case 4), to gather relevant data from the suppliers. If the relevant supply chain actors were further upstream, they sought to engage their sub-suppliers through their direct suppliers. Third, once the data was gathered, it was aggregated and analyzed by the focal company or a third-party to identify risks and define measures in collaboration with the corresponding supplier or sub-supplier. Based on the defined scope, all cases demonstrated enhanced TSC, often focusing on sub-suppliers. In Case 17, the focal company was able to make the business processes of the supplier visible and develop improvement measures to reduce both quality issues and lead times. An action that is also known from automotive companies such as Toyota to help improve suppliers (Wilhelm, 2011). This mechanism is able to work without advanced technology, aside from traditional databases and cloud solutions. Power and dependency were identified as context factors that affect the deployment of mapping in all three cases, as powerful customers or a high dependency on customers (e.g., in cases with contracts) forces suppliers to contribute to the deployment of the TSC mechanism. However, the interviewees indicated also a negative effect, as suppliers fear to disclose more information to their disadvantage.

Event watching: In Cases 1, 19, and 24, the focal companies faced uncertainty regarding disruptions and incidents (e.g., armed conflicts, natural disasters, strikes) in their upstream supply chain. In contrast to mapping, this uncertainty is based on events that have already occurred. Thus, the focal companies had an IPN to increase transparency regarding supply chain disruptions as soon as possible and react to them in order to avoid supply shortages, production stops, or unplanned express deliveries. Therefore, the focal companies deployed several IT tools based on a supply chain map, often as a result of previous mapping and continuously analyzed different data sets (e.g., news, weather data, catastrophic reports) from multiple sources (e.g., Bloomberg, Reuters, social media) to identify supply chain disruptions and incidents. The IT tools in Cases 19 and 24 additionally draw on machine learning algorithms (specifically supervised learning) to continuously improve the accuracy and relevance of identified events. When identifying events, the IT tools send alerts to the focal company and, in Cases 19 and 24, enabled direct communication between the focal company and the affected supplier to clarify the impact of the disruption. Furthermore, the solutions implemented by the focal companies have an interface to their internal ERP systems and warehouse management systems to directly increase transparency regarding the affected components at the inventory level. By deploying event watching solutions, the focal companies enabled timely identification of supply chain disruptions and actions to address the IPN. The achieved enhancement in TSC allowed the focal companies to reduce the reaction time (in Case 1, from 48 hours to 12 hours), thereby improving resilience and responsiveness. Both power and dependency have a positive effect on the deployment of this TSC mechanism. First, focal companies benefit from their power as they are able to request suppliers to make tier-n suppliers visible to them. Thus, the initial supply chain map is likely to be more complete and more accurate. Second, the dependency of the supplier helps in the same way, as it fosters suppliers to reveal upstream supply chain actors.

Auditing: Cases 6, 10, and 16 are examples of focal companies that faced uncertainty regarding the operational, quality, or sustainability performance of their established supply chain partners (mostly suppliers and LSPs). Thus, they identified an IPN to increase transparency regarding the partners’ processes and capabilities to better evaluate future business relationships and identify improvement measures. The focal companies used standardized audits to achieve greater transparency regarding the relevant supply chain partners. In contrast to screening and assessments, audits are conducted in an established business relationship and in which at least one business transaction has been processed. Before conducting the audit, several stakeholders in the focal company (e.g., procurement, quality, production, or logistics) are consulted and involved in the audit process. These stakeholders define the information that must be gathered and analyzed during the audit. The involvement of multiple functions enables transparency to be achieved in all relevant areas and a comprehensive audit to be performed based on expert knowledge from different angles. In the observed cases, a group of experts and a lead auditor (who orchestrates the audits) conducted site visits to the partner and asked for all required information. In addition, information from third-party providers (e.g., certification institutions) was requested. After gathering all relevant data, the group assessed the data and crafted an auditing report that described the current situation of the partner and provided recommendations and measures for the focal company and the partner. By defining specific goals and deadlines, the focal companies sought to improve the performance of the supplier. By deploying audits, the focal companies enhanced transparency for a specific, and often critical, supplier, thereby addressing the IPN. None of the cases exhibited advanced use of technology; rather, they relied on their internal ERP systems, traditional databases, and user-friendly auditing tools. Power and dependency in the relations between the focal company and the partner positively affect the deployment of audits, as they increase the importance of the audit for the partner and thereby the relevance of the provision of the required data for the audit.

Results regarding TSC determinants

Following the descriptions of the TSC mechanisms, we go on to present the corresponding TSC determinants. These TSC determinants serve as requirements for deploying TSC mechanisms and thus enabling a fit between the IPN and IPC. In total, our empirical data revealed 29 determinants, which are illustrated in B-Table 3. These determinants can be clustered into five different groups based on their similarity to each other. First, the *data determinants* describe the attributes of data, required for specific TSC mechanisms. Second, the *organizational* *determinants* describe the organizational requirements to enable the TSC mechanism. Third, the *process determinants* constitute the requirements regarding the process of the TSC mechanism and the process in which the TSC mechanism is embedded. Fourth, the *relationship determinants* are the requirements related to the relationship with the supply chain partners with which the TSC mechanism will be deployed. Fifth, the *solution determinants* describe the attributes required for the TSC mechanism itself on an abstract level. In addition to the determinants in each group, B-Table 3 provides a brief description of each determinant and mapping of the individual mechanisms. The number of cases in which each TSC determinant was found is shown in the corresponding cell.

Our analysis reveals that most TSC determinants are data determinants (ten of 29), followed by relationship determinants (six), solution determinants (five), and organizational and process determinants (both four). Also, the analysis suggests that five of the 29 TSC determinants (availability of data, relevant data, collaboration with partner, user acceptance, and user-friendliness) are relevant for all seven TSC mechanisms, and integration in the process is relevant for all TSC mechanisms except mapping. In contrast, three TSC determinants (ease of data gathering, adequate relationship with partner, adaptability for data processing) are relevant only for a single TSC mechanism, and supportive actions for partner is relevant in only two cases. On average a determinant can be found in 3.86 TSC mechanisms and in 13.6 cases. The number of required TSC determinants span between 12 for screening and assessing and 19 for event watching. Concerning the determinant groups, monitoring reveals the most data determinants (9 of 10), auditing the most organizational determinants (4 of 4), screening and assessing, tracking and tracing as well as event watching the most process determinants (3 of 4), mapping the most relationship determinants (4 of 5) and forecasting the most solution determinants (5 of 5).

In the case, we also identified if the TSC determinants have to be attained solely by the focal company (FC) or required attainment of at least one corresponding supply chain actor as well to deploy the TSC mechanism successfully. For example, accuracy of data has to be attained by the corresponding supply chain actors and the focal company, which confirms the notion of garbage-in, garbage out. All data, relationship and solution determinants require multi-level attainment (MA) while ease of data gathering is the only process determinant that requires MA.

B-Table 3: Specific TSC determinants

	Determinant	Description	Screening and assessing (8, 15, 22, 23)	Forecasting (2, 7, 9, 13)	Monitoring (3, 5, 12)	Tracking and tracing (11, 14, 18, 20)	Mapping (4, 17, 21)	Event watching (1, 19, 24)	Auditing (6, 10, 16)	In number of TSC mechanisms	Count in all cases	Required attainment
Data determinants	Accuracy of data	TSC mechanism depends on accurate input data and has to provide accurate output data	N	A	A	N	N	A	N	3	10	MA
	Availability of data	TSC mechanism depends on data availability and has to make output data available	A	A	A	A	A	A	A	7	24	MA
	Clarity of data	TSC mechanism depends on clarity of data and has to provide clear output data	N	A	A	N	A	A	N	4	13	MA
	Completeness of data	TSC mechanism depends on complete input data and has to provide complete output data	N	N	A	A	N	A	A	4	13	MA
	Correctness of data	TSC mechanism depends on correct input data and has to provide correct output data	A	A	A	N	4	A	A	5	18	MA
	Accessibility of data	TSC mechanism depends on accessible input data	N	A	A	A	N	N	N	3	11	MA
	Timeliness of data	TSC mechanism depends on accessible input data	N	A	A	A	N	A	N	4	14	MA
	Processable data	TSC mechanism depends on processable input data	A	A	A	A	N	N	N	4	15	MA
	Relevant data	TSC mechanism depends on relevant input data and has to provide relevant output data	A	A	A	A	A	A	A	7	24	MA
	Verifiability of data	TSC mechanism depends on verifiable input data	A	N	N	N	A	1, 19	A	3	12	MA
Organizational determinants	Availability of personal	TSC mechanism requires involvement of specific personal with their expertise	N	N	N	N	A	N	A	2	6	FC
	Clear responsibility	TSC mechanism requires clear role and task understanding	N	N	N	A	A	N	A	3	10	FC
	Interfunctional collaboration	TSC mechanism builds on interfunctional collaboration with the FC	A	A	A	N	A	A	A	6	20	FC
	Trained users	TSC mechanism requires adequate training of users in beforehand	N	N	N	N	N	A	A	2	6	FC
Process determinants	Ease of data gathering	Data gathering has to be performed with little effort and at best automatically	N	7	3	A	N	N	N	1	6	MA
	Integration in processes	TSC mechanism has to be embedded in business processes	A	A	A	A	N	A	A	6	21	FC
	Periodic update	TSC mechanism requires an update within a pre-defined timespan	A	A	N	N	A	A	A	5	17	FC
	Timely use of TSC mechanism	TSC mechanism has to be applied at the right time	A	N	N	A	N	A	16	3	12	FC
Relationship determinants	Adequate relationship with partner	TSC mechanism requires an adequate relationship with supply chain partner or third party SP	N	N	N	18	A	N	N	1	4	MA
	Collaboration with partner	TSC mechanism requires close collaboration with supply chain partner	A	A	A	A	A	A	A	7	24	MA
	Collaboration with third party	TSC mechanism requires close collaboration with third party SP	8	N	N	A	A	A	N	3	11	MA
	Common understanding	TSC mechanism builds on common understanding of all involved parties	N	N	A	A	A	A	N	4	13	MA
	Purposeful communication	TSC mechanism requires effective and efficient communication between all involved parties	8	N	N	N	A	24	A	2	8	MA
	Supportive actions for partner	TSC mechanism requires supply chain actors to help each other establishing the mechanism	N	13	N	18	N	N	N	0	2	MA
Solution determinants	Adaptability for data processing	TSC mechanism builds on adaptable IT infrastructure that accounts for heterogeneity and multiple interfaces	N	A	N	14	N	N	N	1	5	MA
	Automated data processing	TSC mechanism requires automated processing of input data	N	A	N	A	N	A	N	3	11	MA
	Standardized data exchange	TSC mechanism requires standardized data (incl. master data) and data exchange	N	A	A	A	A	A	N	5	17	MA
	User acceptance	TSC mechanism requires the acceptance of all involved users	A	A	A	A	A	A	A	7	24	MA
	User friendliness	TSC mechanism builds on user friendliness for ease of operational use	A	A	A	A	A	A	A	7	24	MA
			Σ = 12	Σ = 17	Σ = 16	Σ = 17	Σ = 16	Σ = 19	Σ = 15	Ø = 3.86	Ø = 13.6	

Following the previous presentation of the TSC mechanisms and the TSC determinants, we present the 24 cases in a summary with the observed uncertainty, IPN, short description of the applied TSC mechanism, the use of advanced technologies, structures, processes, and the context in B-Table 4.

B-Table 4: Summary of case findings

	ID	Uncertainties	IPN	Description of TSC mechanism	Required actors to attain determinants	Advanced technology applied	Structures	Processes	Context
Screening and assessing (S&A)	8	Uncertainty regarding upstream (S&AUU) performance dimensions of potential supplier: operational, financial, sustainable, communication, innovativeness	Transparency regarding relevant performance dimensions of potential supplier (S&ATPe)	Structured, multi-angle data gathering and analyzing incl. third party service provider to enable multi-faceted view (S&AS)	Upstream attainment by potential supplier (S&AUA)	None (S&AN)	Inter-functional kick-off meetings (S&AIK) and alignment calls with third party (S&AEC)	Embedded in supplier selection process (S&AIS), Structured process with integration of externals (S&AEI)	Mutual interest (S&AMI+) and initial trust (S&ATr+) positively affect deployment of the TSC mechanism
	22								
	23								
	15			Questionnaire-based web-platform to enter comprehensive information, incl. references to enable multi-angle view (S&AQ)		Cloud storage system (S&AC)			
Forecasting (Fo)	2	Uncertainty on upstream inventories and future production capacity of supplier (FoUU) and uncertainty regarding downstream demand of customers (FoUD)	Transparency regarding future demand (FoTDe) and future supply (FoTSu)	Aggregation of customer and external data, analyzed with statistical methods and broken down into product components (FoC)	Downstream attainment by customers (FoDA)	EDI, BDA, machine learning (FoML)	Internal exchange platforms and communication channels (FoIC), trainings with supply chain partners (FOET)	Embedded in internal business processes (FoIP) and integrated in inter-organizational communication process (FoEC)	Power negatively affects (FoPo-) and trust positively affects (FoTr+) the deployment of the TSC mechanism
	9					EDI, BDA (FoBDA)			
	7			As above, plus automatic comparison with suppliers inventory (FoS)	As above (FoDA) and upstream attainment by suppliers (FoUA)				
	13					EDI (FoEDI)			
Monitoring (Mo)	3	Uncertainty regarding downstream product quality and delivery reliability (MoUD)	Transparency regarding supply chain partners' processes (MoTPr)	Data collection with temperature sensor on cold chain pharmaceuticals, analysis based on limits, triggering deviation reactions (TMo)	Downstream attainment by LSPs (DA)	IoT sensors (MoIoT)	Internal trainings for operations team MoIT), joint escalation meetings and calls (MoEM)	Embedded in internal business processes (MoIP) and integrated in periodic inter-organizational communication process (MoEC)	Power positively (MoPo+) affects deployment of the TSC mechanism
	5	Uncertainty regarding upstream service level and delivery reliability (MoUU)		Data collection with EDI and image recognition sensors of product delivery, analysis based on defined criteria, triggering deviation reactions (MoP)	Upstream attainment by suppliers (MoUA)	IoT sensors, EDI, image analysis (MoIA)			
	12	Uncertainty regarding upstream sustainability (MoUU)		Data collection from suppliers on compliance of sustainability practices (MoS)		None (MoN)			

Appendix

	ID	Uncertainties	IPN	Description of TSC mechanism	Required actors to attain determinants	Advanced technology applied	Structures	Processes	Context
Tracking and tracing (T&T)	11	Uncertainty regarding downstream delivery of products to customer (T&TUD)	Transparency regarding products and components in transit (T&TTTr)	Tracing products in transit based on GPS and identifying deviations based on schedules (T&TS)	Downstream attainment by customers and their LSPs (T&TDA)	GPS (T&TGPS)	Internal trainings with truckers and operators (T&TIT), joint escalation calls, incident-driven (T&TEC)	Data transfer is integrated in logistics activities (T&TIP) and escalation procedures are jointly developed (T&TEP)	Power positively (T&TPo+) affects deployment of the TSC mechanism
	20	Uncertainty regarding upstream (T&TUU) and downstream delivery of products and components (T&TUD)			Combining both downstream (T&TDA) and upstream attainment (T&TUA)				
	14 18	Uncertainty regarding downstream delivery of components from supplier (T&TUU)		As above, plus integrative layer to aggregate external data (e.g., on traffic, weather) (T&TI)	Upstream attainment by suppliers and theirs LSPs (T&TUA)				
Mapping (Ma)	4	Uncertainty regarding upstream supply chain actors that cause quality, sustainability or operational risks (MaUU)	Transparency regarding supply chain actors (MaTAc) and associated risks	Collecting data on involvement, products, quality and sustainability practices of suppliers, indirectly via third party service provider (MaI)	Upstream attainment by suppliers (MaUA)	None (MaN)	Internal trainings (MaIT), upfront calls and support of supply chain actors (MaET)	Structured communica tion, internal (MaIC) and with external supply chain actors (MaEC)	Power (MaPo-) and dependenc y negatively (MaDe-) affects deployment of the TSC mechanism
	17			As above, but directly, without a third party service provider (MaD)	Upstream attainment by suppliers (MaUA)				
	21			As in Case 17, including aggregation of external data to enhance the identification of risks (MaE)					
Event Watching (Ew)	1	Uncertainty regarding upstream supply chain disruptions and incidents (EwUU)	Transparency regarding supply chain disruptions (EwTDi)	In an IT-based tool, the upstream supply chain actors are identified and located, several external data sources (e.g., news portals) are used to identify events of disruptions, which triggers alerts for the FC (EwIT)	Upstream attainment by suppliers (EwUA) and third party attainment (EwTA)	Cloud storage system, BDA (EwBDA)	Internal trainings, escalation meetings/ calls and improveme nt meetings (EwIM), same with correspond ing suppliers (EwEM)	Internal communica tion channels and escalation procedures (EwIP), same with suppliers (EwEP)	Power (EwPo+) and dependenc y positively affects (EwDe+) deployment of the TSC mechanism
	19 24			As above, plus machine learning to improve the accuracy of identified events and direct communication channels in the IT-based tool (EwML)		As above, plus machine learning (EwML)			

	ID	Uncertainties	IPN	Description of TSC mechanism	Required actors to attain determinants	Advanced technology applied	Structures	Processes	Context
Auditing (Au)	6 10 16	Uncertainty regarding upstream suppliers' operational, quality, and sustainability performance (AuUU)	Transparency regarding suppliers' processes and capabilities (AuTCa)	Multi-angle audit with multi-functional involvement in audit, with data collection by on-site visits, questionnaires and references, followed by the definition of improvement measures (AuM)	Upstream attainment by suppliers (AuUA)	None (AuN)	Internal trainings of auditors and auditing team, preparation meetings (AuIT), planning with suppliers (AuEP)	Structured preparation, on-site audit, follow-up meetings and deadlines	Power (AuPo+) and dependency positively (AuDe+) affects deployment of the TSC mechanism

Discussion

Our analysis reveals that all cases are united by their achievement to establish a fit between the characteristics of the IPN and the resulting characteristics of the applied TSC mechanism as the IPC. To cope with uncertainty and satisfy the IPN, the focal companies in the cases achieved adequate IPCs by deploying tailored TSC mechanisms. By contrasting the IPNs and TSC mechanisms in B-Table 4, we identify 24 tailored solutions for the seven TSC mechanisms that match the characteristics of the IPNs of the focal company. In Cases 8, 15, 22, and 23 (screening and assessing), the IPN characterized by the need to increase the transparency regarding various performance dimensions of potential suppliers (S&ATPe) is matched with a comprehensive and rigorous screening and assessing mechanism that provides a comprehensive, multi-faceted, and multi-angle depiction of the suppliers (S&AS, S&AQ). In all cases, a fit was achieved, which resulted in an enhanced level of transparency for the focal company. Hence, the cases suggest that establishing a fit between IPN and IPC is a requirement for enhancing TSC. Thereby, our data confirms the general notion of IPT in the literature, which describes the fit as mandatory to achieve increased performance in general (e.g., Premkumar et al., 2005). With our study, we prove the validity of this general notion of IPT for TSC as well. Thus, we expand TSC literature as we identify the need to enable this fit for the focal company in order to enhance TSC. In line with Tushman and Nadler (1978) and Foerstl, Meinlschmidt, and Busse (2018), our interviewees confirm that a lower level of IPC leads to a reduced level of TSC and that a higher level of IPC would be economically inefficient, as deploying TSC mechanisms causes costs as well. Based on this, we developed the first proposition:

Proposition 1: A fit between IPN and IPC enhances TSC.

By looking more deeply at the unit of observation, we identified the determinants (see B-Table 3) that are required to enable a specific TSC mechanism and thus achieve the aforementioned fit between IPN and IPC. Our analysis indicates homogeneity between the cases of each individual TSC mechanism, as evidenced by the low number of instances of case numbers in B-Table 3 (twelve cells, or 5.9% of the total of 203 cells). When comparing all cases across the TSC mechanisms, we find heterogeneity as well. Only five TSC determinants (availability of data, relevant data, collaboration with partner, user acceptance, and user-friendliness) are required for all TSC mechanisms, and only ten determinants (34%) are associated with five or more TSC mechanisms. These results refine existing research on TSC in two ways. First, the case analysis emphasizes the importance of TSC determinants that go beyond the requirements of data (which we refer to as data determinants), in contrast to Williams et al. (2013), Srinivasan and Swink (2018), and Zhu et al. (2018), who mainly focus on data determinants. Our analysis suggests diversity among the required determinant groups, as each determinant group is associated with all TSC mechanisms. Second, the heterogeneity of the TSC mechanisms suggests that the TSC determinants are specific to the corresponding TSC mechanisms, as they address the IPN. When we contrast the IPN of the Cases 6, 10 and 16 (auditing) in B-Table 4 and the required determinants of auditing in B-Table 3 as an example, we find evidence that specific TSC determinants are required to deploy auditing. The IPN to gain transparency regarding the supplier's processes and capabilities (AuTCa), is reflected in the determinants. The availability and completeness of relevant data allows to gain a complete picture of the processes and capabilities of the relevant supply chain partner. The determinants correctness and verifiability of data enable the focal company to have a truthful picture of the processes and capabilities of the supply chain partner. In order to obtain a comprehensive and truthful reflection of the supply chain partner (e.g., suppliers), an inter-functional team with trained users (e.g., lead auditors) and clear responsibility needs to be available for the audit, which is reflected in the organizational determinants in B-Table 3. The integration in the established business processes and the periodic updates ensure to conduct audits at the right time, while the collaboration with the partner (supplier) and the purposeful communication enables to gather all relevant information. Furthermore, user acceptance and user friendliness account for the ease of conducting audits and thus the successful deployment. Thus, we derive the second proposition:

Proposition 2: Specific TSC determinants enable successful deployment of a TSC mechanism.

The findings of our case study suggest that the attainment of the TSC determinants is not limited to the focal company. Instead, B-Table 3 reveals that 22 of the 29 TSC determinants have to be attained by the corresponding upstream and downstream supply chain actors as well so that the focal company can deploy a TSC mechanism successfully. The multi-level attainment can be demonstrated for example by drawing on the required data determinants of forecasting as a TSC mechanism. The columns “description of the four forecasting solutions” and “required supply chain actors to attain determinants” in B-Table 4 show that the forecasting of the focal company requires data input from downstream supply chain actors (FoDA) such as deliver call-off or received orders and data input upstream supply chain actors (FoUA) such as suppliers’ inventory levels (only in Cases 7, and 13). The TSC determinants data accuracy and data correctness can only be achieved if data on deliver call-offs, received orders or inventory levels from downstream and upstream supply chain actors are accurate and correct. Similarly, it is the case for all other TSC determinants that contain a MA in the last column of B-Table 3. Thereby our findings reveal a new facet to extant TSC research. Extant literature is fuzzy when it comes to the multi-actor attainment of the determinants respectively antecedents. While scholars such as Williams et al. (2013) or Srinivasan and Swink (2018) reveal information sharing as an antecedent, which lets multi-actor attainment shining through, a clear emphasis and a distinctive discussion are missing. In addition, several contributions focus only on the focal company and its intra-firm antecedents (e.g., Zhu et al., 2018). B-Table 4 indicates that none of the TSC mechanism can be deployed successfully when the determinants are only attained by the focal company, as all 24 cases exhibit upstream attainment (UA) or downstream attainment (DA) of the corresponding supply chain actors. Thus, we formulate the third proposition.

Proposition 3: Both the focal company and the corresponding supply chain actors have to attain specific TSC determinants.

The findings reveal that the TSC mechanisms, as IPCs, require IT, structures, and processes. First, the data and solution determinants are built primarily on IT. As illustrated in B-Table 4 the use of IT varies and not all cases make use of advanced IT (S&AN, MoN, MaN, AuN). IoT sensors (MoIoT) and image analysis (MoIA) are cutting edge examples of technology deployment for monitoring in order to increase the availability, accuracy, accessibility, and timeliness of data. EDI is used as an IOIS for data sharing along the supply chain, especially for forecasting (FoML, FoBDA, FoEDI), thereby enabling accessibility and availability of data as well as automated data processing and standardized data exchange. Our analysis confirms the supporting function of IT in enhancing TSC at the focal company (Sanders & Ganeshan, 2018; Srinivasan & Swink, 2018; Zhu et al., 2018). However, we emphasize that the corresponding supply chain actors require adequate IT as well. For example, IoT sensors have to be deployed by suppliers and customers as well in order to fulfill the data determinants. Similarly, EDI usage is required by the corresponding supply chain actors as well to enable data accessibility and availability.

Second, organizational and relationship determinants are built on structures within the focal company and the corresponding supply chain actors. In the focal company, organizational structures establish clear responsibilities, inter-functional collaboration, and the availability of personal and trained users and thus account for the organizational determinants. For example, in the focal companies formalized preparation and trainings for the inter-functional auditing teams (AuIT). The relationship determinants are built on establishing exchange platforms, formalized meetings, and joint trainings to improve relationships and to establish a common understanding between the focal company and the corresponding partners. We identified formalized meetings (mostly calls) between the buying firm and supplier to establish a common understanding of the key performance indicators for monitoring (e.g., MoEM) and the purpose and process of mapping (e.g., MaET). With our findings, we expand TSC literature and emphasize the importance of structure to enhance TSC, as only Daugherty et al. (2006), identified a positive impact of structures in supply chains to enhance visibility.

Third, process and relationship determinants are built on processes within the focal company and the corresponding supply chain actors. Process determinants are achieved by designing internal processes for TSC mechanisms and embedding the TSC mechanisms in well-established business processes of the focal company. However, the process determinants are not limited to the focal company. The determinant ease of data gathering requires the establishment of adequate processes by the corresponding supply chain actors as well (e.g., FoIP, MoIP). The determinants collaboration with partner and third parties and purposeful communication represent relationship determinants that require processes overlapping the focal company and the corresponding supply chain actors (e.g., FoEC, MoEC). With these findings, we expand the TSC literature, which to date has only examined the design of processes in relation to sustainable supply chains, in which traceability plays a key role (Foerstl et al., 2018).

Consequently, in order to attain the variety in determinants and deploy a TSC mechanism, both the focal company and the corresponding supply chain actors need to make investments, build up resources and skills for IT, create structures and design processes. This confirms the general findings of organizational study of Bensaou and Venkatraman (1995) on the required IT, structures, and processes for a focal company. By identifying the need for adequate IT, structures and processes at the corresponding supply chain actors, we refine IPT to inter-organizational IPT in the context of TSC. Thus, we developed the fourth proposition:

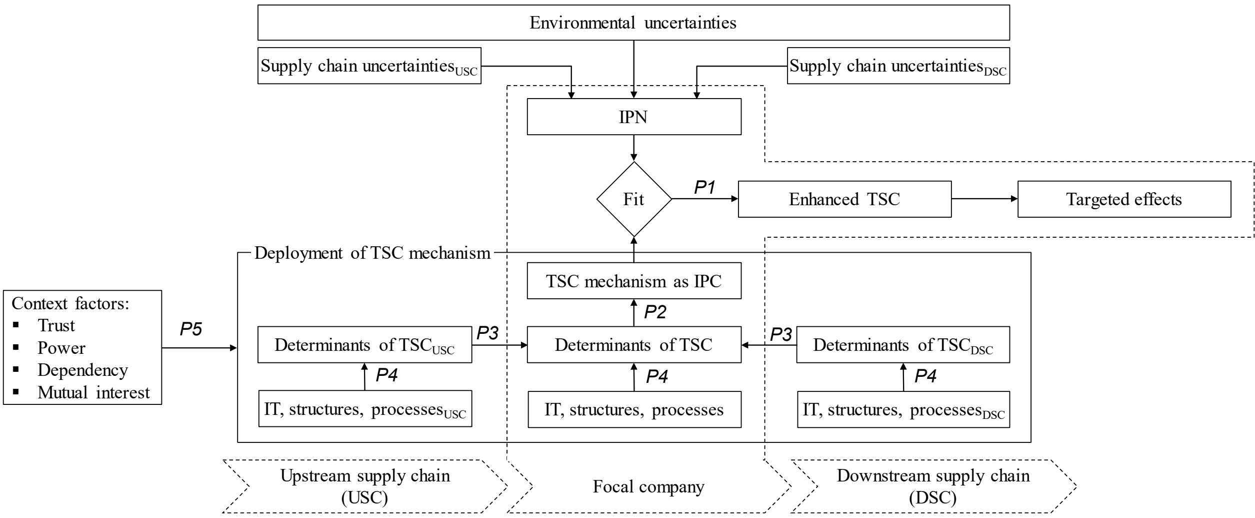
Proposition 4: Both the focal company and the corresponding supply chain actors have to establish IT, structures, and processes to attain the specific TSC determinants.

Moreover, the case data reveals context factors. These affect the deployment of the TSC mechanisms. Trust, power, and dependency between supply chain partners as well as mutual interest were identified as context factors that affect the deployment of TSC mechanisms as illustrated in B-Table 4. While trust, power, and dependency were revealed in multiple TSC mechanisms, mutual interest was only identified as a context factor that positively affected the deployment of screening and assessing for the focal company (MI+). Furthermore, the findings demonstrate a positive effect of trust between the focal company and the corresponding supply chain actor (Tr+) on the deployment of screening and assessing as well as forecasting. While trust and mutual interest affect the deployment of both TSC mechanism positively, power and dependency show positive and negative effects. On one side, the cases evidenced that the power of the focal company and the dependency of the corresponding supply chain actor can have a positive influence on the deployment of a TSC mechanism, as partners are more likely to disclose information to the focal company, e.g., for auditing of upstream supply chain actors (AuPo+, AuDe+). On the other side, supply chain partners are reluctant to disclose information to a powerful or superior focal company as they fear to lose bargaining power, create another disadvantage and increase their dependency as well as the power of the focal company, e.g., for mapping (MaPo-, MaDe-). This two-sided relation between power and TSC has been touched in literature on information disclosure (Egels-Zandén et al., 2015) and inter-organizational coordination (Clemons & Row, 1993). Our findings refine these first notion of the two-sided relation. Moreover, the identified context factors expand the extant literature (Brandon-Jones et al., 2014; Wamba

& Chatfield, 2009) and enable to understand the enhancement of TSC from the perspective of a focal company. As our study has an integrative nature to contribute to the understanding of how organizations can enhance TSC, the context factors have to be taken into account. Hence, we developed the fifth proposition:

Proposition 5: Context factors affect the deployment of a TSC mechanism.

Our case study of TSC elaborates on IPT in the inter-organizational context of TSC. From the perspective of the focal companies, which are led by uncertainties and resulting IPNs to deploy TSC mechanisms, this study determines the importance of intra-firm and inter-organizational information processing for enhancing TSC. Although upstream supply chain actors (e.g., suppliers in forecasting in Cases 7, and 13) and downstream supply chain actors (e.g., customers in forecasting and event watching in Cases 1, 2, 7, 9, 13, and 19) can benefit from enhanced TSC as well, the focal company is the main beneficiary. However, our data clearly indicate the importance of TSC determinants for the focal company and the corresponding supply chain actors to deploy a TSC mechanism. Only by addressing these determinants both within the focal companies and the corresponding supply chain actors, can focal companies attain the TSC determinants that lead to enhanced TSC. Thus, corresponding IT systems, structures, and processes must be established and used by the corresponding supply chain actors as well. Thereby, we expand on the extant IPT literature that focuses on the inter-organizational context of supply chains and develop a framework of TSC, shown in B-Figure 1 that illustrates how focal companies can enhance TSC.



B-Figure 1: TSC framework from the perspective of the focal company

Conclusion

As the interest in TSC is increasing in both practice and academia, we conducted a multiple-case study to investigate how focal companies can enhance TSC, thereby addressing the research gap described by Swift et al. (2019). The case study allowed us to develop an integrative study on TSC that placed TSC in context, analyzed the TSC mechanisms that are deployed to enhance TSC, and, ultimately, identify the common ground of TSC determinants, including supportive IT, structures, and processes. We identified the importance of the fit between IPN and IPC. Moreover, we revealed the specific characteristics of TSC mechanisms by exploring the diversity of associated TSC determinants. Along with this, we explored the different groups of determinants and the need to attain them through IT, structures, and processes both within the focal company and the corresponding supply chain actors. By drawing on IPT and synthesizing our findings, we built an integrative framework of TSC that illustrates the enhancement of TSC from the perspective of a focal company. In this way, we contribute to both theory and practice.

Theoretical contribution

Our theoretical contribution is threefold. First, we developed a framework of TSC (see B-Figure 1) that places the phenomenon in context, synthesizing and empirically expanding on existing TSC research (e.g., Barratt & Oke, 2007;

Williams et al., 2013) as well as helping to guide future research on this phenomenon. The framework enables researchers to focus on individual elements of TSC or on individual TSC mechanisms. It is especially important to investigate individual mechanisms, as heterogeneity between the seven TSC mechanisms was revealed.

Second, our study addresses the need for further clarification and operationalization of TSC (Wieland et al., 2016; Williams et al., 2013). We place TSC in context, providing a clearer picture of TSC and identifying the TSC determinants. As a result, we reveal how firms can enhance TSC. The determinants can be used to model TSC in future survey-based studies and can be applied as selection criteria in qualitative studies when researchers seek to study advanced levels of TSC. Moreover, future researchers can assess the benefit of a new technology at an early stage by analyzing its contributions to each determinant. Thereby, the operationalization of the TSC mechanism allows them to base their argumentation on the revealed TSC determinants.

Third, our study elaborates on IPT in the inter-organizational context of TSC using abductive reasoning, supplementing the studies of Williams et al. (2013), Srinivasan and Swink (2018), and Zhu et al. (2018). Our analysis suggests that intra-firm and inter-organizational alignment is important when focal companies seek to enhance TSC. While the literature on IPT mostly focuses on how organizations can be designed to establish a fit between IPN and IPC and thus improve performance in general (Galbraith, 1974; Tushman & Nadler, 1978), our study contributes to the stream of inter-organizational research on IPT (i.e., Bensaou & Venkatraman, 1995; Premkumar et al., 2005). We go beyond extant literature and elaborate on the inter-organizational aspects of information processing that allow organizations to enhance TSC. Our study reveals that the motivation to enhance TSC and the target effects are mainly centered on the focal company, but in order to enhance TSC, the focal company greatly depends on the inter-organizational information processing of its corresponding supply chain actors. Hence, to enhance TSC, both the focal company and its corresponding supply chain actors must build intra-firm and inter-organizational IT, structures, and processes.

Managerial contribution

The managerial contribution of our study is also threefold. First, by placing TSC in context, we illustrate the existing relationships and dependencies between the illustrated elements in B-Figure 1. Based on our framework in B-Figure 1, supply chain managers can account for these relationships and dependencies during efforts to enhance TSC. Our study provides a clear picture of the causal relationships between the motivation to enhance TSC and the deployment of the TSC mechanisms.

Second, we derive a clear list of required TSC determinants to deploy specific TSC mechanisms to enhance TSC. Following our study, supply chain managers should analyze uncertainty and the resulting IPN precisely, to choose the appropriate TSC mechanism. Then, they should take into account the TSC determinants and determine how they can build IT, structures, and processes to attain the relevant determinants for the chosen TSC mechanism. In addition, our study emphasis to collaborate with the relevant supply chain actors to foster the buildup of the required IT, structures and processes early on. This will help supply chain managers enhance TSC and cope with perceived uncertainty. Furthermore, they can draw on the TSC determinants and assess the attainment of IT, structures, and processes to identify reasons for low TSC after deploying a TSC mechanism.

Third, supply chain managers can use the identified determinants as a basis to assess the potential of novel technologies, such as DLT, for implementing a specific TSC mechanism and, ultimately, enhancing TSC. More specifically, managers can identify the technologies' contribution to attaining the required TSC determinants for a TSC mechanism. For example, in the case of DLT, extant literature (Babich & Hilary, 2019; Roeck, Sternberg, & Hofmann, 2019; Schmidt & Wagner, 2019; Wang et al., 2019) shows that DLT can contribute to the attainment of eight determinants: availability, accessibility, timeliness, processable, verifiable data, periodic update, automated data processing, and standardized data exchange. Seven of these are related to forecasting, and six are related to tracking and tracing. A brief initial assessment of DLT underlines the potential of the technology for both mechanisms. The list of determinants also allows managers to assess whether a technology is unsuitable or over-engineered for a specific TSC mechanism.

Limitations and future research

Our integrative study has limitations that provide opportunities for future research. Although we analyze a rather large number of cases, our integrative framework requires further external validation with a larger empirical dataset. Furthermore, our selection criteria strived to study good practices related to TSC mechanisms. While we carefully monitored the process of enhancing TSC and requested proof of positive effects (e.g., reaction time in Case 1), we were unable to isolate the positive effects completely and solely trace it back to enhanced TSC. Thus, future studies should investigate the causal relations between enhanced TSC and different performance effects, as Swift et al. (2019) began to do in their study. Moreover, we briefly outlined the deployment of intra-firm and inter-organizational IT, structures, and processes. Future studies can address this limitation by focusing on the practices for deploying intra-firm and inter-organizational IT, structures, and processes. Moreover, our case findings revealed the existence of context factors, which we included in our framework. Future studies should address these context factors and draw on contingency theory to research these in-depth. As our study has an integrative nature, we were unable to study the context factors in more detail, which provides opportunities for future research.

Appendix

Appendix A. Interview instrument[65]

A.1. Focal company’s interview instrument

A.1.1 General information

[65] The authors included the interview instrument in the appendix, however, the authors are happy to provide the full case study protocol following Yin (2017) upon request.

- Introduction, career, department, position and job description
- Company information, supply chain overview

A.1.2. Understanding of TSC and its importance

- Please describe your understanding of TSC. What is included in TSC according to your understanding?
- What is your understanding of visibility and traceability in the supply chain?
- Please describe the role of transparency for your supply chain.
- Please describe the role of transparency for your organization in general.
- How is TSC linked to your corporate strategy?
- Please describe how transparency in your supply chain has an effect on the organization's performance.
- What KPIs are affected by transparency currently?
- How is the effect currently (negative or positive)?

A.1.3. Usage and success of each of the seven TSC mechanisms[66]

- Please go through the list of the seven TSC mechanism and address the following questions for each:
    - Are you using this TSC mechanism in your organization?
    - What is the reason for the usage?
    - How successful is the usage of this TSC mechanism?
    - Can you underline the success with KPIs or other evidence of increased performance? Can you compare the success of your TSC mechanism with your competitors?
    - Please describe the positive effect of this TSC mechanism for a tangible performance dimension.
- Please assess, which of the discussed TSC mechanisms would qualify as an industry-wide good practice solution?

A.1.4. The selected TSC mechanism

- Please describe why you deploy this TSC mechanism. What was the reason for the deployment? How was the initial situation before you deployed the TSC mechanism?
- Please describe the TSC mechanism.
    - How does the TSC mechanism work?
    - How are the solution, the process, and the structures designed?
    - Who is involved (internally and externally)?
    - What are the different roles of the involved stakeholders (internal and external)?
    - What data is needed?
    - Where is the data coming from?

[66] As described in the section Data collection, these questions have only been answered by focal companies that are not award winners for their TSC solutions.

    - How is the data processed?
    - Which technologies are used and why?
- Please describe what is needed to use the TSC mechanism successfully?
    - What attributes would you associate with the successful deployment of the TSC mechanism?
    - What would you classify as the determinants that make the deployment of the TSC mechanism successful?
    - What capabilities are needed to deploy the TSC mechanism?

A.2. Corresponding supply chain actor's or solution provider's interview instrument

A.2.1 General information

- Introduction, career, department, position and job description
- Company information, supply chain overview (*only for supply chain actors*), link to focal company

A.2.2. The selected TSC mechanism

- Please describe the TSC mechanism from your perspective.
    - How does the TSC mechanism work?
    - How are the solution, the process, and the structures designed?
    - Who is involved from your organization?
    - What are the different roles of the involved stakeholders?
    - What data is needed?
    - Where is the data coming from?
    - How is the data processed?
    - How is it transferred to the focal company?
    - Which technologies are used and why?
- Please describe what is needed to use the TSC mechanism successfully from your perspective?
    - What attributes would you associate with the successful deployment of the TSC mechanism from your perspective?
    - What would you classify as the determinants that make the deployment of the TSC mechanism successful from your perspective?
    - What capabilities are needed to deploy the TSC mechanism from your perspective?

Appendix B. Exemplary coding tree[67]

Exemplary quotes	Exemplary first-order codes	Second-order codes on TSC determinants after selective coding
"Before, the local distributors often reported their stock levels wrong. That was the problem. Consequently the inventory level was too low at times. [...] We need a good customer forecast accuracy." Case 13, Fo	- Inventory distortion of customer as problem for forecasting - Distortion led to inadequate level of TSC - Inadequate level of TSC led to supply shortage - Accuracy of forecast input required for forecasting	- TSC determinant: Data accuracy - Multi-actor attainment of data accuracy
"It is important that the data we need for our mapping is available for the contact person at the supplier. And that he can make it available to us." Case 4, Ma	- Mapping depends on data availability - Supplier has to have data availability - Data availability at focal company needed	- TSC determinant: Data availability - Multi-actor attainment of data accuracy
"The most important thing is that we have a clarity about the unambiguousness of the part numbers we are talking about with our suppliers and internally." Case 1, Ew	- Unambiguousness of data important for event watching - Clarity is required for event watching - Importance of part numbers for event watching	- TSC determinant: Clarity of data - Multi-actor attainment of clarity of data
"We need all the required data, to perform a release. Otherwise we have to issue an additional request to the distributor, which leads to delays." Case 3, Mo	- Complete data must be transferred from LSP - Incomplete data causes delays - Importance of part numbers for event watching	- TSC determinant: Completeness of data - Multi-actor attainment of completeness of data
"We let him confirm his information, i.e. he guarantees us that his information is correct, which is crucial for our evaluation." Case 15, S&A	- Confirmation is required to ensure correctness - Correct data is crucial - Data is basis for next step, based on TSC	- TSC determinant: Correctness of data - Multi-actor attainment of correctness of data

References

Alvesson, M., & Kärreman, D. (2007). Constructing mystery: Empirical matters in theory development. *Academy of Management Review*, *32*(4), 1265–1281.

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*, 172–184.

Babich, V., & Hilary, G. (2019). Distributed ledgers and operations: What operations management researchers should know about blockchain technology. *Manufacturing & Service Operations Management*, *Forthcoming*.

Barratt, M., & Oke, A. (2007). Antecedents of supply chain visibility in retail supply chains: A resource-based theory perspective. *Journal of Operations Management*, *25*(6), 1217–1233.

Basole, R. C., & Bellamy, M. A. (2014). Supply network structure, visibility, and risk diffusion: A computational approach. *Decision Sciences*, *45*(4), 753–789.

Bensaou, M., & Venkatraman, N. (1995). Configurations of interorganizational relationships: A comparison between U.S. and Japanese automakers. *Management Science*, *41*(9), 1471–1492.

Brandon-Jones, E., Squire, B., Autry, C. W., & Petersen, K. J. (2014). A contingent resource-based perspective of supply chain resilience and robustness. *Journal of Supply Chain Management*, *50*(3), 55–73.

Brusset, X. (2016). Does supply chain visibility enhance agility? *International Journal of Production Economics*, *171*, 46–59.

[67] Coding tree is only illustrated for five TSC determinants. However, the authors are happy to provide additional coding trees for this study upon request.

Caridi, M., Crippa, L., Perego, A., Sianesi, A., & Tumino, A. (2010). Do virtuality and complexity affect supply chain visibility? *International Journal of Production Economics*, *127*(2), 372–383.

Carter, C. R., & Easton, L. P. (2011). Sustainable supply chain management: Evolution and future directions. *International Journal of Physical Distribution & Logistics Management*, *41*(1), 46–62.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, *38*(5), 360–387.

Cegielski, C. G., Allison Jones-Farmer, L., wu, Y., & Hazen, B. T. (2012). Adoption of cloud computing technologies in supply chains: An organizational information processing theory approach. *The International Journal of Logistics Management*, *23*(2), 184–211.

Cheng, M. J., & Simmons, J.E.L. (1994). Traceability in manufacturing systems. *International Journal of Operations & Production Management*, *14*(10), 4–16.

Clemons, E. K., & Row, M. C. (1993). Limits to interfirm coordination through information technology: Results of a field study in consumer packaged goods distribution. *Journal of Management Information Systems*, *10*(1), 73–96.

Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarriá, D., & Menesatti, P. (2013). A review on agri-food supply chain traceability by means of RFID technology. *Food and Bioprocess Technology*, *6*(2), 353–366.

Cramer, J. M. (2008). Organising corporate social responsibility in international product chains. *Journal of Cleaner Production*, *16*(3), 395–400.

Daugherty, P. J., Richey, R. G., Roath, A. S., Min, S., Chen, H., Arndt, A. D., & Genchev, S. E. (2006). Is collaboration paying off for firms? *Business Horizons*, *49*(1), 61–70.

Doorey, D. J. (2011). The transparent supply chain: From resistance to implementation at Nike and Levi-Strauss. *Journal of Business Ethics*, *103*(4), 587–603.

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Luo, Z., & Roubaud, D. (2017). Upstream supply chain visibility and complexity effect on focal company's sustainable performance: Indian manufacturers' perspective. *Annals of Operations Research*, 1–25.

Edmonson, A. C., & McManus, S. E. (2007). Methodological fit in management field research. *Academy of Management Review*, *32*(4), 1155–1179.

Egels-Zandén, N., Hulthén, K., & Wulff, G. (2015). Trade-offs in supply chain transparency: The case of Nudie Jeans Co. *Journal of Cleaner Production*, *107*(16), 95–104.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

Foerstl, K., Meinlschmidt, J., & Busse, C. (2018). It's a match! Choosing information processing mechanisms to address sustainability-related uncertainty in sustainable supply management. *Journal of Purchasing and Supply Management*, *24*(3), 204–217.

Galbraith, J. R. (1974). Organization design: An information processing view. *Interfaces*, *4*(3), 28–36.

Gardner, J. T., & Cooper, M. C. (2011). Strategic supply chain mapping approaches. *Journal of Business Logistics*, *24*(2), 37–64.

Gerring, J. (2004). What is a case study and what is it good for? *American Political Science Review*, *98*(02), 341–354.

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational Research Methods*, *16*(1), 15–31.

Glaser, B. G. (1992). *Basics of grounded theory analysis.* Mill Valley, CA: Sociology Press.

Glaser, B. G., & Strauss, A. L. (2009). *The discovery of grounded theory: Strategies for qualitative research* (4. Edition). New Brunswick: Aldine.

Gold, S., Seuring, S., & Beske, P. (2010). Sustainable supply chain management and inter-organizational resources: A literature review. *Corporate Social Responsibility and Environmental Management*, *17*(4), 230–245.

Gross, A. (2019). Tech paves way for transparency in supply chains: Consumers and investors demand to know the provenance of purchases and investments. Retrieved from https://www.ft.com/content/033b9f2e-dfb5-11e9-b8e0-026e07cbe5b4

Gunasekaran, A., Subramanian, N., & Rahman, S. (2015). Supply chain resilience: Role of complexities and strategies. *International Journal of Production Research*, *53*(22), 6809–6819.

Hofmann, E., Sternberg, H., Chen, H., Pflaum, A., & Prockl, G. (2019). Supply chain management and Industry 4.0: Conducting research in the digital age. *International Journal of Physical Distribution & Logistics Management*, *49*(10), 945–955.

Holweg, M., Disney, S., Holmström, J., & Småros, J. (2005). Supply chain collaboration: Making sense fo the strategy continuum. *European Management Journal*, *23*(2), 170–181.

Ivanov, D., & Dolgui, A. (2018). Low-Certainty-Need (LCN) supply chains: A new perspective in managing disruption risks and resilience. *International Journal of Production Research*, *57*(15-16), 5119–5136.

Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative Science Quarterly*, *24*(4), 602–611.

Jin, Y. "H.", Williams, B. D., Tokar, T., & Waller, M. A. (2015). Forecasting with temporally aggregated demand signals in a retail supply chain. *Journal of Business Logistics*, *36*(2), 199–211.

Kärkkäinen, M., Ala-Risku, T., & Främling, K. (2004). Efficient tracking for short-term multi-company networks. *International Journal of Physical Distribution & Logistics Management*, *34*(7), 545–564.

Kent, J. L., & Mentzer, J. T. (2003). The effect of investment in interorganizational information technology in a retail supply chain. *Journal of Business Logistics*, *24*(2), 155–175.

Ketokivi, M., & Choi, T. (2014). Renaissance of case research as a scientific method. *Journal of Operations Management*, *32*(5), 232–240.

Kim, Y. H., & Davis, G. F. (2016). Challenges for global supply chain sustainability: Evidence from conflict minerals reports. *Journal of Business Logistics*, *59*(6), 1896–1916.

Kovács, G. (2008). Corporate environmental responsibility in the supply chain. *Journal of Cleaner Production*, *16*(15), 1571–1578.

Liu, H., Ke, W., Wei, K. K., & Hua, Z. (2013). The impact of IT capabilities on firm performance: The mediating roles of absorptive capacity and supply chain agility. *Decision Support Systems*, *54*(3), 1452–1462.

McFarlane, D., & Sheffi, Y. (2003). The impact of automatic identification on supply chain operations. *International Journal of Logistics Management*, *14*(1), 1–17.

Meredith, J. (1998). Building operations management theory through case and field research. *Journal of Operations Management*, *16*(4), 441–454.

Mighty Earth (2019). Cargill: The worst company in the world. Retrieved from https://stories.mightyearth.org/cargill-worst-company-in-the-world/index.html

Miller, J. W., Fugate, B. S., & Golicic, S. L. (2017). How organizations respond to information disclosure: Testing alternative longitudinal performance trajectories. *Academy of Management Journal*, *60*(3), 1016–1042.

Min, S., Zacharia, Z. G., & Smith, C. D. (2019). Defining supply chain management: In the past, present, and future. *Journal of Business Logistics*, *40*(1), 44–55.

Morgan, T. R., Richey, R. J. G., & Ellinger, A. E. (2018). Supplier transparency: Scale development and validation. *International Journal of Logistics Management*, *4*(1), 959–984.

Oliva, R., & Watson, N. (2009). Managing functional biases in organizational forecasts: A case study of consensus forecasting in supply chain planning. *Production and Operations Management*, *18*(2), 138–151.

Oliveira, R. R., Cardoso, I. M.G., Barbosa, J. L.V., da Costa, C. A., & Prado, M. P. (2015). An intelligent model for logistics management based on geofencing algorithms and RFID technology. *Expert Systems with Applications*, *42*(15), 6082–6097.

Pagell, M., & Wu, Z. (2009). Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars. *Journal of Supply Chain Management*, *45*(2), 37–56.

Premkumar, G. P., Ramamurthy, K., & Saunders, C. S. (2005). Information processing view of organizations: An exploratory examination of fit in the context of interorganizational relationships. *Journal of Management Information Systems*, *22*(1), 257–294.

Rauer, J., & Kaufmann, L. (2015). Mitigating external barriers to implementing green supply chain management: A grounded theory investigation of green-tech companies' rare earth metals supply chains. *Journal of Supply Chain Management*, *51*(2), 65–88.

Roeck, D., Sternberg, H., & Hofmann, E. (2019). Distributed ledger technology in supply chains: A transaction cost perspective. *International Journal of Production Research*, 1–18.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117–2135.

Sanders, N. R., & Ganeshan, R. (2018). Big data in supply chain management. *Production and Operations Management*, *27*(10), 1745–1748.

Schmidt, C. G., & Wagner, S. M. (2019). Blockchain and supply chain relations: A transaction cost theory perspective. *Journal of Purchasing and Supply Management*, *25*(4), 100552.

Srinivasan, R., & Swink, M. (2018). An investigation of visibility and flexibility as complements to supply chain analytics: An organizational information processing theory perspective. *Production and Operations Management*, *27*(10), 1849–1867.

Steinfield, C., Markus, M. L., & Wigand, R. T. (2011). Through a glass clearly: Standards, architecture, and process transparency in global supply chains. *Journal of Management Information Systems*, *28*(2), 75–108.

Swift, C., Guide Jr., V. D. R., & Muthulingam, S. (2019). Does supply chain visibility affect operating performance? Evidence from conflict minerals disclosures. *Journal of Operations Management*, *65*(5), 406–429.

Tomlin, B. (2006). On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management Science*, *52*(5), 639–657.

Tushman, M. L., & Nadler, D. A. (1978). Information processing as an integrating concept in organizational design. *Academy of Management Review*, *3*(3), 613–624.

Urquhart, C. (2013). *Grounded theory for qualitative research. a practical guide. Cathy Urquhart*. London: SAGE.

Visich, J. K., Li, S., Khumawala, B. M., & Reyes, P. M. (2009). Empirical evidence of RFID impacts on supply chain performance. *International Journal of Operations & Production Management*, *29*(12), 1290–1315.

Wadhwa, S., Mishra, M., Chan, F. T.S., & Ducq, Y. (2010). Effects of information transparency and cooperation on supply chain performance: A simulation study. *International Journal of Production Research*, *48*(1), 145–166.

Wamba, S. F., & Chatfield, A. T. (2009). A contingency model for creating value from RFID supply chain network projects in logistics and manufacturing environments. *European Journal of Information Systems*, *18*(6), 615–636.

Wan, Z., & Beil, D. R. (2009). RFQ auctions with supplier qualification screening. *Operations Research*, *57*(4), 934–949.

Wang, E. T. G., & Wei, H.-L. (2007). Interorganizational governance value creation: Coordinating for information visibility and flexibility in supply chains. *Decision Sciences*, *38*(4), 647–674.

Wang, G., Gunasekaran, A., Ngai, E. W.T., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. *International Journal of Production Economics*, *176*, 98–110.

Wang, Y., Han, J. H., & Beynon-Davies, P. (2018). Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. *Supply Chain Management: An International Journal*, *24*(1), 62–84.

Wang, Y., Singgih, M., Wang, J., & Rit, M. (2019). Making sense of blockchain technology: How will it transform supply chains? *International Journal of Production Economics*, *211*, 221–236.

Wieland, A., Handfield, R. B., & Durach, C. F. (2016). Mapping the landscape of future research themes in supply chain management. *Journal of Business Logistics*, *37*(3), 205–212.

Wilhelm, M. M. (2011). Managing coopetition through horizontal supply chain relations: Linking dyadic and network levels of analysis. *Journal of Operations Management*, *29*(7-8), 663–676.

Williams, B. D., Roh, J., Tokar, T., & Swink, M. (2013). Leveraging supply chain visibility for responsiveness: The moderating role of internal integration. *Journal of Operations Management*, *31*(7-8), 543–554.

Yaffe-Bellany, D. (2019). From environmental leader to ‘worst company in the world’. Retrieved from https://www.nytimes.com/2019/07/29/business/brazil-deforestation-cargill.html

Yan, T., Choi, T. Y., Kim, Y., & Yang, Y. (2015). A theory of the nexus supplier: A critical supplier from a network perspective. *Journal of Supply Chain Management*, *51*(1), 52–66.

Yin, R. K. (2017). *Case study research and applications: Design and methods* (6. Edition). Thousand Oaks, CA: SAGE.

Zhu, S., Song, J., Hazen, B. T., Lee, K., & Cegielski, C. (2018). How supply chain analytics enables operational supply chain transparency. *International Journal of Physical Distribution & Logistics Management*, *48*(1), 47–68.

Appendix C – Study 3

The struggle is real: Insights from a supply chain blockchain case

Henrik Sternberg[a], Erik Hofmann[b] and Dominik Roeck[b]

[a] Debbie and Jerry Ivy College of Business, Iowa State University, USA

[b] Institute of Supply Chain Management, University of St.Gallen, Switzerland

Accepted and published online in Journal of Business Logistics

Abstract

Despite the anticipated benefits and the numerous announcements of pilot cases, we have seen very few successful implementations of blockchain technology (BCT) solutions in supply chains. Little is empirically known about the obstacles to blockchain adoption, particularly in a supply chain's inter-organizational setting. In supply chains, blockchains' benefits, for example BCT-based tracking and tracing, are dependent on a critical mass of supply chain actors' adopting the technology. While previous research has mainly been conceptual and has lacked both theory and empirical data, we propose a theory-based model for inter-organizational adoption of BCT. We use the proposed model to analyze a unique, in-depth revelatory case study. Our case study confirms previous conceptual work and reveals a paradox as well as several tensions between drivers for and against (positive and negative determining factors, respectively) of BCT adoption that must be managed in an inter-organizational setting. In this vertical context, the adoption and integration decision of one supply chain actor recursively affects the adoption and integration decisions of the other supply chain actors. This paper contributes mid-range theory on BCT in supply chain management (SCM), future research directions, and managerial insights on BCT adoption in supply chains.

Keywords: Blockchain technology, Case study research, Inter-organization systems, Provenance, Supply chain transparency, Technology adoption

Introduction

Few information systems are currently gaining as much as attention as the ones building on blockchain technology (BCT) (Babich and Hilary 2019; Panetta 2018). BCT has generated trust in cryptocurrencies, such as Bitcoin and Ethereum, by ensuring the authenticity of digital resources and identities. Therefore, the technology is often referred to as a “trust machine” (e.g. Beck et al. 2016; Clemons et al. 2017). Beyond cryptocurrencies, several BCT initiatives (e.g., Provenance.org (Wheeler 2017)) are riding on the trend of the increasing pressure on retailers, for example, to increase transparency and disclose supply chain information (Marshall et al. 2016; Saberi et al. 2019). Moreover, shippers and logistics service providers like Maersk, Nestlé, and Walmart are declaring BCT will greatly change and improve supply chain management (SCM) (Doe 2017).

However, change and improvement in supply chains only come with the adoption of such technology across the involved parties and value chain partners. When the state of BCT in SCM was examined at the time of this writing, only a few BCT projects had been adopted on a larger scale. IBM’s TradeLens and Food Trust are rare examples of BCT-enabled solutions in supply chains that have moved beyond a pilot state. However, this scarcity of BCT projects does not mean that the interest in this new technology has decreased (Budman et al. 2019; Panetta 2018) but shippers and their logistics service providers seem to struggle (Higginson et al. 2019) because cases of scalable adoptions in their supply chains are rare (Budman et al. 2019). At the same time, several academic conferences have hosted BCT in supply chain tracks, several journals have announced forthcoming special issues on BCT applications (e.g., Koh et al. 2018; Rao et al. 2017), and the first scientific papers about BCT in SCM have been published in academic journals (Babich and Hilary 2019; Roeck et al. 2019; Wang et al. 2019).

While existing papers have merit in increasing the understanding of BCT and conceptually explaining BCT in operations and SCM, they have two limitations. First, they are mainly conceptual (Babich and Hilary 2019; Schmidt and Wagner

2019; Treiblmaier 2018; Wüst and Gervais 2017). Second, no papers have been theory based nor have any addressed the critical question of BCT adoption in inter-organizational supply chain settings. Extant contributions are limited to general explorations of BCT's benefits and obstacles (e.g., Wang et al. 2019). However, without any empirical evidence or theory, studying BCT adoption conceptually renders neither a full understanding of the adoption phenomenon in the complex setting of inter-organizational supply chains nor the benefit from previous knowledge accumulated in the theory. To contribute to theory and practice, theoretical and empirical grounding is necessary when studying BCT adoption in supply chains.

Information systems (IS) research deals with technology adoption spanning organizational boundaries, i.e. inter-organizational information systems (IOIS) (Premkumar et al. 1997). In the case of BCT in supply chains, the value of a single organization's adopting BCT is at best limited because the benefits are reaped when a critical mass of stakeholders and value chain partners adopt the technology. In other words, BCT entails *network effects* (Katz and Shapiro 1994) because they are only achieved when the number of members in a network adopting a technology is at or above the threshold at which the technology yields benefits. BCT-enabled transparency in supply chains is an example of such a network effect as multiple members and value chain partners share information through a distributed ledger. As indicated by the significant attention practitioners and scholars pay to this issue, understanding the specific characteristics of BCT adoption in supply chains is important, especially when considering the BCT's large anticipated impact on supply chains (Blossey et al. 2019; Casey and Wong 2017). Despite the impact and promised benefits, the adoption is described as having "lack of progress" (Higginson et al. 2019). Therefore, we aim to conceptualize BCT adoption in supply chains and contribute to SCM theory by asking the following research question:

Why do supply chains, despite the promising benefits, struggle to adopt BCT?

In answering this question, we elaborate on IOIS adoption theory (Iacovou et al. 1995; Premkumar et al. 1997) while aiming to address the lack of empirically and theoretically grounded work on BCT adoption in supply chains. We investigate the applicability of IOIS adoption theory to our aim by using this theory to frame our results from a BCT pilot study. The focus is on BCT-enabled vertical supply chain transparency in an IOIS context. Supply chain finance, trade platforms, and other horizontal or diagonal applications of BCT are outside this paper's scope.

Because the technology is still in an early stage and an ex-ante evaluation is difficult, we cannot comprehensively elaborate on BCT. However, our study offers two main mid-range theoretical contributions (Stank et al. 2017). Through an-depth case study, we complement previous conceptual or expert-based studies by identifying and conceptualizing trade-offs (tensions) going beyond previous literature (Babich and Hilary 2019; Wang et al. 2019) as well as paving the way for future design research to address the issues that currently prevent large-scale adoption. This study also proposes a model, based on IOIS theory, to determine adoption of BCT in supply chains.

Theoretical background

To theorize on innovation or technology adoption in supply chains, SCM scholars often draw from IS research (Autry et al. 2010; Hazen et al. 2012), which has a long history of studying inter-organizational adoption of technical innovations (Barrett and Konsynski 1982; Grover 1993). Innovation diffusion is typically divided into three stages: (1) initiation (awareness), (2) adoption (the decision to implement), and (3) routinization (actual use) (Zhu et al. 2006). The focus of most IS – as well as SCM – research is on the second stage, the adoption (Hazen et al. 2012).

A subset of the IS literature focuses on IOIS adoption. According to Johnston and Vitale (1988), "an IOIS is built around information technology, i.e., around computer and communications technology, that facilitates the creation, storage, transformation, and transmission of information. An IOIS differs from an internal distributed information system by allowing information to be sent across organizational boundaries. Access to stored data and applications programs is shared, sometimes to varying degrees, by the participants in an IOIS" (p. 154). Thus, BCT is an IOIS; and the application of IOIS adoption theory to BCT adoption in supply chains is warranted.

Adoption of inter-organizational information systems

IOIS adoption differs from general technology adoption in that the decision to adopt is made by the focal firm considering not only its own business but also the adoption decisions of other actors in the supply chain. Researchers have used technologies such as electronic data interchange (EDI), barcodes, and RFID when developing and testing IOIS adoption theories. Several factors influence technology adoption; and a large part of the research is mid-range theory, i.e., contextualized based on a specific technology, a single industry, or a distinct organizational setting (Grover 1993; Venkatesh et al. 2003). While studying a single organization's adoption of an innovation is complex, studying and anticipating future adoption of IOIS in inter-organizational settings is even more complex due to numerous environmental and firm-specific factors (Riggins and Mukhopadhyay 1994).

Several models exploring IOIS adoption have been tested with mixed results (cf., Autry et al. 2010; Grover 1993). Although numerous factors have been found to influence technology adoption (Venkatesh et al. 2003), most studies determine that the following three factors are significantly and consistently related to inter-organizational adoption: (1) relative advantage, (2) complexity, and (3) compatibility (Iacovou et al. 1995; Premkumar et al. 1997).

Blockchain characteristics and supply chain application

In contrast to traditional centralized databases, BCT distributes the ledger of transaction data in a network of multiple members. Consequently, BCT is part of the distributed ledger technology (DLT). The transaction data are stored in blocks that are chronologically chained together, thus the name *blockchain* (Swan 2015). Within such a network, every member (represented as a node) stores the entire blockchain (BC) and, therefore, has all the transaction data ever stored in the BC.

Thus, all nodes possess the same data, and manipulation of the historical transaction's data is detected by automatically comparing the ledger within the network (Beck et al. 2017). To enter new transaction data (i.e., adding a block with transaction data to the existing BC), a consensus among the network's nodes is needed. Once this consensus is reached, the new block is distributed through peer-to-peer communication to all members in the network. Consequently, all members have the same record of transactions. Unlike in centralized database systems, this peer-to-peer communication and the distributed ledger eliminate the technical need for a trusted central party to coordinate and communicate these changes (Beck et al. 2016). There are two main types of blockchains (Wüst and Gervais 2017):

- *Public blockchains*: With this type, every transaction is public (and, thus, "permissionless"), and users can remain anonymous. The network typically has an incentivizing mechanism to encourage more participants to join the network.
- *Permissioned blockchains*: With this type, participants must receive an invitation or otherwise have permission to join. Access tends to be controlled by a consortium of members (consortium blockchains) or by a single organization (private blockchains).

Scholars have started conceptualizing the technology's benefits in supply chains. In the operations management context, Babich and Hilary (2019) identify visibility, aggregation, validation, automation, and resiliency as BCT's main promised benefits. Saberi et al. (2019) see transparency, trust, automation, security, and decentralization as BCT's key benefits in SCM. Blossey et al. (2019) identify transparency, automation, and validation as the technology's benefits, while Kolb et al. (2018) add immutability and high accessibility to the long list of perceived benefits. In the supply chain context, the interviews by Wang et al. (2019) suggest these benefits:

- *BCT improves supply chain transparency*. Allowing the development of services such as track-and-trace, BCT reduces the need for double-checking because data validation is automated. Furthermore, BCT allows tracing transactions, thus providing a proof of provenance.

- *BCT ensures secure information sharing and builds trust.* The information (one data pool) within blockchains is viewable by all participants and cannot be altered by a single entity, thus creating trust and reducing fraud. Users can remain anonymous or provide proof of their identity.
- *BCT allows for operational improvements.* It speeds end-to-end supply chain execution and allows for increased volume as well as data accuracy. BCT-enabled solutions distribute data within seconds throughout the entire network. The consensus mechanisms validate the data integrity and build an integer basis for smart contracts, enabling automation along the supply chain.

As previously noted, the promised benefits arise from a network—i.e., the benefits only occur if multiple supply chain actors adopt the technology (cf., Sternberg and Andersson 2014), something previous studies of blockchains in SCM and OM have not addressed. In terms of a network effect (Katz and Shapiro 1994), other supply chain actors' decision to apply and use the technology affects the possible added value for all the participating and using members. Improved supply chain transparency, secure information-sharing, and operational improvements cannot be achieved solely by individual technology adoption. According to Shapiro and Varian (1998), each actor who adopts and uses a certain product or service (e.g., a BCT-enabled supply chain transparency solution) increases the value of that product or service. Such a supply chain-wide BCT adoption on an inter-organizational level is necessary for achieving gapless visibility and for disclosing a product's journey along the supply chain.

Besides considering BCT's many promised benefits and other supply chain actors' decisions to adopt and integrate the technology, the SCM and operations management literature points to the importance of considering the obstacles to BCT adoption (Babich and Hilary 2019; Schmidt and Wagner 2019). For example, Babich and Hilary (2019) discuss five weaknesses: (1) the lack of privacy, 2) the lack of standardization, (3) the “garbage in, garbage out" (GIGO) problem, (4) the black box effect (i.e., the need for consumers to trust the implementation), and (5) inefficiency.

Based on Wang et al. (2019), the following possible obstacles of BCT adoption and usage in SCM (with sample issues) are identified:

- *Cultural:* Changing operational protocols is a hurdle. Conflicting stakeholder objectives and cultural hurdles to overcome with innovations might interfere with a successful adoption along the supply chain.
- *Necessity and confidence*: Many organizations are unsure of BCT functions and benefits. Thus, they decline the adoption in their organization.
- *Information-sharing*: Ensuring input data’s integrity is difficult and requires much effort. These factors can discourage organizations from adopting BCT in their supply chains.
- *Technological*: Adopting BCT poses the inherent risk of overcomplicating the supply chain’s ecosystems. Moreover, the lack of standards hampers BCT’s adoption along the supply chain.
- *Cost, legality, and privacy*: Involved organizations’ resistance to a high level of transparency and regulatory uncertainties are opponents of BCT adoption in supply chains.

It should be noted that several recent studies (e.g., Babich and Hilary 2019; Schmidt and Wagner 2019; Wang et al. 2019) are at a general level. They provide valuable theoretical implications, though neither address BCT’s adoption in the supply chain context nor are they based on empirical evidence from BCT projects. Thus, given the complexity of the BCT phenomenon in the supply chain context, in-depth research is warranted that accounts for the technology as well as the intra-firm and inter-organizational factors of supply chain adoption. This complexity calls for including the interdependency of obstacles and benefits on a detailed level. For example, the obstacle *information-sharing* is apparently related to the benefits *BCT ensures secure information sharing and builds trust*. To fully understand the adoption of BCT in supply chains, these benefits and obstacles cannot be listed without their interrelationships.

Synthesized model

Using the IOIS adoption model proposed by Iacovou et al. (1995), we explore the struggle with adopting BCT in supply chains based on real-life case study data. Thus, we go beyond the existing literature's generic listing of benefits and obstacles. Including economic, organizational, and environmental determining factors for IOIS adoptions, this

model was chosen for three main reasons. First, its key determining factors – *perceived benefits, organizational readiness, and external pressure* – have stood the test of time. Numerous other studies have been framed using similar factors (e.g., Chwelos et al. 2001; Zhu et al. 2003). Second, this model consists of an outside-in dimension (external pressure), enabling us to emphasize the different power levels and potential influences of the supply chain actors involved (Cox 2004; Premkumar et al. 1997). Third, in contextualizing IOIS adoption, by considering BCT's benefits and obstacles in supply chains (Babich and Hilary 2019; Wang et al. 2019; Wüst and Gervais 2017), it becomes apparent that not only positive IOIS factors of adoption (factors that make an adoption decision more likely, henceforth denoted as *positive IOIS factors*) but also negative IOIS factors of adoption (factors that make an adoption decision less likely, henceforth denoted as *negative IOIS factors*) must be accounted for. Although Iacovou et al. (1995) model primarily addresses positive IOIS factors, it is also useful for incorporating technology adoption's perceived negative effects, i.e., negative IOIS factors.

As previously outlined, the anticipated benefits of BCT in supply chains arise from its inter-organizational use (network effects). For instance, full transparency (e.g., in terms of provenance or tracking and tracing) is only achieved when all supply chain actors adopt and contribute their data, requiring multiple partners in the supply chain to adopt in order to leverage the network effect.

This requirement is important to consider because other IOIS, such as EDI, can be highly beneficial at an intra-firm level or in a dyad between only two firms. Therefore, factors determining adoption, promised benefits, and potential challenges on an inter-organizational level both positively and negatively affect BCT's adoption in supply chains. As a result, trade-offs between positive and negative IOIS factors must be considered when exploring the reasons supply chains struggle to adopt BCT.

Synthesizing technology adoption's determining factors (by considering both the anticipated benefits and the potential challenges of BCT in supply chains), we propose the following conceptual frame:

- On the positive side, *perceived benefits* include awareness of the focal organization's direct and indirect savings. Direct savings include reduced transaction costs, reduced inventory levels, and improved information quality in supply chain. Indirect benefits (opportunities) include increased operational efficiency, improved customer service, improved trading partner relationships, and increased ability to compete. Perceived benefits include factors related to supply chain operations. On the negative side, *perceived obstacles* to technology adoptions in supply chains are always accompanied by implementation costs. These perceived obstacles may include inefficiencies (e.g., necessary process adjustments or additional handlings to operate the technology).
- *External pressure* (in the positive sense) to adopt comes from the organizational environment in the form of promises and threats from two main categories: (1) competitors and (2) trading partners. Firms that encounter pressure from the competition or that are exposed to environmental uncertainty adopt novel technologies in their supply chains more frequently than those that do not encounter such pressure or uncertainties. Likewise, *external resistance* to adoption – a negative IOIS

factor – among supply chain partners defers adoption. Reasons for resistance might be the unwillingness to implement the technology in partners' respective supply chain operations or the lack of top-management support.

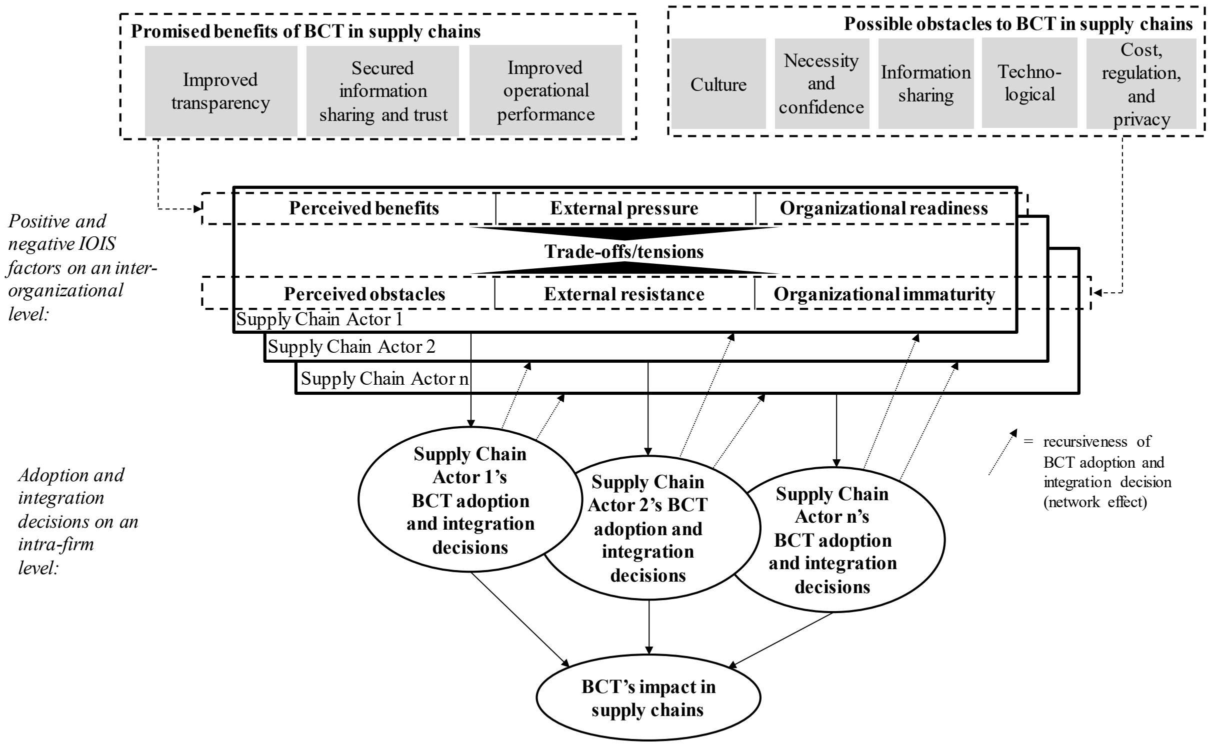
- *Organizational readiness* – in its positive sense – is defined as "the availability of the needed organizational resources for adoption" (Iacovou et al. 1995, p. 467). Financial resources and technological readiness as well as other resources are included. Firms with higher organizational and information communication technology readiness are more likely to adopt novel technology in the supply chain than firms with low readiness levels. Targeted forms of support (e.g., management support or technology and financial assistance) are positively associated with an organization's intention to adopt technology in the supply chain. Organizational readiness mainly indicates strategic readiness (or the lack thereof) for IOIS adoption. In contrast, *organizational immaturity* represents the unavailability of required resources for adopting technology in the supply chain.

We apply the suggested positive IOIS factors' perceived benefits, organizational readiness, and external pressure together with the corresponding negative IOIS factors to the supply chain actors' individual firm. The relations among positive and negative IOIS factors lead to trade-offs and tensions:

- *Trade-offs:* The individual decision of whether to adopt and integrate the technology is based on evaluating the trade-off between the positive and negative IOIS factors. However, because BCT is an IOIS, each decision affects other supply chain actors' perceptions of BCT's pros and cons and, thus, recursively the decision of whether to adopt.
- *Tensions:* Specifically, such trade-offs that cannot be properly resolved (e.g., positive arguments cannot fully rebut negative circumstances) lead to tensions. Such tensions as arguments and counterarguments can exist either within or among supply chain actors (because the positive

and negative IOIS factors are ex-ante perceptions) and can vary among managers or functions within a firm.

C-Figure 1 summarizes the synthesized model of inter-organizational BCT adoption in supply chains as our conceptual framework. The logic for using the model is that BCT's promised benefits and possible obstacles in supply chains foster the consideration of both positive and negative IOIS factors. One supply chain actor's decision to adopt and integrate is not made in a vacuum; decisions recursively affect both the positive and the negative IOIS factors of other supply chain actors.



C-Figure 1: The synthesized model of inter-organizational BCT adoption in supply chains, based on Iacovou et al. (1995) and adapted using Wang et al. (2019).

After describing the research design and the BCT pilot study, ReLog, we apply this theoretical model to analyze and reveal why supply chains struggle to adopt BCT.

Research design

This paper's purpose and research question aim to contribute to the theory by both conceptualizing and elaborating on BCT adoption in SCM. As outlined in the background and despite "the buzz," there is a scarcity of actual blockchain adoptions in SC settings. There is an even greater scarcity of BCT pilots in the SC field, rendering them important targets for in-depth investigations because the specifics of many pilot implementations are not disclosed to the public; instead, only superficial and unilateral promotion material is available (Wüst and Gervais 2017). Thus, we studied a BCT pilot implementation along supply chains with several actors to gain in-depth insights in order to fulfill this paper's purpose. Because we were able to follow ReLog's BCT application from conception to the project's discontinuation, the case was a solid basis for closely studying how BCT in supply chains is perceived. Thus, we observed ReLog's pilot implementation, which constitutes our unit of observation and all the involved project partners.

Case study

In short, ReLog's aim was to offer a mobile application, with a BCT backend, to enhance traceability along sections of supply chains and to provide end-consumers with product-specific information such as social sustainability (working conditions), vehicles' environmental characteristics, and the product's touchpoints. To allow for this inter-organizational traceability and provenance, the solution featured a BC backend to store and retrieve data related to product traceability and sustainability. The mobile application allowed downstream actors to retrieve product information by scanning QR codes or entering product numbers attached to the product. Inspired by Provenance.org and building on a previous crowdsourcing study on social sustainability issues in transportation, the concept of ReLog was first presented at a conference by one of the authors Henrik Sternberg.

In 2016, a researcher engaged a group of project partners (listed in C-Table 1, among them Henrik Sternberg) and acquired a nine-month pilot grant of 2 096 00 SEK (US$ 224, 000) from the Swedish funding agency Vinnova. In the call for proposals, the principal Vinnova specified that financed projects should aim to accelerate digitalization in the Swedish industry. In 2017, a research coordination organization became the administrative project leader; *Hernik Sternberg* became the technical project leader; and the university took over the driving role from the research institute. They formed a new consortium (with only some project partners remaining) and received another pilot grant of 1 420 000 SEK (US$152,000) from Vinnova (again for a nine-month project).

C-Table 1: Overview of involved supply chain actors with associated employees[68]

Supply chain actor	Involved employees and interview partners	Type of actor and role in supply chain
Retailer 1 (P1F)	Head of logistics development Logistics developer Logistics CSR Head of transport purchasing	Primary member, Retailer (selling)
Retailer 2 (P1I)	Logistics developer Terminal manager	Primary member, Retailer (selling)
Logistics service provider 1 (LSP 1) (P1,3I)	Head of quality Logistics developer (2) Head of network planning Account manager	Primary member, LSP (handling, storing)
Logistics service provider 2 (LSP 2) (P2F)	Integration analyst Project manager (2)	Primary member, LSP (handling, storing)
Logistics service provider 3 (LSP 3) (P1I)	Account manager	Primary member, LSP (handling, storing)
Hauler association (P1,2,3F)	CEO Head of member relations	Ancillary member
Hauler 1 (P1F)	Driver	Primary member, Hauler (transportation)

[68] (P1 = Pilot 1, I=informal, F=formal). Formal denotes an actor that was formally part of a funded ReLog project. In addition to these actors, a research institute (first grant), a research coordination organization (second grant), and a university (both grants) were active. Henrik Sternberg was an employee of the university.

Hauler 2 (P1I)	Driver Terminal manager	Primary member, Hauler (transportation)
Environmental association (P1,2,3F)	Head of freight sustainability certification	Ancillary member
Transport union	Secretary general	Ancillary member
Transport booking provider (P2F)	Head of enterprise customers Account manager Integration analysts (2)	Ancillary member
Food manufacturer	Global supply chain manager Head of terminal	Primary member, Supplier (production)
Vineyard (P3I)	CEO	Primary member, Supplier (production)
Technology provider (P2F)	Technology executive Nordic blockchain leader Lead architect	Ancillary member
BC software company (P1I)	CEO Lead architect Head of operations	Ancillary member
Technology consultancy (P1,2,3F)	Technical architect Head of innovation Blockchain programmer	Ancillary member

The BCT pilot, ReLog, was divided into three phases over 24 months (with project work continuing independent of grants), thus constituting a longitudinal case study with an embedded single-case design involving three units of analysis (Yin 2018). For clarity, it should be noted that the project was not planned to be phased; instead, each phase was an attempt to get ReLog into a running supply chain pilot. Therefore, the consortium followed a trial-and-error approach over the project's duration and was characterized by the willingness to break new ground. The three phases and how the different stakeholders were involved in the product and data flows are outlined in C-Figure 2.

Following Flyvbjerg (2006) and Ellram (1996), we deployed "the force of example" from a longitudinal single-case study to examine BCT adoption in SCM at an early stage. While the goal of achieving traceability remained for the project's duration, several participants in the consortium (listed in C-Table 1) as well as the product varied between phases. The BC backend also varied because the solution in Phase 1 was built on one BC backbone (from a BC software company) while Phases 2 and 3 were built on another backbone (from a major technology provider). Therefore, each of the three project phases represents a single unit of analysis for the case study, thus creating an embedded single-case examination.

The main project partners were companies using the BCT-enabled transparency solution to store transaction data along the supply chains. In addition to these main partners, several other project partners were specialists (e.g., an environmental association, providing expertise on sustainability certifications and disclosure programs) without participating directly in the supply chain transactions (we refer to these organizations as *ancillary partners*). Yet others (e.g., the Transport union) supported the project, were anticipated to play a part, and provided ad-hoc input; however, they were never involved in any transactions (as illustrated in C-Figure 2). While the partners in all three phases were willing to test the technology, they were not tied to it. When a supply chain member was considered to give input but did not actually do so, the other project members either provided that partner's input or the programmer hardcoded it into the BCT. The aim of all three phases was to find an adequate solution to make this application work in practice (i.e., focusing on supply chain transparency). This approach provided an objective perspective on the technology itself, in contrast to many other initiatives merely defined by their application of BCT. In conclusion, ReLog was well suited for studying the early adoption process of BCT as IOIS in supply chains. Each of the phases had a slightly different emphasis:

- Phase 1 focused on the haulers and the end-consumers.[69]
- Phase 2 focused on the warehousing and LSP operations.[70]

[69] Long version (in Swedish): https://youtu.be/6VcdIIuCe1Y. Short version (in English): https://youtu.be/nWVdg6KU1MI.

[70] Jeppsson and Olsson (2017) reported on Phase 2 in detail.

- Phase 3 focused on the supplier and products.

Sampling, data collection, and data analysis

The first pilot phase started in March 2016 and ended in December 2016 (the same time period as the first grant), while the second and third phases started in January 2017 and ended in February 2018. The members, both formal (i.e., officially involved in the project's funded phases) and informal (i.e., participating but not formally involved), varied during the pilots (as labeled in C-Table 1)

Henrik Sternberg was involved in all the phases and collected data in several spontaneous face-to-face conversations, semi-structured interviews, workshops, meetings, and on-site observations. This involvement offered a rare chance to gain in-depth insights from all project partners and to study the BCT adoption along the supply chain from multiple perspectives in three phases. It also enabled trust to be established between the accompanying researcher and the project partners, thus increasing integrity alongside data triangulation (Wallendorf and Belk 1989). Jones and Bartunek (2019) suggest including co-authors in the analysis and writing as an efficient way to mitigate flaws resulting from a researcher being extensively involved in the studied phenomena. While *Henrik Sternberg* was deeply involved in the project including data collection and initial analysis, the other two authors (experienced in blockchain studies but not involved in ReLog) audited the interpretations from a neutral perspective, in line with Jones and Bartunek (2019). Therefore, all researchers studied the collected data and reviewed the path from data collection to interpretation.

During the time span of 23 months, workshops, meetings (often daily among the core project's team members), on-site visits, and interviews were held. These encounters generated data in the form of workshop and meeting protocols, videos, photos, and notes from observations and interview transcripts.[71] Therefore, the ReLog case's main data are not post-ante interviews on participants' opinions, but rather interviews reflecting discussions on the potential adoption, i.e., reflecting

[71] Note: Most of the workshops were held in Swedish. Direct citations in this paper are translated into English by the authors.

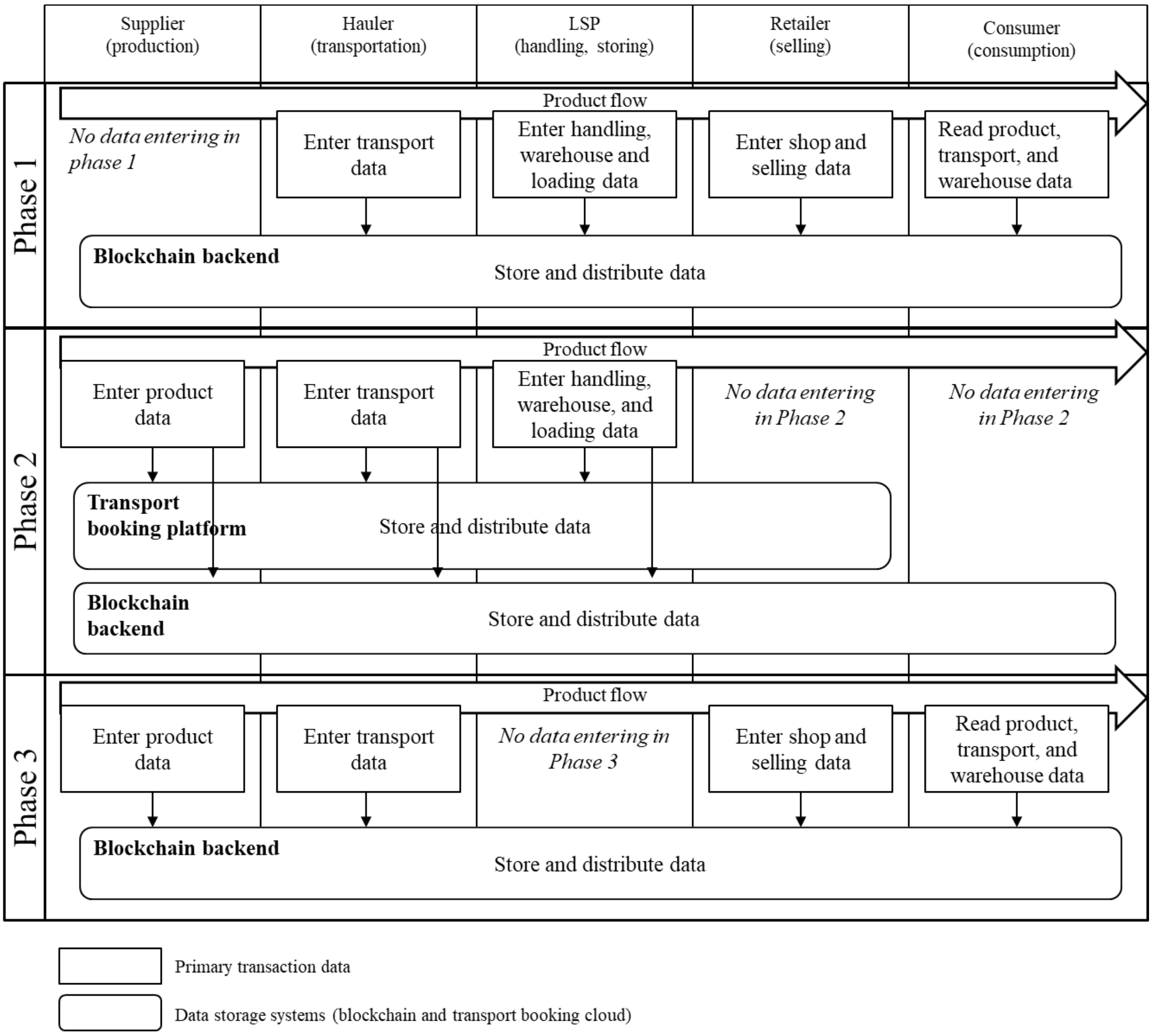
the project's daily work. As a result, the data from workshops, meetings, and on-site visits provided unique and in-depth findings.

Throughout the ReLog project, the lead programmer (employed by the technology consultancy) worked with the BCT providers and conducted weekly tests mimicking supply chain operations using BCT. (The sub-section "Illustration of blockchain logic applied" describes some of the outcomes of the tests and technical meetings.) In addition to the previously mentioned data sources, interviews were conducted to gain additional explanatory information to uncover causalities that were not evident before. The open-ended interviews, conducted in either English or Swedish, allowed follow-up questions to the work with the pilot. The interviews were recorded or documented with notes, transcribed (if recorded), and reviewed by the interviewee to achieve content validation. To increase construct validity, the interview data was triangulated with other data sources such as workshop, meeting, and observation protocols and notes as well as web site information. Earlier versions of this manuscript were shown to project members to get feedback and ensure trustworthiness (Wallendorf and Belk 1989).

The data from meetings, workshops, observations and additional interviews were aggregated in an Excel file, which formed the case study's database. All statements addressing the adoption of BCT in the corresponding supply chains were identified. Similar statements were grouped so that each new statement reported a new item. Subsequently, the items were analyzed to identify overarching clusters, which are presented in this paper's results section with selected statements from interviewees.

Relog project

ReLog was primarily about creating product traceability in the supply chain by disclosing and logging individual and organizational identities, characteristics, and activities in the BC. As previously mentioned, ReLog resembled the concept behind Provenance.org, a digital platform enabling companies to achieve greater transparency in terms of product origin; however, Relog focused on the links and nodes between the point of production and the point of consumption, rather than focusing on production itself (see C-Figure 2). Suppliers (e.g., the vineyard in Pilot 3) entered product data (e.g., bottling data for vine and grape batches). Furthermore, various participants added the following data from their BC transactions: haulers (e.g., first names of drivers and their trucks' environmental characteristics), LSPs (e.g., loading and unloading dates and workers' first names) and retailers (e.g., unloading date). Consumers could read the transaction information by scanning the product's QR codes.



C-Figure 2: Product and data flow and storage during the ReLog project's three pilot phases

Due to the domain's complexity (e.g., assets, multilevel packaging, shipments, aggregated shipments, vehicles, trailers), the ReLog team chose not to model the domain itself, but instead the language describing it. It was noted that identities, assets, and aggregated assets (packaging, shipments) can be expressed in sentence form (e.g., A has B and C.). The language models a complex domain that can be produced by assuming three ground rules:

- A is either an identity or an asset.
- B and C are assets.
- The word *has* is meant broadly, but its meaning is precise within a context; for example, if A is an identity, *has* means "is current holder of." If A is an asset of type "pallet" and B is an asset of type "package," then *has* means "is part of," etc. We were able to not only accurately describe the whole process but also do some basic automated reasoning about the domain (if A has B and B has C, then A has C.). This design is suitable for a BC application, but can be more easily implemented in a traditional database/private cloud solution.

This data model was heavily influenced by Hyperledger's architecture (The Linux Foundation 2019) and was designed in collaboration with the BC software company, the technology provider, and the technology consultancy. The model records every activity from creating identity/asset to transferring/aggregating/splitting assets. This fact set is huge, but the structure is primitive; these facts form a simple, flat, and timestamped sequence of documents such as in the fictitious example in Figure 3.

Logic in blockchain backend	Actors involved	Activity of actors	Information entered
1. Vineyard (VY) creates {wine w: 300} and {wine r: 300}	VY	Attach barcode/OR code to package and upload information	Product name and date and time, use-by date, location, name of VY
2. VY creates {wine box w: 50} and {wine box r: 50}	VY	Attach barcode/OR code to package and upload information	Product name and date and time, use-by date, location, name of VY
3. VY transferred {wine box w: 50} to Retailer 1 (R1)	VY, R1	Scan barcode/QR code during handover of wine box w	Delivery date and location, name of R1, changed ownership
4. VY transferred {wine box r: 50} to LSP1 for transport.	VY, LSP1	Scan barcode/QR code and enter change of ownership	Changed ownership, name of LSP1
5. LSP1 subcontracts Haulier 1 (H1) and transferred {wine box r: 50}.	LSP1, H1	Scan barcode/QR code and enter subcontractors information	Name of H1
6. H1 subcontracts to Haulier 2 (H2) and transferred {wine box r: 50}.	H1, H2	Scan barcode/QR code during handover of wine box r (CF, H2)	Handover date and location, name of H2, driver information
7. H2 delivered and transferred {wine box r: 50} to R1	H2, R1	Scan barcode/QR code during handover of wine box r (CF, H2)	Handover date and location, name of R1, name of warehousing employee
8. R1 aggregated {wine box r: 50}, {wine box r: 50} to {shop_cage{wine box r: 50}, {wine box w: 50}: 1}	R1	Scan barcode/QR code and enter shop and shelf allocation during shop distribution	Shop location, allocation date, shelf location, name of shop employee
9. R1 transferred {shop_cage[{wine box r: 50}, {wine box w: 50}]: 1} to customer (C)	R1, C	Scan barcode/QR code during sale	Sale data and location
10. {shop_cage[{wine box r: 50}, {wine box w: 50}]: 0} is not active (delivered to destination)	None	None	Shelf location cleared
11. {wine box r: 50} is not active	None	None	Item marked as delivered
12. {wine box w: 50} is not active	None	None	Item marked as delivered

C-Figure 3: Logic of blockchain, involved actors, their activities, and stored information

The example in C-Figure 3 demonstrates each actor's involvement along the supply chain. C-Figure 3 also identifies each actor's activities step by step and the stored information to outline the scope for handling the products and providing the information.

Findings

Using the previously introduced framework, this section describes this study's conceptual and empirical work. First, we emphasize the positive IOIS factors (i.e., perceived benefits, external pressure, and positive readiness). Second, we elucidate the negative IOIS factors (i.e., perceived obstacles, external resistance, and organizational immaturity). The findings are organized based on our frame.

Positive IOIS factors influencing BCT adoption in supply chains

In C-Table 2, we summarize the main positive aspects of BCT adoption in supply chains based on our case analysis.

C-Table 2: Factors positively influencing the decision to adopt BCT in the supply chain[72]

Positive IOIS factors		**Reasons**	**Associated actors**
Perceived benefits (PB)	PB1. positive awareness of sustainability	Provided possibility of sharing information with end-consumers about environmental and social sustainability	All primary members
	PB2. increased product traceability	Enabled tracing product and offered consumers valuable insights on the product's lifecycle	All primary members
	PB3. enhanced trust	Allowed building a basis for trust among unknown supply chain actors based on enhanced transparency	All primary members
External pressure (EP)	EP1. need for product traceability	Responded to the customer demand to increase product traceability	Suppliers, retailers
	EP2. push for revealing social conditions	Improved competitive position by entering data into the BCT solution, thus increasing visibility	LSP, haulers, union
	EP3. need for improving traceability	Actively working with improving traceability (improved status updates for shipments) was desired by several stakeholders, motivating them to push other actors to participate.	Suppliers, LSP
Organiza-tional readiness (OR)	OR1. initial investment	Cost for initiation supported by research funding	All
	OR2. sufficient financial resources	Actors' ability to invest in the BCT solution (financially strong)	LSPs
	OR3. adequate technical capability	Actors' IT capabilities, helping adopt the technology in these organizations	Retailers
	OR4. data availability	Sufficient availability of data, making the BCT solution easier to use	Retailers, transport booking provider

[72] Note: Primary members denote supply chain actors actually handling the goods.

The downstream primary supply chain members wanted to promote their sustainable practices (PB1). The head of Retailer 1's logistics development noted, "Unfortunately we do not capitalize [towards end-consumers] on our sustainable transportation, but it is definitely on our agenda to do so." They aimed to address their competitive position by increasing visibility, thereby addressing the push to reveal social conditions along the supply chain. Retailer 1 considered itself sustainable when choosing logistics suppliers.

In the ReLog case, the need for transparency, especially for increasing product traceability, and the curiosity to explore and learn about BCT were manifested by the large interest in project participation. Several stakeholders (especially, Retailer 1 and the Vineyard) considered it to be very valuable to enable end-consumers to trace their products' transport sustainability in their journey through the supply chain (PB2).

Further upstream, the supplying companies and the retailers addressed the customers' need for product traceability (EP1). The subcontracted LSP, the associated haulers, and the hauler association were also positive about sharing sustainability information, viewing such sharing as an opportunity both to strengthen ties with customers (including the retailers) and to improve competitiveness (EP2). LSP1's quality manager noted, "…we participate in the project [Transparent transportation/ReLog] where we hope to make it easier for customers to choose the right transporter" (Melander 2017, p.36). However, the stakeholders knew that this project required the involvement of multiple partners in their supply chain and ultimately in the adoption, emphasizing the BCT solution's network effect to address the need for improving traceability. Hence, the retailers and hauler association persuaded other actors (including suppliers (e.g., food manufacturer) and LSP1) to participate (EP3). The hauler association's head of member relations observed, "We are the only group of haulers following the collective agreements; we are dependent on [LSP1] to stick to their standards." Power in supply chain relations is always important to consider when examining pressure (Daugherty 2011; Fugate et al. 2009). As is often the case, the retailers (shippers) held the power position. LSP2's project manager said, "Our entire business is built around [retailer's name]. If they want it [transparency], we will deliver it; otherwise, it does not make any sense for us to build the capabilities." Moreover, the technology's emergence presented the ideal time to convince internal decision makers and external supply chain partners.

ReLog was mainly externally funded with the full support and involvement of two tech companies (with both receiving funding in the second grant) as well as a full-time programmer. Hence, initial investment and adequate technical capabilities were provided (OR1, OR3).[73] Several of the actors are also profitable firms with not only advanced IT capabilities (i.e., technically capable of integrating new information systems) but also financial resources to invest in the BCT solution (OR2, OR3). Many of the supply chain members already collected much data on shipment statuses, providing an adequate starting point for inserting tracing data into the system (OR4). To explore piggy-backing on an actor with considerable data, the transport booking provider joined the project in the second phase. As the head of enterprise customers noted, "We have all the transport booking data from our customers; if we can help our customers to use it more, it strengthens our business."

As C-Table 2 demonstrates, all the primary supply chain members identified the perceived benefits. Specifically, organizational readiness and external pressure indicate the discrepancies among the different players. While the research funding was advantageous for everyone involved, additional required financial resources, technical capability, and data availability were not provided for all the project participants. The is true when examining external pressures, which are actor specific and do not apply to all actors. Therefore, the importance of studying BCT adoption both on the intra-firm and the inter-organizational levels is reemphasized.

[73] Two rounds of external funding totalled 3.52M SEK, i.e., about $377,000 (1US$ = 9.32 SEK, as of December 20th, 2019).

Negative IOIS factors influencing BCT adoption in supply chains

C-Table 3 presents negative factors in the ReLog project that influenced the decision to adopt BCT in supply chains.

C-Table 3: Factors negatively influencing the decision to adopt BCT in supply chains

Negative IOIS factors		**Reasons**	**Associated actors**
Perceived obstacles	PO1. decreased operational efficiency	BCT solution requires gathering additional data on a batch level (e.g., scanning parcels) for uploading.	All primary members
	PO2. incurred nuisance	Employees consider scanning/typing to be annoying.	All primary members
	PO3. increased IT handling complexity	Operating additional interfaces (data entry into BCT) leads to additional complexity (e.g., in a legacy architecture) and requires new IT routines.	All primary members
External resistance	ER1. industry stakeholder resistance	BCT solution reveals personalized data to others (e.g., personal information about front-line SC workers is disclosed).	All primary members' workers, hauler association
	ER2. external lack of commitment	Transparency of sustainability information is of minor importance inside the firms, resulting in minor willingness to make significant process and system alterations and to deal with lack of standardization.	All primary members
	ER3. rival business relations	All participants were part of multiple supply chains, with limited interest in making disproportionate efforts in one selected supply chain.	All primary members

Organiza-tional immaturity	OI1. necessary IT training investments	Operating the BCT solutions requires additional IT capabilities that must be developed.	Supplier, LSP
	OI2. needed infrastructure	Deploying the BCT solutions requires additional infrastructures (e.g., scanners and Wi-Fi connection) to fully capture data.	All primary members
	OI3. increasing coordination demand	BCT solution requires jointly establishing data standards for data upload and agreeing to those standards.	All
	OI4. required openness	BCT solution discloses actor-specific data to other supply chain partners and customers (e.g., warehouse processing of LSPs).	All primary members

The integration analyst (transport booking provider) outlined a major challenge: "I do not want to be the party pooper, but it is going to be a struggle to have the workers update the statuses. Already today, with much fewer statuses than you anticipate in a transparent supply chain, the firms are struggling to keep the status of the shipments correct." This integration analyst was right. All actors struggled with the human factor and time pressure in entering data in the pilot system. During the ReLog pilot phases, the data entry (e.g., scanning barcodes) was often forgotten. In some processes, data entry involved considerably more time than before, thus decreasing operational efficiency (PO1). In Phase 3, the supplying vineyard's CEO said, "There is no chance whatsoever that I will manage to do this [scanning boxes and bottles] in high season." Without the supporting infrastructure that would allow for automated scanning, the data collection created additional work that consumed more time and was perceived as an annoying task for the workers (PO2).

From the technology perspective, IOIS like BCT pose compatibility problems. The technology must be compatible not only with the organization (for organizational compatibility see organizational readiness) but also with the existing information systems that write and read to the BC, a more difficult task for legacy production systems and embedded systems, as experienced in the

ReLog project (PO3). It cannot be expected that the present BC systems (such as Hyperledger Fabric, R3 Corda or Ethereum) will be capable of seamless synchronization or that a specific system will be established or emerge as the de facto industry standard. Clearly defined industry standards, which are currently missing, could minimize barriers to BCT adoption (Korpela et al. 2017).

The transport union emphasized that although it is generally positive about enhancing transparency (especially visibility of collective agreements), the transport workers' privacy must be investigated more thoroughly before a large-scale adoption can be fully supported. According to the transport union's secretary general, "In order for this to fly, we need to have some clear benefits for our members; otherwise, we cannot just give in to increased monitoring, which this, in practice, means". The drivers were likewise skeptical about having their identities and names shown (ER1).

Given the challenging IT operations needed and the lack of standardization to tackle this challenge, several parties lacked the commitment for successfully adopting the novel technology (ER2). Against the backdrop of multiple and rival business relationships, the lack of standardization posed a substantial barrier because several stakeholders were unwilling to invest too much effort in an individual supply chain (ER3). In addition, the stakeholders had to invest in IT trainings for the workers and operators of the new BCT solution, which presented another obstacle, especially for the vineyard and the LSPs (OI1).

The large-sized (in terms of employees) primary members of ReLog used legacy systems. Such systems rely heavily on relational databases and synchronous transactions, thus changing their foundation is much more complex, relatively speaking, than a regular system's integration/extension (Wüst and Gervais 2017). LSP1's internal consultant said, "We have been working on implementing our ERP system for 12 years; we cannot do any changes to the architecture for a long time." Thus, creating a system integration for a specific goods' flow (i.e., connecting it to an atomic BC) with existing legacy systems is very challenging.

On the other hand, the small primary members were not burdened by legacy systems, but lacked strategic IT management.

The decreased operational efficiency (outlined previously as PO1 and PO2) could have been addressed with automation through for example, NFC, RFID, Bluetooth, or image recognition cameras. However, these solutions would have required substantial changes in the hardware and software IT infrastructure, including the ERP systems, thus presenting an enormous obstacle for all the primary supply chain members (OI2).

As previously emphasized, many of the participants considered transparency in the supply chain to be the ReLog project's most important contribution. However, this contribution was not linked to the BCT per se because such a solution can also be provided using traditional relational databases (Wüst and Gervais 2017). The actors in the ReLog project did not confirm the relative advantage of the degree to which BCT was perceived as being better than the established systems. In one meeting, the lead programmer described the application: "BC creates digital trust, not physical monitoring; actually, it says nothing about the characteristics of the product." In the same meeting, the lead programmer used the previous sample ledger (C-Figure 3):

If VY creates a {wine r: 210} that is not actually a true red wine but rather grape juice, the ledger does not help us. We can see the history of transactions related to {wine r: 210}, but we cannot know how or where the fake red wine, in this case a red grape juice, entered the supply chain (cf. GIGO challenge by Babich and Hilary (2019)). Thus, the trust of the authenticity of {wine r: 210} can never be greater than the trust we have for actors R1, VY, C, LSP1 and H1 and H2.

Six members is a low number in real-world supply chains. All these actors must ensure that all updates are executed perfectly because any BC application is dependent on a stable state, which will become highly complex in a network (OI3).

Finally, the project revealed that a BCT solution required increased openness from the primary members. In a Phase 1 workshop, one of Retailer 2's project managers stated, “We already have very good data; as we control the whole supply chain already today, we are not interested in sharing additional data with other parties.” ReLog failed to present enough value to motivate increased openness (OI4).

Discussion

In this section, we first contrast BCT adoption’s pros and cons and elaborate on the tensions revealed in the empirical data. Second, we discuss whether the findings are transferable to other supply chain settings.

Tensions regarding BCT adoption in supply chains

This paper uses IOIS adoption theory (Iacovou et al. 1995) to answer the research question of why, despite the promising benefits outlined by previous studies, supply chains struggle to adopt BCT. Our analysis reveals that several trade-offs exist between positive and negative IOIS factors that cannot be resolved. The trade-offs stem from the relationship between positive and negative IOIS factors because realizing some of the positive IOIS factors also entails negative IOIS factors at the same time. These trade-offs lead to tensions between opposing perceived adoption factors. To provide a holistic understanding of BCT adoption in supply chains, these tensions must be considered.

Positive awareness of sustainability (PB1) and enhanced product traceability (PB2) were incentives for participating project members. The project members saw the novel technology as an opportunity to enhance transparency in their supply chain and to offer customers sustainability insights into the product’s journey along the supply chain. Therefore, they shared the same opinion on the BCT benefits as proposed in recent studies (e.g., Kshetri 2018). At the same time, data entry’s operational cost was a big barrier (PO1, PO2), causing a *traceability-efficiency tension* between PB1/PB2 and PO1/PO2. While some primary members (including retailers and the transport booking provider, see OR4) had all the data in place, others struggled to provide the data and faced a substantial additional workload or infrastructural investments (see OI2) to provide the relevant data (e.g., vineyard, see PO1 and PO2). In addition, the process of data entry would require standardization, thus amplifying obstacles PO1 and PO2. Only a few scientific studies have addressed this topic (e.g., Korpela et al. 2017; Wang et al. 2019). While focusing on the function of BCT and the data within, many studies have omitted the data input. As the ReLog case indicates, such an omission – when supply chain actors are unable or unwilling to provide the required data – can be a deal breaker.

The participating associations (haulers' association, transport union, and environmental association) were generally positive about creating awareness of the working conditions in the supply chain and saw such awareness as advantageous for their competitive position (EP2). This finding aligns with that of Mol (2015) and Marshall et al. (2016), who emphasize improved visibility's positive effect on customers' sustainability perceptions. However, the transport union in particular was critical to the privacy of supply chain frontline workers (ER1), in addition to improved visibility, allowing for more monitoring. The solutions require openness to make processes visible (OI4), which in turn can also have negative effects, such as data leaks (Wüst and Gervais 2017). According to Clemons and Row (1993), data leaks within IOIS can potentially lead to reduced bargaining power. Thus, the *visibility-privacy tension* merges, manifesting that visibility; even though it is intended to improve sustainability, it limits individuals' privacy. Disclosing information, such as the processing LSP employee, would allow different employees' performance to be assessed based on the number of processed products and, thus, would constitute a significant obstacle for employee organizations.

Next, the study revealed a paradox, which is a special case of tension (Smith and Lewis 2011; Wilhelm and Sydow 2018). A *paradox* refers to elements that seem logical when considered in isolation, but which are irrational or inconsistent when juxtaposed. Enhanced trust (PB3) is not only a perceived benefit of BCT in that special case but also a central value proposition of BCT in supply chains (Saberi et al. 2019) and a major challenge in supply chain networks (Daugherty 2011). Honesty-based credibility stresses the exchange partner's integrity, e.g., in terms of sincerity (Asare et al. 2016). The data are secure in the BC; i.e., the data cannot be manipulated by a supply chain actor. However, as illustrated before (cf. Figure 3 and OI3), the BC does not ensure that the correct data were entered into the ledger. One of BCT's promises is being a "trust machine" (Beck et al. 2016; Clemons et al. 2017). However, to establish a BCT-enabled IOIS in a vertical supply chain setup (Babich and Hilary 2019), a long-term relationship (which in turn assumes that trust exists based on positive experiences over time) is necessary. If trust already exists among the supply chain actors, BCT-enabled trust does not offer any significant value to the relationships. Hence, the *trust-investment paradox* (PB3 vs. OI2/3) arises. On the one hand, the supply chains that need trust cannot implement the technology due to lack of trust. On the other hand, the supply chains with well-established relationships that can implement a BCT solution do not need additional trust. This paradox is a unique finding in BCT literature. Scholars have thought that the novel technology would enhance the use of spot markets because trust can be established earlier without long-term relationships (e.g., Catalini and Gans 2016; Seidel 2018). However, these contributions have focused on BCT's core function and have been misguided regarding interorganizational adoption and integration that require long-term investments.

Finally, the broader *performance-commitment tension* was discovered. While the members saw PB1, PB2 and PB3 as performance improvements by adopting the BCT solution (given their interest in promoting their own sustainability), they were also aware of the significant commitment required—i.e., training employees (PO3) and improving their IT capabilities (OI1). In addition, the pilot required commitment to establish common standards for data processing, which also limited each actor's freedom and room for maneuvering. Moreover, the need for coordination (e.g., for administering and verifying an organization's BCT identity) (OI3) made the team realize that the ReLog project would have to continue beyond implementation in order for the supply chain actors to productively use BCT. Hence, the actors had to commit not only to their supply chain relations but also to the new intermediary/ies, the BC software administrator (ReLog), and/or the selected technology provider. For some supply chain actors, enhancing transparency was not a high priority (ER2); and initiatives in other, more important supply chains resulted in a lack of commitment (ER3). When considering the network effect of a BCT solution that enhances transparency in supply chains, a broad commitment is critical for such a solution's success. According to Saberi et al. (2019), lack of collaboration can represent a barrier for BCT, and fragmented product traceability substantially reduces the perceived benefits (PB1, PB2 and PB3). The ReLog case also reveals that in addition to setting collaborative standards, supply chain actors' commitment threatens the realization of perceived benefits and, thus, leads to this tension. C-Table 4 lists the four major tensions found in our research.

*C-Table 4: Tensions of BCT adoption in supply chains [Note: *= denotes all]*

Tensions	**Reasons**	**+ (pros)**	**- (cons)**
Traceability-efficiency	To realize enhanced product traceability's perceived benefit, supply chain actors must overcome the hurdles of inefficiencies largely resulting from organizational immaturity.	PB1, PB2	PO1, PO2, OI2, OI3
Visibility-privacy	To enhance visibility in their supply chain and reveal their sustainability awareness, supply chain actors must respond to data privacy concerns of workers and supply chain partners.	PB1	ER1, OI4
Trust-investment (paradox)	To enhance trust by using BCT-based solutions, supply chain actors must invest in the technology, which, in turn, is only attractive when long-term trust among supply chain partners is already established.	PB3	OI1, PO3, OI2
Performance-commitment	To enhance product traceability, visibility, and trust, supply chain actors' long-term commitment is required to establish capabilities, which, in turn, depends on the BCT solution's importance and the associated supply chain.	PB*	PO3, OI1, OI3, ER2, ER3

All four tensions result from unresolved positive and negative IOIS factors. Organizational readiness and external pressure positively influence supply chain actors' intentions to adopt BCT solutions (e.g., OR*); these factors do not lead to tensions. Instead, especially the positive determining factors of organizational readiness (OR*) can be understood as requirements to adopt BCT. In case they are not present (e.g., as in the vineyard's scanning example), these factors must be addressed to successfully adopt BCT (e.g., by investing in automated barcodes or RFID scanners). Furthermore, the determining factor of external pressure encourages or even forces technology adoption.[74]

Model transferability

In contrast to, for example, cryptocurrencies (horizontal applications of BCT), supply chains represent a vertical application area of BCT. Although more research is needed to test the proposed model, it is very likely that heterogeneous supply chain actors will face tensions similar to those in the ReLog case. This assumption is based on both the case and the promised benefits and obstacles identified in the literature. The ReLog case not only provides unique access to an actual BCT project but also has breadth and depth through numerous stakeholders and its long duration. Moreover, the model can be transferred to the adoption of inter-organizational IOIS and other technologies requiring a high degree of adoption along the supply chain. Therefore, this model is likely applicable for all vertical BCT applications in supply chains such as end-to-end traceability or transport applications.

Conclusions

Revisiting our goal and research question, we present the main insights from our research in light of the inter-organizational system's adoption and recent literature on blockchains in SCM. Aligning with previous research on IOIS adoption (Iacovou et al. 1995), we propose that the adoption of BCT in supply chains can be determined by considering economic, organizational, and environmental factors. Informed by BCT's benefits and challenges in supply chains, both the positive and the negative IOIS factors are important to consider. Furthermore, our discussion highlights the tensions arising between positive and negative IOIS factors of adoption.

[74] As of August 2019, the ReLog project was on hold because of these challenging tensions.

Managerial implications

Our research insights aid practitioners in objectively viewing the potential effects and adoption obstacles to a BCT-based information system in their supply chains. The in-depth elucidation of the ReLog project also provides a pedagogical introduction to supply chain majors wanting to understand blockchains' underlying mechanisms as an approach to capture BCT's state.

Given that logistics magazines and SCM news are filled with information from blockchain startups and given the costs associated with blockchain pilots (e.g., one technology provider charges from $300,000 to $400,000 for a basic supply chain pilot), this paper provides helpful insights into what blockchains in supply chains can and cannot leverage in terms of transparency and trust. Decision makers who understand the BC trust-investment paradox introduced in this paper can save resources by avoiding exaggerated expectations and failed projects that may not yield novel insights.

Finally, while implementing BCT in supply chains, managers should be aware that they must maneuver in complex circumstances, especially in addressing several specific tensions. Decision makers should not overemphasize the promised benefits of BCT adoption in their supply chain; instead, they must be aware of the obstacles, such as those empirically outlined in this paper, that are outside the decision makers' control. With BCT's benefits in supply chains being mainly network effects, decision makers must ensure the ability and willingness of all the involved internal stakeholders and external supply chain partners to implement such an IOIS. BCT's full impact in supply chains can only be realized when the technology has been adopted along the supply chain without major exceptions and gaps; otherwise, the BCT initiative will fail. The list of tensions in the potential adoption outlined in the ReLog case provides important considerations for SC managers attempting similar implementations.

Theoretical implications

While explaining why supply chains are struggling to adopt BCT, we contribute to theory in several ways. First, this paper conceptualizes the adoption of BCT in supply chains by drawing from IOIS adoption theory and empirically expanding on previous conceptual work. We emphasize that BCT's anticipated impacts in supply chains are network effects dependent on a critical mass of adopters. This dependency could serve as a basis for future examinations, thoroughly analyzing the nature of BCs' network effects in not only vertical but also horizontal or diagonal network settings (Babich and Hilary 2019).

Second, we contribute mid-range SCM theory by introducing a model of the factors determining IOIS adoption of BCT in supply chains. The model specifies not only perceived benefits, external pressure, and organizational readiness (positive IOIS factors) but also perceived obstacles, external resistance, and organizational immaturity (negative IOIS factors) as well as how these factors affect the willingness to adopt an IOIS (such as BCT) in supply chains. Based on this foundational work, future research can potentially elaborate on specific configurations of BCT application areas beyond the physical supply chain (e.g., supply chain finance) or on other IOIS applications in the supply chain context (e.g., packaging systems spanning multiple competing organizations).

Third, several trade-offs of inter-organizational BCT adoption were identified. Therefore, the study empirically derived the *trust-investment paradox* as well as the tensions *traceability-efficiency*, *visibility-privacy,* and *performance-commitment* as specific phenomena of BCT adoption in supply chains. Thus, we emphasize the importance of simultaneously studying positive and negative adoption factors for all relevant supply chain actors. While contributing to literature on paradoxes in SCM (e.g., Wilhelm and Sydow 2018), we are also proposing an inter-organizational adoption model that can guide future research. The tensions among positive and negative IOIS factors merit future investigation to expand the understanding of inter-organizational BCT adoption in supply chains. Based on our findings, both SCM scholars and practitioners are able to address how to handle these tensions. A relevant factor to consider is the specifics of supply chains, typically involving several layers of outsourcing and many small- and medium-sized enterprises with limited capabilities of adopting innovations (Wagner 2008). Because BCT's dissemination in practice is still in its infancy, in-depth case studies or cross-case studies of future successful implementations as well as science-based research (Holmström et al. 2009) seem to be appropriate methodological approaches for such investigations.

Finally, we have elaborated on trust, using ReLog's vine supply chain as a sample and, thus, raising the question of how we know that the information in the blockchain accurately represents the state of the physical world. Due to technical and human errors, the digital world often inaccurately represents the physical world's state. This misrepresentation is an interesting challenge to examine by considering the aforementioned logic of identities and by trying to determine if the identities in the supply chain's blockchain correspond to physical identities. This issue should be addressed regarding not only social sustainability issues in supply chains (Marshall et al. 2016) but also increased digitalization of supply chain work. On a similar note and in light of strong unions and worker retention, we emphasize that privacy concerns (including those of supply chain workers) present an important BCT issue in supply chains from a human-centric perspective.

Limitations and future research

Although our research design is a good fit for our research question at this early stage of BCT adoption in supply chains, our explorative single case study has limitations opening avenues for future research. As for all single case studies, our findings' external validity must be tested by future research. Thus, generalizability is limited, presenting an opportunity for future research to study different BCT applications (e.g., trade finance applications) in supply chains. Moreover, our case study potentially suffers from subjective interpretations. While one of the authors was engaged in the ReLog project, the other authors functioned as auditors to reduce this potential subjectivity. Thus, future approaches should test our framework and elaborate on our findings.

Aside from our methodological limitations and beyond our case study's findings, we see the additional need for research in relation to BCT in SCM in the broader sense. Future research must address the management of distributed ledgers and BC platforms in multi-actor supply chains. Specifically, more efforts should be devoted to managing data governance (Mattila et al. 2016), sharing responsibility for such a platform ecosystem, and establishing standards to enable the use of multiple BCT applications in inter-organizational supply chain settings. The following questions should be explored: *Are new or existing actors in the ecosystem going to take responsibility? Is disintermediation going to affect or even disrupt supply chain actors, as some experts are suggesting (Gupta 2017; Mabe 2018)?* Additionally, interoperability strategies are necessary to provide several BCT solutions juxtaposed in the supply chain. In terms of technology, future research should investigate the suitability of non-critical transactions, such as commodity shipments because BCT was initially developed for banking transactions, and some research suggests it should not be used for supply chains (Wüst and Gervais 2017). Very few articles about BCs highlight the enormous redundancy of data blockchains with many nodes generated and the related GIGO problem (Babich and Hilary 2019). However, regarding BCT's financial applications, the assets tokenization should be studied, especially in the context of supply chain financing.

Babich and Hilary (2019), among many others, state that BCT is hyped. Thus, practitioners as well as researchers should have a critical attitude about the technology's promised benefits. We hope to have contributed a path towards balancing the positive and negative IOIS adoption factors and what to consider while maneuvering amid tensions. Has BCT failed in supply chains? Although it's not over till it is over, justifiable doubts exist, as the elaborated struggles of our case indicate.

Appendix

Appendix A. Classification

Classification of the ReLog application according to the developed taxonomy in Study 1:

Underlying technology	Underlying protocols [UP]	BCT ●	DAG				
	Permission right [PR]	Public	Private ●	Consortium			
	Consensus mechanisms [CM]	Proof-of-work	Permissioned voting ●	Permissioned notary	DAG consensus		
	Databases as sources for data input [DI]	Single	Multiple ●				
	Additional technologies for data gathering [AT]	Required ●	Not required				
	Tag with physical product [TP]	Required ●	Not required				
	Transaction space [TS]	Only on-ledger	Off-ledger ●				
Participation structure	Scope of participation network [SP]	Supply chain	Industry ●	Open			
	Participating supply chain actors [PA]	Physical actors	Physical and support actors ●				
	Usage by end customer [UE]	Yes ●	No				
	Role as operator of nodes [RO]	Not required	Operated as a service ●	Operated by individual actors			
Targeted task	Underlying asset [UA]	Physical product ●	Information	Financial resources			
	Main objective [MO]	Traceability of products ●	Visibility of actors and processes	Authenticity of products	Digitalization of processes	Financing and escrow	
	Industry [IN]	Automotive	Aviation	Chemicals	Food ●		
		Minerals	Pharmaceuticals	Textile	Multiple industries		
	Scope of the application [SA]	Transport and logistics	Procurement	Production	Distribution ●	SCF	SCM
	Direction of objective [DO]	Downstream supply chain actors	Upstream and downstream actors	End customers	All ●		

References

Asare, A.K., Brashear-Alejandro, T.G., and Kang, J. 2016. "B2B Technology Adoption in Customer Driven Supply Chains." *Journal of Business & Industrial Marketing* 31 (1):1-12.

Autry, C.W., Grawe, S.J., Daugherty, P.J., and Richey, R.J.G. 2010. "The Effects of Technological Turbulence and Breadth on Supply Chain Technology Acceptance and Adoption." *Journal of Operations Management* 28 (6):522–536.

Babich, V., and Hilary, G. 2019. "Distributed Ledgers and Operations: What Operations Management Research Should Know about Blockchain Technology." *Manufacturing and Service Operations Management* Forthcoming.

Barrett, S., and Konsynski, B. 1982. "Inter-Organization Information Sharing Systems." *MIS Quarterly* 6:93–105.

Beck, R., Avital, M., Rossi, M., and Thatcher, J.B. 2017. "Blockchain Technology in Business and Information Systems Research." *Business & Information Systems Engineering* 59 (6):381–384.

Beck, R., Stenum Czepluch, J., Lollike, N., and Malone, S. 2016. "Blockchain: The Gateway to Trust-free Cryptographic Transactions." 24th European Conference on Information Systems (ECIS), Istanbul, Turkey.

Blossey, G., Eisenhardt, J., and Hahn, G. 2019. "Blockchain Technology in Supply Chain Management: An Application Perspective." In *Proceedings of the 52nd Hawaii International Conference on System Sciences*, edited by Tung Bui.

Budman, M., Hurley, B., Khan, A., and Gangopdhyay, N. 2019. "Deloitte`s 2019 Global Blockchain Survey ". Deloitte. https://www2.deloitte.com/content/dam/Deloitte/se/Documents/risk/DI_2019-global-blockchain-survey.pdf.

Casey, M.J., and Wong, P. 2017. "Global Supply Chains are About to Get Better, Thanks to Blockchain." Harvard Business Review. https://www.hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain.

Catalini, C., and Gans, J.S. 2016. Some Simple Economics of the Blockchain: Working Paper.

Chwelos, P., Benbasat, I., and Dexter, A.S. 2001. "Research Report: Empirical Test of an EDI Adoption Model." *Information Systems Research* 12 (3):304–321.

Clemons, E.K., Dewan, R.M., Kauffman, R.J., and Weber, T.A. 2017. "Understanding the Information-based Transformation of Strategy and Society." *Journal of Management Information Systems* 34 (2):425–456.

Clemons, E.K., and Row, M.C. 1993. "Limits to Interfirm Coordination Through Information Technology: Results of a Field Study in Consumer Packaged Goods Distribution." *Journal of Management Information Systems* 10 (1):73–96.

Cox, A. 2004. "The art of the possible: relationship management in power regimes and supply chains." *Supply Chain Management: An International Journal* 9 (5):346-356.

Daugherty, P.J. 2011. "Review of logistics and supply chain relationship literature and suggested research agenda." *International Journal of Physical Distribution and Logistics Management* 41 (1):16-31.

Doe, L. 2017. "Watch: IBM-Maersk Unite on Global Blockchain Initiative." accessed 24.03.2018.

https://www.porttechnology.org/news/watch_blockchain_digitizing_global_logistics.

Ellram, L.M. 1996. "The use of the case study method in logistics research." *Journal of Business Logistics* 17 (2):93-138.

Flyvbjerg, B. 2006. "Five Misunderstandings About Case-Study Research." *Qualitative Inquiry* 12 (2):219–245.

Fugate, B.S., Davis-Sramek, B., and Goldsby, T.J. 2009. "Operational collaboration between shippers and carriers in the transportation industry." *International Journal of Logistics Management* 20 (3):425-447.

Grover, V. 1993. "An Empirically Derived Model for the Adoption of Customer-based Interorganizational Systems." *Decision Sciences* 24 (3):603-640.

Gupta, V. 2017. "The promise of BC is a world without middlemen." *Harvard Business Review* March.

Hazen, B.T., Overstreet, R.E., and GCegielski, C.G. 2012. "Supply Chain Innovation Diffusion: Going Beyond Adoption." *The International Journal of Logistics Management* 23 (1):119-134.

Higginson, M., Nadeau, M.-C., and Rajgopal, K. 2019. "Blockchain's Occam Problem." accessed 22.06.2019. https://www.mckinsey.com/industries/financial-services/our-insights/blockchains-occam-problem.

Holmström, J., Ketokivi, M., and Hameri, A.-P. 2009. "Bridging Practice and Theory: A Design Science Approach." *Decision Sciences* 40 (1):65-87.

Iacovou, C.L., Benbasat, I., and Dexter, A.S. 1995. "Electronic Data Interchange and Small Organizations: Adoption and Impact of Technology." *MIS Quarterly* 19 (4):465-485.

Jeppsson, A., and Olsson, O. 2017. "Blockchains as a solution for traceability and transparency." MSc thesis, Division of Packaging Logistics, Lund University.

Johnston, H.R., and Vitale, M.R. 1988. "Creating Competitive Advantage with Interorganizational Information Systems." *MIS Quarterly* 12 (2):153–165.

Jones, E.B., and Bartunek, J.M. 2019. "Too Close or Optimally Positioned? The Value of Personally Relevant Research." *Academy of Management Perspectives* Forthcoming.

Katz, M.L., and Shapiro, C. 1994. "Systems Competition and Network Effects." *Journal of Economic Perspectives* 8 (2):93–115.

Koh, L., Dolgui, A., and Sarkis, J. 2018. "Special Issue on Blockchain in Transport and Logistics." *International Journal of Production Research*.

Kolb, J., Hornung, D.J., Kraft, F., and Winkelmann, A. 2018. "Industrial Application of Blockchain Technology: Erasing the Waknesses of Vendor Managed Inventory." 26th European Conference on Information Systems (ECIS), Portsmouth, United Kingdom.

Korpela, K., Hallikas, J., and Dahlberg, T. 2017. "Digital Supply Chain Transformation toward Blockchain Integration." 50th Hawaii International Conference on System Sciences, Waikoloa Village, HI, USA.

Kshetri, N. 2018. "Blockchain's Roles in Meeting Key Supply Chain Management Objectives." *International Journal of Information Management* 39:80–89.

Mabe, J. 2018. "A Blockchain Primer for Logistics and Supply Chain." accessed 17.12.2019. http://www.techgistics.net/blog/2018/2/28/a-blockchain-primer-for-logistics-and-supply-chain.

Marshall, D., McCarthy, L., McGrath, P., and Harrigan, F. 2016. "What's Your Strategy for Supply Chain Disclosure?" *MIT Sloan Management Review* 57 (2):37–45.

Mattila, J., Seppälä, T., and Holmström, J. 2016. "Product-Centric Information Management: A Case Study of a Shared Platform with Blockchain Technology." Industry Studies Association Conference Minneapolis, MN, USA.

Melander, H. 2017. "Transparens gynnar seriösa aktörer." *DB Schenker Magazine*, 36-39.

Mol, A.P.J. 2015. "Transparency and Value Chain Sustainability." *Journal of Cleaner Production* 107:154–161.

Panetta, K. 2018. "Gartner Top 10 Strategic Technology Trends for 2019." Last Modified 2018. https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019/.

Premkumar, G., Ramamurthy, K., and Crum, M. 1997. "Determinants of EDI Adoption in the Transportation Industry." *European Journal of Information Systems* 6 (2):107–121.

Rao, S., Senthilkumar, C., Patton, J., and Rhodes, Y.E. 2017. "Call for papers - Blockchain: Applications and Strategies for Supply Chain Research and Practice." Wiley, accessed 19th of April. https://wol-prod-cdn.literatumonline.com/pb-assets/assets/21581592/Block_Chain_Applications_and_Strategies_for_Supply_Chain_Research_and_Practice-1509470804000.pdf.

Riggins, F.J., and Mukhopadhyay, T. 1994. "Interdependent Benefits from Interorganizational Systems: Opportunities for Business Partner

Reengineering." *Journal of Management Information Systems* 11 (2):37-57.

Roeck, D., Sternberg, H., and Hofmann, E. 2019. "Distributed ledger technology and supply chain transactions: A multiple case study." *International Journal of Production Research* Forthcoming.

Saberi, S., Kouhizadeh, M., Sarkis, J., and Shen, L. 2019. "Blockchain Technology and its Relationships to Sustainable Supply Chain Management." *International Journal of Production Research* 57 (7):2117–2135.

Schmidt, C.G., and Wagner, S.M. 2019. "Blockchain and Supply Chain Relations: A Transaction Cost Theory Perspective." *Journal of Purchasing and Supply Management* 25 (4):100552.

Seidel, M.-D.L. 2018. "Questioning Centralized Organizations in a Time of Distributed Trust." *Journal of Management Inquiry* 27 (1):40–44.

Shapiro, C., and Varian, H.R. 1998. *Information Rules: A Strategic Guide to The Network Economy*: Harvard Business Press.

Smith, W.K., and Lewis, M.W. 2011. "Toward a Theory of Paradox: A Dynamic Equilibrium Model of Organizing." *Academy of management Review* 36 (2):381-403.

Stank, T.P., Pellathy, D.A., In, J., Mollenkopf, D.A., and Bell, J.E. 2017. "New Frontiers in Logistics Research: Theorizing at the Middle Range." *Journal of Business Logistics* 38 (1):6-17.

Sternberg, H., and Andersson, M. 2014. "Decentralized Intelligence in Freight Transport - a Critical Review." *Computers in Industry* 65 (2):306-313.

Swan, M. 2015. *Blockchain: Blueprint for a New Economy*. 1. ed. ed, *Safari Tech Books Online*. Beijing: O'Reilly.

The Linux Foundation. 2019. accessed 17.12.2019. https://www.hyperledger.org/.

Treiblmaier, H. 2018. "The impact of the blockchain on the supply chain: a theory-based research framework and a call for action." *Supply Chain Management: An International Journal* 23 (6):545-559.

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

Wagner, S.M. 2008. "Innovation Management in the German Transportation Industry." *Journal of Business Logistics* 29 (2):215-231.

Wallendorf, M., and Belk, R.W. 1989. "Assessing Trustworthiness in Naturalistic Consumer Research." *ACR Special Volumes*.

Wang, Y., Singgih, M., Wang, J., and Rit, M. 2019. "Making sense of blockchain technology: How will it transform supply chains?" *International Journal of Production Economics* 211:221-236.

Wheeler, M. 2017. "The Woman Whose Mum Inspired Her to Track Ethical Food." Last Modified 24.03.2018. http://www.bbc.com/news/business-38773878.

Wilhelm, M., and Sydow, J. 2018. "Managing Coopetition in Supplier Networks – A Paradox Perspective." *Journal of Supply Chain Management* 54 (3):22–41.

Wüst, K., and Gervais, A. 2017. "Do You Need a Blockchain?" *IACR Cryptology ePrint Archive* 2017:375–381.

Yin, R.K. 2018. *Case Study Research and Applications. Design and Methods.* . Sixth edition ed. Thousand Oaks, CA, USA: SAGE.

Zhu, K., Dong, S., Xu, S.X., and Kraemer, K.L. 2006. "Innovation Diffusion in Global Contexts: Determinants of Post-adoption Digital Transformation of European Companies." *European Journal of Information Systems* 15 (6):601–616.

Zhu, K., Kraemer, K.L., and Xu, S. 2003. "Electronic Business Adoption by European Firms: A Cross-country Assessment of the Facilitators and Inhibitors." *European Journal of Information Systems* 12 (4):251-268.

Appendix D – Study 4

Distributed ledger technology in supply chains: A transaction cost perspective

Dominik Roeck[a], Erik Hofmann[a] and Henrik Sternberg[b]

[a] Institute of Supply Chain Management, University of St.Gallen, Switzerland

[b] Debbie and Jerry Ivy College of Business, Iowa State University, USA

Accepted and published online in International Journal of Production Research

Abstract

With the emergence of distributed ledger technology (DLT), numerous practitioners and researchers have proclaimed its beneficial impact on supply chain transactions in the future. However, the vast majority of DLT initiatives are discontinued after a short period. With the full potential of DLT laying far down the road, especially managers in supply chain management (SCM) seek for short-term cost saving effects of DLT in order to achieve long-term benefits of DLT in the future. However, the extant research has bypassed grounding long-term as well as short-term effects of DLT on supply chain transaction with empirical data. We address this shortcoming, following an abductive research approach and combining empirical data from a multiple case study design with the corresponding literature. Our study reveals that the effects of DLT on supply chain transactions are two-sided. We found six effects of DLT solutions that have a cost-reducing or cost avoidance impact on supply chain transactions. In addition, we found two effects that change the power distribution between buyers and suppliers in transactions and a single effect that reduces the dependency of supply chain transactions on third parties. While cost-reducing and avoidance as well as dependency-reducing effects are positive effects, the change in power distribution might come with disadvantages. With these findings, the paper provides the first empirical evidence of the impact of DLT on supply chain transactions, which will enable managers to improve their assessment of DLT usage in supply chains.

Keywords: distributed ledger technology; blockchain technology; supply chain management; supply chain transparency; transaction cost economics; theory elaboration

Introduction

Distributed ledger technology (DLT), the superordinate technology to blockchain technology, is associated with the potential to enhance transparency (Kshetri 2018), trust (Kamble, Gunasekaran, and Arha 2018) and to enable disintermediation (Saberi et al. 2018). Inspired by the potential of DLT, numerous companies and academic scholars are seeking to harness and assess these benefits in supply chains (Blossey, Eisenhardt, and Hahn 2019). However, sceptics believe that widespread DLT implementation will be take a long time to occur (e.g. Wüst and Gervais 2017; Higginson, Nadeau, and Rajgopal 2019). Hence, there is significant interest in exploring the potential impact of DLT on supply chain transactions as well as practice, as demonstrated by recent calls for research and research agendas (e.g. Clemons et al. 2017; Rao et al. 2017; Dolgui and Ivanov 2018).

As over 50% of all global production crosses a border, the complexity of monitoring supply chain transactions continues to increase (Ortiz-Ospina, Beltekian, and Roser 2018). Against this backdrop, the need for transparency in supply chain transactions has further increased the interest in DLT (Blossey, Eisenhardt, and Hahn 2019). Several retailers (e.g. Carrefour and Walmart) are teaming up with blockchain solution providers (e.g. IBM, Provenance, Modum.io and Ship.io) to test DLT in an effort to comply with consumer preferences and pressure to disclose supply chain sustainability information (Wheeler 2018; Marshall et al. 2016; Slocum 2018). Other initiatives aim at providing more trust to transaction partners (Ostern 2018). For example, the diamond mining company DeBeers launched Tracr to re-establish trust in the diamond industry by making it possible to register and store documents and certificates for diamonds. Clemons et al. (2017) view DLT as a potential enabler of a 'world without intermediaries', and Gupta (2017b) believes it could lead to the elimination of intermediation. A number of DLT solutions aim at cutting out intermediaries in supply chain transactions e.g. TradeIX (2018). Regardless of whether DLT initiatives are aimed at transparency, trust or disintermediation, they influence supply chain transactions in all cases.

Thus, both practitioners (e.g. Batra et al. 2019) and researchers (e.g. Blossey, Eisenhardt, and Hahn 2019; Saberi et al. 2018) see reducing (transaction) costs as the short-term benefit of DLT in supply chain management (SCM). Long term, the technology is seen as a radical (Beck and Müller-Bloch 2017) or disruptive innovation (Saberi et al. 2018; Casey and Wong 2017). Moreover, supply chain transactions between firms are subject to radical changes (Blossey, Eisenhardt, and Hahn 2019), potentially altering the transaction cost economics (TCE) of supply chains (Catalini and Gans 2016).

TCE has been a dominant perspective in the investigation of boundary decisions, perhaps the most central phenomenon of interest in SCM theory (Williamson 2008). The design of effective supply chain networks is dependent on understanding transaction costs, and thus the effect of emerging technologies on TCE is a topic of utmost importance. DLT promises to significantly reduce transaction costs (Catalini and Gans 2016), which would likely cause firms to outsource larger portions of their supply chains. However, these effects are not certain, and numerous DLT projects have been abandoned due to a failure to achieve the targeted effects (Trujillo, Fromhart, and Srinivas 2017; Sternberg and Baruffaldi 2018). The majority of projects are halted after a short period of time, failing to fulfil short-term and long-term expectations (Marr 2018). In addition, literature has paid little attention to proof the expectations of the technology. Thus, managers are left to assess the potential of DLT on their own. Hence, it is important to uncover the perceived effects of DLT on supply chain transactions by drawing on TCE as a theoretical frame. In contrast to previous, mainly conceptual, desktop approaches for conceptualising DLT in SCM, we apply an abductive approach to explore the impact of DLT in supply chain transactions.

Our aim is to contribute mid-range theory on transaction cost economics in supply chains. We do this by addressing two research questions:

RQ1: What are the implications of distributed ledger technology on the transaction cost economics of supply chains?

RQ2: What are the distributed ledger-based causes of these implications?

We start by briefly outlining DLT in SCM and illustrating what is known on TCE in SCM. While we go on to elaborate the implications of DLT, we limit our exploration to transparency-enabling DLT applications in order to gather and analyse data from real-world implementations in supply chains. Thus, the unit of observation in our abductive case study is the pilot application of DLT-based transparency solutions in physical supply chains. This makes it possible to study the inter-organisational DLT-based transaction between a buyer and a supplier in a physical goods supply chain as our unit of analysis. In this way, we provide the first empirical evidence of reduced transaction costs through the use of DLT in supply chain transactions. Furthermore, this study allows us to identify seven effects of DLT that extend the extant literature on TCE in SCM and justify the reduction of transaction costs. However, we also disclose two effects that constitute a shift in power through the usage of DLT in supply chain transactions.

Literature background

First, we introduce DLT as an enabler of transparent, trusted and disintermediated transactions in supply chains. Based on the literature, we elaborate on the potential value of DLT enablers in supply chains. Second, we position the TCE as the primary frame for exploring supply chain transactions in the context of DLT in our abductive multiple case study.

Distributed ledger technology in supply chains

DLT enables storing new transactions in a distributed, decentralised network after validation by peers (Hawlitschek, Notheisen, and Teubner 2018). Each transaction is secured by cryptography, verified, immutable and tamper-proof (Underwood 2016). Even though cryptocurrencies and financial services were the first applications of DLT (Gupta 2017a), numerous other applications in different areas have sprung up (Clemons et al. 2017). In supply chains, DLT introduces (1) transparency, (2) trust and (3) disintermediation as key value propositions (Catalini 2017).

- *Transparency:* Several scholars, such as Kamble, Gunasekaran, and Arha (2018), see DLT as an enhancer for transparency. Following Morgan, Richey, and Ellinger (2018), supply chain transparency is enabled by visibility and traceability. DLT improves the visibility in supply chains, as it discloses transaction data (e.g. provenance information) to peers within a DLT network (Ivanov, Dolgui, and Sokolov 2018). Traceability is enabled by the ability of a DLT solution to trace back every transaction (Kamble, Gunasekaran, and Arha 2018) and reveal the involved actors as well as other information (e.g. value creation step).
- *Trust:* Numerous scholars (e.g. Auinger and Riedl 2018) discuss the benefits of applying DLT in terms of building trust between different parties. According to Mayer, Davis, and Schoorman (1995), trust is operationalised by ability, benevolence and integrity. While benevolence as an attitude is difficult to apply in terms of DLT solutions, the ability and integrity of transaction partners can be captured with DLT (Ostern 2018). For instance, Catalini and Gans (2016) illustrate that DLT helps to verify the abilities of transaction partners after a transaction. Smart contracts, which are programmed contracts that trigger pre-defined actions, make it possible to verify adherence to agreements by transaction partners and thus support integrity (Blossey, Eisenhardt, and Hahn 2019).
- *Disintermediation:* Early pioneers of DLT prophesised the elimination of intermediaries (Gupta 2017b). Later, the sentiment shifted toward DLT as a substitution for intermediaries (Auinger and Riedl 2018). Following Saberi et al. (2018) and Auinger and Riedl (2018), DLT reduces the need for intermediation in supply chains as trust and transparency are enhanced by DLT. Without DLT, intermediaries have a powerful role in mediating

between transaction partners (Camek and Mills 2004), but with the emergence of DLT, this role can be reduced (Davidson, De Filippi, and Potts 2018).

These projected effects have caused scholars such as Catalini and Gans (2016) and Seidel (2018) to predict an impact on transaction costs, for example, through the usage of DLT-enabled smart contracts. Within a DLT, any transaction ever processed through its network might be tracked and can be used later as a single version of the truth to verify that the transaction took place. It therefore serves as a shared, distributed accounting ledger. Such a ledger can be shared across multiple parties, and it can be public, private or semi-private (Mougayar 2016).

Due to its relatively young history, there are still many challenges and uncertainties regarding the adoption in practice and theoretical reasoning of DLT in supply chains. The most frequently discussed concerns are related to transaction scalability, uncertain regulatory status, large energy consumption, security and privacy and integration concerns (e.g. Avital et al. 2016; Swan 2015).

Transaction cost economics in supply chains

TCE explains intra-firm and inter-organisational transactions, their related costs as well as the appropriate governance mode. This makes it an excellent choice for studying transactions in inter-organisational supply chain relationships and how the adoption of a technology impacts the transactions and their associated governance mode (cf. Goldsby and Eckert 2003). Williamson (2008) further advocates for the suitability of TCE as a lens for analysing intermediation and transactions in SCM.

Basic concept and key characteristics of TCE

The core assumptions of TCE are based on human behaviour and include bounded rationality and opportunism (Grover and Malhotra 2003). Furthermore, TCE characterises transactions based on the dimensions of uncertainty and asset specificity (Rindfleisch and Heide 1997). Williamson (1975) also defines transaction frequency as an additional third dimension. The assumptions and dimensions affect the costs for a specific transaction as well as the choice of the governance mode (Crook et al. 2013). In TCE, a distinction is made between markets, hybrids or hierarchies as governance modes (Williamson 1985). Grover and Malhotra (2003, p. 459) define transaction costs as follows: 'Transaction costs = coordination costs + transactional risk.'

The coordination costs include costs for information exchange and the executed decision process associated with the transaction (Clemons, Reddi, and Row 1993) in addition to the transactional risk 'that other parties in the transaction will shirk their agreed upon responsibilities' (Grover and Malhotra 2003, p. 459). According to the selected governance mode, the coordination costs and transaction risk will either increase or decrease (Rindfleisch and Heide 1997).

Assumptions of TCE

Following TCE, decision-makers must characterise a transaction based on the assumptions and its dimensions and select the appropriate governance mode to minimise affiliated transaction costs (Clemons, Reddi, and Row 1993). Two main assumptions are made in TCE: bounded rationality and opportunism. *Bounded rationality* describes the cognitive limitations of humans with regard to receiving and processing information (Williamson 1975). It makes it challenging for individuals as well as organisations to capture the full complexity of situations. This is crucial in TCE, as it hinders the decision-making of managers prior to transactions. This assumption is discussed only in a few studies. Aubert and Rivard (2016) emphasise that some types of IT can support mangers during the decision-making process by providing and enabling faster processing of information, thus reducing the importance of bounded rationality.

In contrast to bounded rationality, *opportunism* has received considerable attention in TCE research. According to McIvor (2009, p. 47) it refers to 'decision makers acting with guile as well as out of self-interest'. Grover and Malhotra (2003) state that opportunism gives rise to transaction costs, as there is a higher transactional risk and the associated safeguards result in higher coordination costs. Consequently, when facing a high level of opportunism, managers tend to use hierarchies to reduce this risk and thereby the cost by performing transactions internally. In TCE, the assumption of opportunism has been well established since the first contributions of Williamson (1975). However, contrary to opportunism, researchers, especially those in the field of SCM, have assessed trust between transaction partners. Recently, TCE has been criticised for its negative assumption regarding human nature. Zipkin (2012) argues that trust is indeed a contrary assumption that negates the assumption of opportunism. However, scholars have been conservative in restricting the assumption of opportunism in inter-organisational transactions. Kwon and Suh (2004) state that a lack of trust causes an increase in transaction costs. Congruent with this finding, Ireland and Webb (2007) find that a high level of trust reduces ex ante and ex post transaction costs, as the need for coordination in the form of negotiating and constant monitoring is diminished. Consequently, the assumption of trust in inter-organisational transactions reduces transaction costs, as less efforts is required to mitigate the transactional risk. Hence, the assumption of trust has an opposing effect on the assumption of opportunism.

Dimensions of transactions

Whereas in TCE the assumptions model human behaviour, the dimensions of transactions characterise the transaction itself (Zipkin 2012). In this contribution, we focus on uncertainty and asset specificity as characterising dimensions.

The environment or the behaviour of transactions can cause *uncertainty* between transaction partners. This uncertainty manifests in difficulties in monitoring the transaction partners' behaviour and compliance to contracts due to elusive performance evaluation and information asymmetry (Williamson 1985). According to Grover and Malhotra (2003), behavioural uncertainty accentuates bounded rationality, causing ex post transaction costs to arise due to an increasing need for monitoring. In addition, the difficulties that stem from elusive performance evaluability and information asymmetry lead to ex ante and ex post opportunism (Akerlof 1970). The research outside of TCE illustrates that IT in the form of sensors, database systems or analytics enriches data availability in the supply chain and thereby reduces information asymmetry and facilitates performance evaluations (Morgan, Richey, and Ellinger 2018). However, this finding has not yet been fully linked to TCE. In TCE, information asymmetry itself is more connected with the role of intermediaries in transactions (e.g. the role of financial institutes) without having an explicit value in the context of a physical supply chain. As intermediaries possess information about at least one transaction partner and arrange an agreement with the other transaction partner or that transaction partner's intermediary, they distort information and thus are a source of information asymmetry (Casson 1997). Consequently, intermediaries have a sort of 'monopoly' on specific information, giving rise to uncertainty for the corresponding transaction partner.

Asset specificity, the second dimension of transactions, describes the customisation level of a transaction and whether the used assets are deployable in another setting. According to Williamson's (2008) work on outsourcing, high asset specificity leads to hierarchical governance. While, in general, this declaration is a little controversial (Zipkin 2012), the impact of IT on asset specificity and consequently on the governance mode depends on the type of IT observed. On the one hand, Bakos and Treacy (1986) show that IT usage in productions can increase flexibility and thereby reduce asset specificity. On the other hand, Subramani (2004) illustrates that IT increases the asset specificity of transactions in collaborative supply chain systems. As IT is a broad term, the field of application and the particular solution determine its effect on asset specificity and consequently on the choice of the appropriate governance mode.

Transaction costs and governance mode

Williamson (2008) describes the governance mode as a consequence of the dimensions of transactions. While markets and hierarchies form polar structures, hybrids are situated in between (Zipkin 2012). Because *transaction costs* are closely related to the *governance mode*, this subsection provides findings from research on both topics in an aggregated fashion.

The general notion of TCE is that a decision-maker's choice of governance mode is driven by the costs associated with the transaction in question. The research shows that IT has a reducing impact on transaction costs and consequently is favourable for use in markets (e.g. Balakrishnan, Mohan, and Seshadri 2008; Hitt 1999; Malone, Yates, and Benjamin 1987). According to Bakos and Brynjolfsson (1993b), Bakos and Treacy (1986) and Clemons et al. (2017), IT reduces ex ante coordination costs by providing information on transaction partners, prices, products and conditions more effectively for buyers as well as for suppliers. Moreover, IT enables contracting with a greater number of transaction partners through the use of contract databases and communication technologies that have a positive impact on the correctness of contracts at a lower price (Banker, Kalvenes, and Patterson 2006). Furthermore, IT also reduces ex post transaction costs. Through the usage of real-time databases, improved data availability and processing, IT also reduces the costs of monitoring the transactions between buyers and suppliers (Balakrishnan, Mohan, and Seshadri 2008).

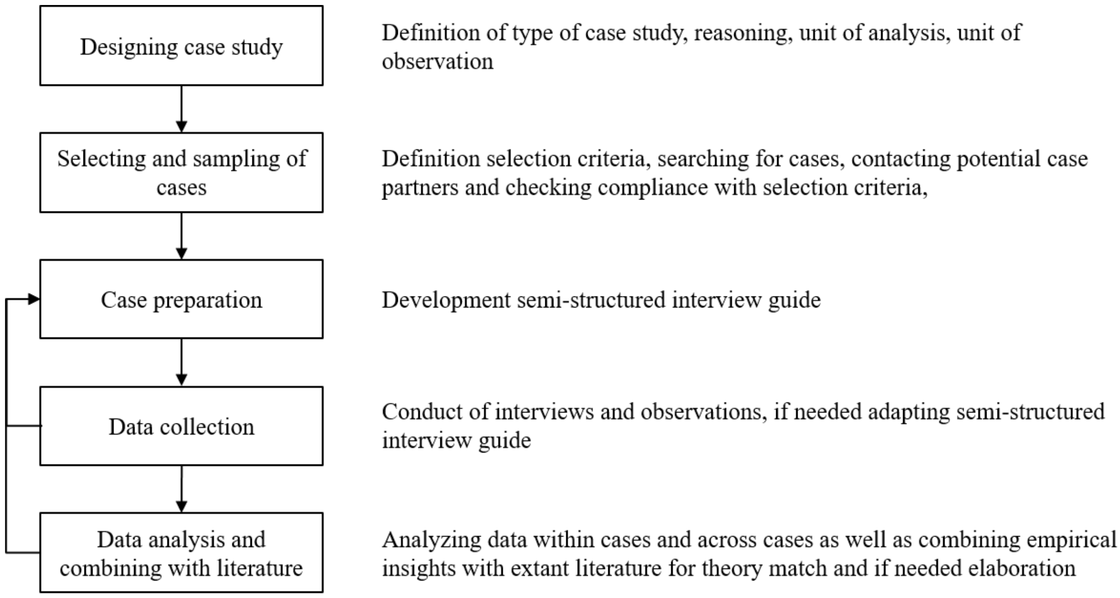
Considering IT's effect on reducing transaction costs, it might appear that IT favours markets, particularly since buyers might choose to work with a large number of different partners to diversify transactional risk by limiting opportunism and dependency on individual suppliers. However, Bakos and Brynjolfsson (1993a) state that buyers face a trade-off between coordination costs and the expected benefit from having multiple suppliers. Clemons, Reddi, and Row (1993) find that buyers choose to work with a small number of long-term partners rather than of an increasing number of suppliers.

While the cost-reducing effect of IT stems largely from the improved availability and processing of data, which brings more transparency into transactions between buyers and suppliers, it also comes with an adverse effect. Clemons and Row (1993) show that retailers resist deploying IT for enhanced coordination because they fear a loss bargaining power. According to Holcomb and Hitt (2007), bargaining power is of particular importance when only a small number of transaction partners are available. Consequently, in situations with reduced bargaining power, decision-makers tend towards hierarchies. Interestingly, these behaviour patterns are in contrast to the notion that in a general setting IT favours outsourcing.

Methodology and case descriptions

Following the background of this paper, the starting point for our abductive research is the observation that the new phenomenon of DLT is affecting transactions, associated costs and governance modes in supply chains. Abductive case studies are characterised by the parallelism of data collection and searching for complementary theory, in essence ‘matching theory and reality’ (Dubois and Gadde 2002, , p. 554). Given the lack of empirical evidence and theory on how and why DLT impacts TCE in supply chains, we posit the need to conceptualise and derive propositions for future deductive research. Kovács and Spens (2005) argue that abduction is suitable for bridging an early stage of a research phenomenon (in our case, DLT in supply chains) with already established theoretical foundations (in our case, TCE). Given the novelty of DLT in supply chains (Nærland et al. 2017) and the scientific maturity of TCE in operations management, SCM and IS, abduction seems to be an appropriate strategy. Consequently, our research follows an abductive approach for theory elaboration, as proposed by Ketokivi and Choi (2014).

Dubois and Gadde (2002) describe this approach as systematic combining. Hence, we go back and forth between the theoretical contribution of TCE in supply chains and our empirical data from multiple case studies. The literature background of this study condenses the complementary contributions, which form the basis for our elaboration. For the empirical data, we decided to use a multiple case study design for to the following three reasons. First, case studies are well suited for elaborating theory and therefore are a fit to the goal of our research (Ketokivi and Choi 2014). Second, in order to answer both research questions a deep understanding of the phenomenon under study is required, which plays to the strengths of case study research (Barratt, Choi, and Li 2011). Third, case study research is suitable for a small number of in-depth revelatory cases, which is needed for a new phenomenon such as DLT (Eisenhardt 1989). D-Figure 1 illustrates the abductive case study approach, including case design, selection and sampling, data collection and data analysis.



D-Figure 1: Case study process

Case study design

We apply an abductive multiple case study design with five cases. Hence, our design is different from the inductive case study approach described by Eisenhardt (1989), as we do not aim at building new theories. Rather we elaborate existing theory on TCE against the backdrop of DLT as a new phenomenon in supply chains. Our unit of analysis is the inter-organisational DLT-based transaction between a buyer and a supplier in a physical goods supply chain. Thus, we use a holistic multiple case study design, with a single unit of analysis (Yin 2014). Consequently, the study is not looking at transactions within organisations (e.g. between different functions). The unit of observation is the pilot application of DLT-based transparency solutions in physical supply chains. Thus, we analysed solutions that aim at providing more supply chain transparency to (a) supply chain actors and/or (b) end consumers and that have reached at least the pilot phase. More precisely, supply chain transparency can be defined as ‘reporting to and communicating with key stakeholders to provide traceability regarding the history of the product and visibility about current activities throughout the supply chain while also incorporating stakeholder feedback for supply chain improvement' (Morgan, Richey, and Ellinger 2018, p. 960). D-Table 1 provides an overview of the five cases.

D-Table 1: Case overview

ID	Case description	Field of application	Number of involved supply chain actors	Interview partners
1	DLT-based platform to provide transparency on the proof of origin of gemstones and diamonds for end customers and supply chain actors. In addition, provides transparency on the involvement of actors and their actions.	Diamond industry	>5	CEO, Head of Development, Purchasing Director, Business Developer
2	DLT-based platform to provide transparency on the origin and value creation processes along the supply chain for consumers and supply chain actors.	Food industry	>5	CEO, Business Developer, Project Manager Purchasing
3	DLT-based platform to provide transparency on the origin of diamonds and the involvement of actors for end customers, banks and supply chain actors.	Diamond industry	>5	CFO, Business Developer, Project Manager Baking and Relations
4	DLT-based platform to provide transparency on the condition of the transportation of pharmaceutical goods for supply chain actors.	Pharma industry	5	COO, Retail Manager, Project Manager Packaging
5	DLT-based platform to provide transparency on the origin of diamonds and their quality for supply chain actors and end customers.	Diamond industry	>5	CEO, Software developer, Purchasing director

Case sampling

To obtain a purposeful sample, we apply criterion sampling. Purposeful sampling requires access to key informants in the field who can help in identifying information-rich cases (Suri 2011). As the authors (working on different continents) independently started out conducting engaged scholarship (Van de Ven 2007) on DLT in SCM, they had excellent access to key informants in the industry. As a first step in our case selection, we devised the following criteria for the criterion sampling:

- *Homogeneity of unit of analysis:* The cases had to aim at providing more transparency on a physical product's transactions within the supply chain with other supply chain actors, end customers or both. This established a homogenous unit of observation.
- *Sense of purpose:* In order to avoid the observation of pointless DLT initiatives, we followed Wüst and Gervais (2017). Thus, we only study sense-making DLT initiatives.
- *Maturity of unit of observation:* The cases had to comprise a DLT solution that has at least been tested in a pilot phase to ensure proper functionality. This allowed us to observe real impacts and not just predictions. Furthermore, we were able to interrogate different involved parties to gain insights from multiple perspectives.
- *Industry diversity:* The cases had to be applied in different industries to allow better generalisability of our findings. In this way, we ensured that our findings were not dependent on the context of a single industry, and thus our sample also exhibited heterogeneity.

The criteria 'sense of purpose' and 'maturity of unit of observation' ensured homogeneity of the unit of observation and thus allowed comparability in our cases. As a second step, we performed a media search to identify potential cases for our study. Once we made a pre-selection based on the defined criteria, we approached one of the participants of the DLT pilot. After we determined through short interviews whether the DLT pilot fulfilled our criteria, as a third step, we asked the approached participant to identify additional involved parties that might be willing to be part of additional interviews in the case. Thus, this participant was the 'door opener' for us. Once we had obtained the approval of multiple participants for one case in the fourth step, we prepared our data collection process.

Data collection

Following Dubois and Gadde (2002), we entered the field with our prior theoretical knowledge on TCE in supply chains. Based on this and the perception of DLT in supply chains, we crafted a case study protocol with a semi-structured interview guideline for our interviews and set up a case database to store all collected data. Following the abductive approach, we elaborated additional questions aimed at specific constructs that we found in the extant literature and which were necessary to properly understand the cases and their impact on TCE. Thus, the guideline was refined over time.

First, we conducted interviews with the 'door opener' before conducting additional interviews with other partners. In total, we conducted sixteen interviews. The interviews lasted between 1 and 3.5 hours and were conducted on-site or via phone/video link when a physical visit was impossible. Each case includes interviews with at least one representative of the DLT solution provider and with at least one user of the solution. The door opener was one of them. We managed to interview interviewees from various backgrounds (e.g. business, engineering, natural science, computer science) and positions (e.g. CEO, COO, CTO, business developer, software developer, purchasing director) in order to incorporate different perspectives. Thirteen of the sixteen interviews were taped and subsequently transcribed. We also combined this data with the notes we took during the interviews. For the other three interviews carried out without recording, we took comprehensive notes. Afterwards, we sent the interviewee the corresponding notes or transcript for review to ensure correctness. We then stored all transcripts and notes in our case study database for analysis. Following Dubois and Gadde (2002), we constantly searched for complementary theoretical contributions that explained the observations from our data collection.

Data analysis

In addition to the collected data from our interviews, we gathered data for triangulation purposes from company websites, press releases, whitepapers, videos and solution demonstrations in cases where they were available. Our analysis process was structured in four steps to elaborate theory on TCE. First, we coded the transcripts and notes case by case using ATLAS.ti to gain a deeper understanding of the phenomenon and the cases as well as to contour the emerging topics stemming from the codes. Second, we used these topics to explore the extant literature on TCE. At the same time, we used this knowledge for structuring and clustering of the established codes. Therefore, we drew on the TCE framing that we developed in our literature search. Third, based on the clustering and framing, we drew a comparison between our cases to reveal empirical findings on a cross case level. Thus, the empirical findings were results of the synthesis of related codes and DLT-caused effects on TCE constructs. Fourth, in accordance with Dubois and Gadde (2002), we went back and forth between the empirical findings and the extant literature on TCE. In this step, we analysed the relation of our empirical findings to the extant literature. We found three types of relations: confirming, expanding and refining.

- We considered an empirical finding as confirming when the extant literature revealed an IS-caused effect on TCE constructs similar to the one we found in our data on DLT-caused effects.

- We found DLT-caused effects that expanded a discovered IS-caused effect. Thus, this represented an expanding relation to the extant literature.

- Other empirical findings refined the extant literature and provided concrete specifications of IS-caused effects that were revealed on a high level in literature.

In addition to this allocative analysis, we wanted to identify where these effects came from. Therefore, we used the three DLT enablers - transparency, trust and disintermediation -, which were described in the existing literature. We applied the this operationalisation from the literature to draw conclusions regarding where the effects came from. We drew on the richness of our data to discover the enabler for these effects. The rich data also allowed us to identify whether these enablers occurred in multiple codes of all cases or only in few codes of some cases.

Quality criteria

We took several measures to ensure the high quality of our case study. We increased the transparency of our case study execution and its replicability by using a case study database for all our cases and developing a case study protocol, which ensured reliability (Yin 2014). Furthermore, we improved construct validity by applying data triangulation by considering multiple sources of evidence. In addition, we created a chain of evidence from our research objective to the data collection process, the case study database and the coding as well as to the step of analysing and systematically combining the empirical findings and the literature. To strengthen internal validity, we used the extant TCE literature to structure our data and crafted our semi-structured interview guideline according to established methods (Gerring 2004). In addition, we insured external validity by applying our case selection criteria to our cases to achieve generalisability across cases (Eisenhardt 1989).

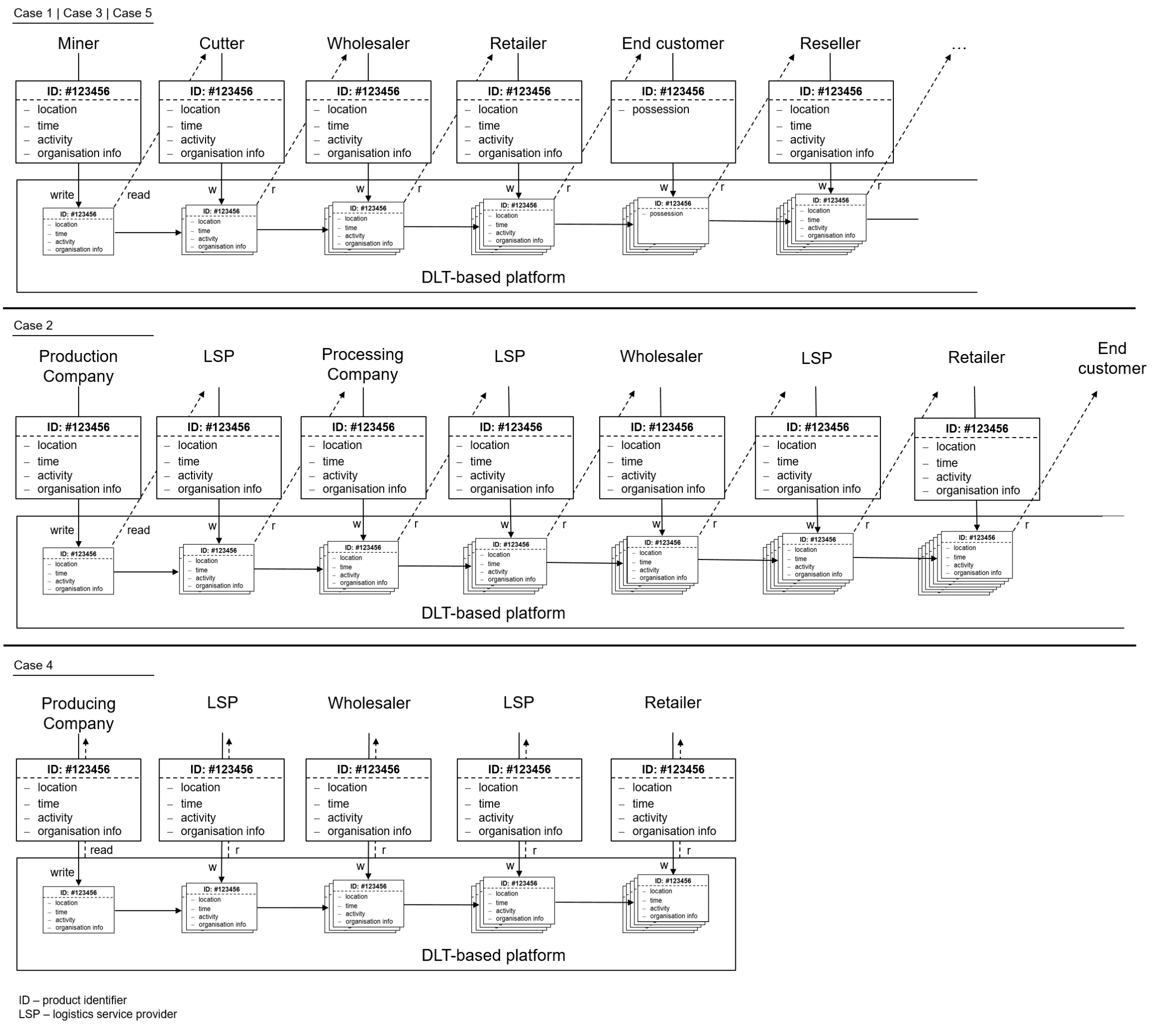
Case description

D-Figure 2 illustrates the transactions mapped by the DLT-based solutions for supply chain transparency in all five cases. The figure gives an overview of the type of information that is entered in the DLT-based solution in the supply chain, how this information is shared and processed as well as which organisations are included. We emphasise that D-Figure 2 only displays information regarding one physical product within the transactions of a supply chain (or parts of the supply chain, as in Case 4). However, all of the solutions mapped numerous examples of such product flows, with multiple transactions in their DLT-based platform during the pilot phase. Hence, each actor that uses the solution and is involved in a transaction within the particular supply chain has access to the corresponding information based on the actor's position within the supply chain. The cases can be characterised as follows:

- Case 1, 3 and 5 aim at providing more transparency and trust to the diamond supply chain. The focus of the solution is on providing information on the origin of the physical product and the value creation along the supply chain. Consequently, each supply chain actor and the end customer can see the value created by the upstream actors in the supply chain, including all transactions. This is achieved, as each supply chain actors enters their value creation information with timestamp, affiliation and additional product information, such as illustrations and certificates, into the DLT solution. Each subsequent actor is then able to view this information and verify its correctness. By checking the information entered by prior actors, it is possible to ensure data integrity and thereby enhance trust. Building on the available and verified data in the DLT solution, Case 5 enables the sale of stones without the involvement of third parties.
- Case 2 is aimed at providing upstream transparency and trust in the transactions within a food supply chain. Each supply chain actor and customer can trace back the origin of the product and the transactions in the upstream supply chain. Further, each actor in the supply chain verifies the provenance of the product and thereby creating a gapless, trusted chain of custody that reveals the origin of the product through multiple supply chain stages.
- Case 4 focuses on providing transparency and trusted information regarding the last-mile delivery of pharmaceuticals to the supply chain actors. While providing proof of provenance, the focus is on monitoring the conditions during the last transactions within the pharmaceutical supply chain. During transit, different data points are recorded (e.g. temperature) and ultimately stored in the distributed ledger. The sender, recipient and transportation service provider verify the entered data and

can monitor the temperature conditions during transportation. Unlike the other cases, Case 4 also enables transparency regarding downstream actors and their corresponding activities.

- In all cases, historical transparency on all transactions with upstream actors can be achieved by aggregating the information of multiple products. In addition, all the solutions include DLT-based smart contracts, which enable the automation of specific processes based on pre-defined events. Additionally, the solutions of Case 2 and 5 employ artificial intelligence to analyse the data stored within the DLT solution and provide better processing (e.g. through pattern recognition).



D-Figure 2: Description of the solutions of the empirical cases

Empirical analysis and theory elaboration

Following the description of the cases and the prevailing literature on TCE, this section describes the interpretation of our empirical data on DLT in supply chains, which leads to theory elaboration. Since the interpretation of data from a case study design cannot lead to completely validated results (Ketokivi 2006), we present our theoretical interpretations in detail in order to achieve plausibility.

DLT-based supply chain transparency and its impact on the TCE assumptions

DLT-enabled assistance effect: The observed DLT solutions make it possible to collect, store and share a broad range of relevant information along the supply chains on products, processes, conditions and stakeholders. Although the focus of the solutions in Case 1, 3 and 5 is different from the focus of the solutions in Case 2 and Case 4, each of the solutions improves the availability and the processing of information for the transaction partners through the use of DLT. As DLT verifies data before entering them and stores it immutably by preventing manipulation with the distributed storage and consensus mechanism, the data provide a reliable and verified basis for decision-making. In addition, the DLT solutions provide traceability of each transaction and its data along the supply chain. Thus, the involvement in a certain transaction is traceable at all times. Pairing verified, reliable and traceable transaction data with smart contracts (as in all cases) or artificial intelligence (as in Case 2 and 5) facilitates, managers' decision-making process. In particular, the assessment of the available data is improved. Moreover, smart contracts automate specific processes based on pre-defined conditions and thus provide data as well as recommendations for decision-makers. Artificial intelligence prepares the available data of the DLT solutions, identifies patterns and draws managers' attention to special patterns that may be caused by, for example, anomalies. Consequently, DLT makes the information processing and decisions in supply chain transactions more accurate. The enhanced transparency promotes better and verified data availability, which is the direct cause of the DLT-enhanced assistance effect. This is supported strongly in all our cases, as exemplififed in this quote from Case 2:

"Besides that [note: the traceability] our solution also includes anomaly detection, meaning we also have certain intelligent processes in place that perform tests based on the available data and find patterns that may stem from anomalies. [...] Based on this [the anomaly detection], our solution creates notification reports via smart contracts that are used to communicate with the relevant stakeholders". [Case 2]

Even though research on the relation between IT and bounded rationality in transactions is limited, our empirical findings are in line with the findings of Aubert and Rivard (2016) showing that IT enables the provision and preparation of information for management decision-making and thus limits the bounded rationality. Consequently, the observed DLT solutions fall into the category of IT systems that are beneficial because they reduce the bounded rationality of decision-makers during transactions in an inter-organisational setting and enable better decisions. Thereby, the DLT-enabled assistance effect helps to avoid costs that would arise from incorrect decision-making under bounded rationality. However, DLT is only facilitating the decision process of managers by limiting the bounded rationality of humans, not eliminating it. Thus, the assumption of bounded rationality still holds, although its importance decreases due to the use of DLT solutions for supply chain transparency.

DLT-enhanced substitution effect: Our data show that trust and mistrust is a commonly-discussed topic in the examined supply chains. Cases 1, 3 and 5 employ solutions that are intended to establish trust between transaction partners in an industry that is characterised by mistrust. An interviewee in Case 3 summarises the motivation to initiate the DLT solution in the industry:

"We knew what the problem was in the industry which was a lack of trust. [...] This is not a stable relation and we are trying to rebuild this trust with this initiative" [Case 3]

In addition to the lack of trust, the missing transparency allows actors in the supply chain to act in their own interest. As an interviewee in Case 1 explains:

“Before, there was little transparency on the activities along the value chain. Some of the involved parties did not add value but surcharged their margin as nobody could disclose what they have done or haven’t done.” [Case 1]

As described above, all the DLT solutions disclose information on supply chain transactions and thereby provide more transparency to the supply chain actors. Moreover, this information is verified and validated within the DLT. By adding the traceability and immutability of these DLT solutions, a high degree of trust is created (Seebacher and Schueritz 2017) as indicated by an interviewee in Case 3:

“They wouldn’t have trust if we did not have this distributed ledger, that is why, for example, banks/diamond traders prefer to have their information on a decentralised option [note: DLT]. Another important argument for more trust is using DLT with its immutability. So, the fact that it is impossible to manipulate things and that every modification recorded with the user name or the user-ID, a time stamp etc. If we want to provide transparency, it has to be in a fully temper-proof and immutable way.” [Case 3]

Case 3 demonstrates that although deployed in environment of mistrust and opportunism, the DLT solution is able to establish trust between transaction partners, as the chances to act opportunistically are limited due to the added transparency. This effect was for example reported in Case 5:

“Frauds will not be on this platform because they’d need to be transparent and have much less ways to get away with their actions.” [Case 5]

Although opportunistic behaviour may still exist among supply chain actors, DLT provides an opportunity to uncover this behaviour. Consequently, the opportunistic behaviour of the users of such DLT solutions is limited. While opportunism is a key assumption of TCE (Williamson 1975), in light of DLT, the impact of opportunism is becoming less important in supply chain transactions. Meanwhile, DLT-based transparency solutions provide a new way to establish trust between transaction partners, consistent with the contributions of Seidel (2018) and Nærland et al. (2017). Therefore, we observe a DLT-enhanced substitution effect that proclaims to replace the TCE assumption of opportunism with trust. As opportunism leads to higher transactional risk - and requires increased efforts to prepare for this risk - in increased transaction costs (Grover and Malhotra 2003). Thus, developing trust through the use of DLT reduces transaction costs. Our data show that this DLT-enhanced substitution effect is directly caused by DLT-enhanced trust and indirectly by transparency as an enabler for trust. Both causes are found in all cases and are thus classified as strong.

DLT-based supply chain transparency and its impact on the transaction dimensions

DLT-enhanced disclosure effect: All observed DLT-based solutions enable access to data of all historic transactions in the supply chain. When aggregating this historical data, a new opportunity arises. The organisations using the solutions of Case 1, 2, 3 and 5 are able to trace back the transactions of their downstream partners, and this gives them a better opportunity to evaluate their performance based on historical records. The solution in Case 4 also enables upstream and downstream transparency in the supply chain. This allows both sides of a supply chain transaction to evaluate the performance of the partner, as indicated by the following quotes:

"The solution offers producers for example to track the condition during transportation or storage of their products. At the same time, retailers can also track these conditions and see how their orders are handled along the supply chain. Non-compliance is detected and stored forever. [...] This provides a lot more transparency on the processes and thereby enhances the evaluation based on verified data." [Case 4]

"We disclose information on all downstream activities, providing a proof of provenance and a track record of activities for each stone. This gives you [note: upstream actors] the opportunity to see who did what. [...] Track records will always be in the platform; there is no way to get them out." [Case 1]

Consequently, the DLT-based solutions enable a better data-driven evaluation of the performance of downstream actors through more transparency. This reduces behavioural uncertainty, one of the dimensions of transactions according to TCE (e.g. Williamson 1985). We observe this strong diminishing effect of uncertainty on performance evaluation resulting from the DLT-enhanced transparency in all our cases. This reduces the costs required for performance evaluation due to better data availability and verified data within the DLT solution.

DLT-caused scale-pan effect: However, the usage of DLT for performance evaluation in supply chains can result in two opposing directions, as shown in our empirical data. If the solution provides transparency in one direction (upstream or downstream), it reinforces information asymmetry, favouring one side of the transaction. While in Cases 1, 2, 3 and 5 the downstream actors have more information on the previous actors, these previous actors do not benefit because they are not able to access data regarding downstream activities. This increases the costs to overcome the information asymmetry due to a lack of transparency on the part of one transaction partner. Furthermore, as shown in Case 4, a DLT-based solution for supply chain transparency can also reduce information asymmetry. As all involved parties can access the same data, transactions along the supply chain are no longer opaque. This DLT characteristic reduces the costs to overcome information asymmetry - in terms of a scale pan - due to the enhanced transparency for both transaction partners.

DLT-enabled demonopolisation effect: Even though the initiation of the observed pilot DLT solutions came from supply chain actors, other companies, third parties, develop the DLT solutions themselves. However, these third parties do not transmit data, as indicated by interviewees from Cases 1 and 2:

"We have only developed this platform. However, we are not able to access the data that is stored in our blockchain solution." [Case 1]

"We work together with [name of the DLT developer]. They did only the development of the DLT platform. The consortium, however, operates the platform. […] The distribution of transaction data is achieved by peer communication." [Case 2]

As a result, third parties are not able to distort information. In fact, the information is accessible to all the respective supply chain actors through the DLT solution they provide. In contrast to Casson (1997), according to whom such third parties distort information due to their monopoly of information, the DLT providers do not assume this role. The result is in a power shift that equalises the distribution of information among supply chain actors and reduces the information monopoly of third parties. This is also seen as a form of disintermediation; although there is still a third party, their active role in transactions is diminished and thus the respective costs are reduced (Gupta 2017b). This DLT-enhanced transparency, which enables users of the solution to access data without engaging with the third party for every transaction, is thus the indirect cause of this demonopolisation effect.

DLT-caused network effect: The observed DLT-based solutions form networks for specific supply chains and products. The pilots of Case 1, 3 and 5 show that, although started in the same industry, there are different initiatives.

"At the moment we see a number of initiatives in our industry. The majority of them are aiming at bringing more transparency. [Name of a company] is doing exactly that. [Name of another company] is pairing with [Name of another company] to do something similar. […] being part of one solution is meaning that you will not participating in another. I cannot see a company joining multiple initiatives right now. […] sooner or later there will be a consolidation." [Case 3]

Consequently, when adopting one of these solutions, it is not compatible with the other solutions because they use different DLT platforms and interfaces as well as different data formats to upload to the distributed ledger. The more actors join such a solution, the more supply chain transparency is provided by mapping a gapless supply chain.

"The more players join the platform, the more transparency can be achieved. […] All players but also the [note: end] customer will benefit from this complete traceability." [Case 1]

Following this logic, the DLT solutions create a network effect (Shapiro and Varian 1998) caused by the notion of gapless transparency, which is found in all our cases. This increases the asset specificity of DLT-based solutions for transactions. Consequently, these solutions fall into the category of IT that increases asset specificity and dependency on the network. As the observed DLT solutions are addressing the inter-organisational transparency of transactions in supply chains, they constitute a collaborative aspect. This is consistent with the findings of Subramani (2004), who argues that such collaborative IT systems increase asset specificity.

DLT-based supply chain transparency and its impact on transaction costs and governance mode

DLT-enabled segregation effect: As described above for the DLT-enhanced disclosure effect, all of the studied solutions make it possible to trace back and disclose activities along the supply chain and thereby provide data for evaluating other supply chain actors. Hence, the actors are only willing to disclose all this information, if they do not fear it will disadvantage them to do so. Therefore, a network of actors is established that meet certain performance criteria.

"In the long run, this separates the good from the bad. Only partners will be part of network that have nothing to hide. Others, who try to hide their non-value-adding will not join, as everybody else can see it now, what they are doing." [Case 1]

Cases 2, 4 and 5 show similar characteristics. For example, in Case 4, the traceability of the conditions of supply chain operations, such as transportation or warehousing processes, leads transaction actors to select their partners based on their record displayed in the DLT solution. During this phase of selecting adequate partners for these operations, it is obviously better to have a record than to have one. This segregation effect is directly caused by the DLT-enhanced transparency described above. Moreover, it reduces the ex ante transaction costs, as the search for a partner is facilitated by the segregation. Therefore DLT-based solutions for supply chain transparency show similar cost-reducing effects to those identified by Bakos and Brynjolfsson (1993b) and Clemons, Reddi, and Row (1993).

DLT-enhanced automation effect: The empirical data show that DLT forms the basis for improved monitoring. As all entered data are verified by peers within the supply chain network, can be traced back at all times and are stored immutably, the monitoring of transaction contracts is improved. This enables the solutions of all observed cases using smart contracts or artificial intelligence, such as in Case 2 and 5, to monitor transactions by analysing verified data within the DLT platform.

"All transaction data in our platform is verified by peers within the network. There is no arguing on the correctness of data anymore. The consensus takes care of this. […] You have now verified data, so you can use it as a basis triggering smart contracts. […] We do this to track for example temperature of shipments. Once you defined temperature limit is exceeded, smart contracts trigger alerts." [Case 4]

While the idea of smart contracts and artificial intelligence is not limited to DLT applications, the process of data verification in a peer network is DLT-specific. By this verification, DLT is building a strong foundation to enable automated monitoring of supply chain transactions and thereby reduce ex post coordination costs in the form of monitoring costs. At the same time, this DLT-enhanced monitoring forms the basis for automated process enforcement via smart contracts. For example, the solution in Case 2 comprises smart contracts that trigger payment based on the verified and secured transportation data once the defined delivery terms have been meet.

"This payment process [note: payment of transportation service] is triggered once the customer confirms the incoming goods and the transaction is stored as completed in the blockchain." [Case 2]

With the use of smart contracts, DLT enables the merging of monitoring and enforcement. The key benefit is that due to the enhanced transparency of verified and secured data, this merged monitoring and enforcement can be automated, thereby reducing ex post coordination costs in supply chains. While Balakrishnan, Mohan, and Seshadri (2008) argue that IT can enhance the monitoring of transactions and thus reduce the corresponding costs, the effect on enforcement is new. The cause for this is rooted in the enhanced transparency, which is found in all our cases.

DLT-caused torpedo effect: The identified DLT-caused disclosure effect shows how improved transparency across the supply chain enhances performance evaluation. When looking prior to the transaction, a further impact is found in three of our cases, which illustrates the downside of the DLT-caused disclosure effect. The solution in Case 4 monitors and records the conditions of the last-mile distribution of pharmaceuticals. The DLT-enhanced transparency provides evidence of the performance.

"Of course the track record has an impact on the conditions for the next order. […] When you deliver on time and comply with the negotiated standards, the conditions will be in your favour. When you don't, it will be harder for you to get the order." [Case 4]

"The purpose is to give more information to the banks and to reduce the risks of the banks. This tool should allow banks to have a better appreciation of the risks. […] Traders that were linked to incidents or that have a record with irregularities will have to pay higher rates for their loans." [Case 3]

Thus, while transparency reveals the capabilities of transaction partners on a historical basis, it also uncovers their incapabilities or failures. Consequently, transparency supports clients in their bargaining with their transaction partners. Hence, agents may have a fear of losing bargaining power due to their DLT-based record of non-fulfilment. This fear is in line with the findings of Clemons and Row (1993) on general IT. Therefore, DLT is a type of IT that carries the risk of a loss of bargaining power due to the enhanced transparency it provides. As a result, this torpedo effect causes a power shift, favouring the client during the bargaining process.

Impact of DLT on TCE: Summary of the effects and their causes

D-Table 2 summarises and describes the type of effects and indicates the DLT-enabled cause for the corresponding effect. We differentiate between direct cause and indirect cause and illustrate how often evidence was found in our data. Most of the effects are caused directly by the DLT-enhanced transparency in the supply chain. However, trust and intermediation account for two other effects on TCE. The DLT-enhanced trust fuels the discussion of SCM scholars on the assumption of opportunism in TCE. The DLT-enhanced distribution of information reduces the need for intermediation as an information supplier on transaction partners and diminishes information sovereignty causing intermediaries to lose their information monopoly.

D-Table 2: Effects on supply chain transactions and the DLT-enabled causes for the effects

	Name of effect	Type of effect	Relation to extant TCE	DLT-enabler		
				Transparency	**Trust**	**Disinter-mediation**
TCE assumptions	DLT-enabled assistance effect	Cost avoidance effect due to better decision-making by embanked bounded rationality	Confirming	D ++	-	-
	DLT-enhanced substitution effect	Cost reduction effect due to DLT-enabled trust as substituting assumption for opportunism	Expanding	I ++	D ++	-
Transaction dimension	DLT-enhanced disclosure effect	Cost reduction effect due to better performance evaluation of partners based on DLT data	Confirming	I ++	-	-
	DLT-caused	Cost reduction (increase) effect	Expanding	D ++	-	-

	scale-pan effect	due to equalised (reinforced) information asymmetry				
	DLT-enabled demono-polisation effect	Power shift due to diminished role of third party	Expanding	I +	-	D ++
	DLT-caused network effect	Dependency increasing due to network effect for gapless transparency	Refining	I +	-	-
Transaction costs and governance mode	DLT-enabled segregatio n effect	Cost reduction due to facilitated searching for transaction partners	Expanding	D ++	-	-
	DLT-enhanced automatio n effect	Cost reduction due to automated monitoring and enforcement based on verified data	Refining	D +	-	-
	DLT-caused torpedo effect	Power shift due to the potential to lose bargaining power	Refining	D 0	-	-

Type of relation to DLT-enabled cause:		Strength of relation:	
D	Direct	++	Very strong influence (appearance in all cases, multiple codes)
I	Indirect	+	Strong influence (appearance in all cases, one code)
-	Not related	0	Weak influence (appearance in some cases)

Concluding discussion and future research

Our study revealed managerial and theoretical implications of DLT on TCE in supply chains. In the following, we outline our findings and delineate between the theoretical and managerial implications.

Theoretical implications

This paper set out to contribute mid-range theory to the knowledge gap related to DLT in supply chains and its implications on TCE in supply chains through an abductive multiple case study. Our empirical data suggest that DLT has an impact on TCE in supply chains. More specifically, to answer RQ1 and RQ2, our analysis suggests nine effects of DLT on TCE caused by DLT-enhanced (1) transparency, (2) trust and (3) disintermediation. These nine effects offer confirmation, refinement and expansion of existing theory.

Our evidence shows that DLT aids decision-makers and thereby limits the assumption of bounded rationality, which is in line with the existing contributions of TCE (e.g. Aubert and Rivard 2016). In addition, we have also confirmed that DLT in supply chains enables performance evaluation, consistent with what Morgan, Richey, and Ellinger (2018) found for IT in general. Based on both confirming effects, we derive that DLT has in fact a supporting function for managers' decision-making and helps to avoid and reduce costs of supply chain transactions.

In line with Subramani (2004) we show that DLT solutions for supply chain transparency are IT systems that increase asset specificity in transactions. Following Clemons and Row (1993), we have characterised the observed solutions as IT systems that trigger the fear of losing bargaining power. The empirical data has also led us to derive a new dimension of automation for monitoring and enforcing transactions in supply chains (e.g. Balakrishnan, Mohan, and Seshadri 2008). All three effects constitute refinement to extant literature. While the DLT-enhanced automation effect is a cost-reducing effect, the DLT-caused network and torpedo effects underline also the downsides of DLT use and displays an effect that has to be taken into account for DLT-adoption decisions.

In contrast to the extant literature on TCE (e.g. Williamson 1975, 2008), we have found evidence that assuming opportunism as an assumption of human behaviour in TCE might not be appropriate in light of DLT. Instead, we have shown that trust is more appropriate for modelling human behaviour in transaction settings with DLT-based solutions. In addition, contrary to Casson (1997), we have discussed the scale-pan effect of DLT and its meaning for information asymmetry in supply chain transactions in the demonopolisation of intermediaries. Finally, our data suggest a segregation effect of DLT in supply chains, which is a revelatory finding regarding the search for transaction partners within TCE. Three of the four expanding effects cause cost-reductions for supply chain transactions and thus demonstrate the beneficial improvement of DLT use. The DLT-enabled demonopolisation effect diminishes the role of intermediaries as it reduces the information asymmetry, which is a key finding for TCE. In the end, this might lead to cost reductions as well.

Overall, we have identified a reduction in coordination costs ex ante and ex post through the use of DLT-based solutions for SCM. According to the extant notion of TCE (e.g. Clemons, Reddi, and Row 1993), this favours the use of markets as a governance mode over hierarchies. However, with the DLT-caused network and torpedo effect, we have also found evidence that DLT does not only favour markets. When looking at the governance mode, these projections are based on the indicators within our empirical data. From our observations of pilots, there is no clear impact on the governance mode. urther empirical research should thus look at the impact of DLT on the governance mode in supply chains. However, currently the small number of DLT applications limit to observe this phenomenon. Future research should address the question of whether the cost reducing benefits of DLT in supply chain transactions can overcome the DLT-caused network and torpedo effects.

Managerial implications

When looking at DLT in SCM, managers face the challenge of assessing the potential of DLT in their context. While the potential of the technology appears to be enormous in the long run (e.g. Casey and Wong 2017), widespread implementations are rare, and the technology is still under development (Nærland et al. 2017). Consequently, managers are searching for indicators of short-term benefits in order to assess the role of technologies such as DLT. As of now, it is assumed that these benefits are mainly related to cost efficiency (Higginson, Nadeau, and Rajgopal 2019). In this study, we identified cost-efficiency benefits of DLT in supply chain transactions. In particular, we revealed that DLT solutions for supply chain transparency create cost savings by enabling evidence-based performance evaluation of supply chain partners, supporting managers' decision-making process and reducing the power of costly third-party institutions. Meanwhile, we also disclosed that DLT solutions for supply chain transparency could also cause a loss of bargaining power. Our study supports managers' assessment of DLT in supply chains and offers them an empirical foundation for making decisions on DLT adoption to enhance supply chain transparency. Considering the limited number of empirical studies on DLT in SCM, this work is the first to focus explicitly on costs in supply chains and to show evidence of cost reducing of DLT in SCM at this early stage.

Acknowledgement

We wish to acknowledge the Swiss National Science Foundation (SNSF) for supporting our research on Blockchain Technology in Supply Chains. Moreover, we thank the two anonymous reviewers for their constructive comments and feedback. We also acknowledge the helpful suggestions of audiences at the 30th Annual Nordic Logistics Research Network Conference (NOFOMA) and the 2018 CSCMP Academic Research Symposium.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Swiss National Science Foundation (SNSF), grant number 100018_179036.

Appendix

Appendix A. Semi-structured interview guideline

Authors' note: Our guideline demonstrates the typical topics that we always addressed in each case. The following guideline illustrates the mental line of inquiry during data collection. In each interview, we asked questions following this mental line but in addition, we asked questions that arose out of the situation.

- Personal introduction (name, function, role in DLT Project)
- Introduction of the DLT pilot (solution of DLT pilot)
- Motivation to start DLT pilot and initial situation before start
- Goal of DLT pilot
- Participating organizations of DLT pilot (roles in DLT pilot)
- Status of DLT pilot (achieved progress)
- Overall impact of the DLT pilot
- Impact on behaviour of transaction partners and description of reason (opportunism, bounded rationality)
- Impact on transaction context and description of reason (uncertainty, asset specificity)
- Impact on transaction cost and description of reason (bargaining, monitoring, enforcing)
- Future impact of DLT pilot

Appendix B. Classification

Classification of the five DLT applications (cases) according to the developed taxonomy in Study 1:

Underlying technology	Underlying protocols [UP]	BCT ◆●■□◇	DAG				
	Permission right [PR]	Public	●■□ Private ◇	◆ Consortium			
	Consensus mechanisms [CM]	Proof-of-work	◇ Permissioned voting □◆●■	Permissioned notary	DAG consensus		
	Databases as sources for data input [DI]	Single □	◇◆●■ Multiple				
	Additional technologies for data gathering [AT]	Required ◇□◆■	● Not required				
	Tag with physical product [TP]	Required ◇◆■	□● Not required				
	Transaction space [TS]	Only on-ledger	■◆●□◇ Off-ledger				
Participation structure	Scope of participation network [SP]	Supply chain ◆	◇ Industry ■●□	Open			
	Participating supply chain actors [PA]	Physical actors ◆●■◇	□ Physical and support actors				
	Usage by end customer [UE]	Yes ◆■◇	□● No				
	Role as operator of nodes [RO]	Not required	Operated as a service ◇□	Operated ◆●■ individual actors			
Targeted task	Underlying asset [UA]	Physical product ◇◆●■	□ Information	Financial resources			
	Main objective [MO]	Traceability of products ◇◆●■	Visibility of actors and processes □	Authenticity of products	Digitalization of processes	Financing and escrow	
	Industry [IN]	Automotive	Aviation	Chemicals	◆ Food		
		Minerals ◇●■	Pharmaceuticals □	Textile	Multiple industries		
	Scope of the application [SA]	Transport and logistics	Procurement	Production	Distribution ◇□◆●■	SCF	SCM
	Direction of objective [DO]	Downstream supply chain actors	Upstream and downstream actors ■□●	End customers	◇◆ All		

● Case 1 ◆ Case 2 ■ Case 3 □ Case 4 ◇ Case 5

References

Akerlof, G. A. 1970. “The Market for "Lemons": Quality Uncertainty and the Market Mechanism.” *The Quarterly Journal of Economics* 84 (3):488-500.

Aubert, B. A., and S. Rivard. 2016. “A Commentary on: “The Role of Transaction Cost Economics in Information Technology Outsourcing Research: A Meta-Analysis of the Choice of Contract Type”.” *The Journal of Strategic Information Systems* 25 (1):64–67.

Auinger, A., and R. Riedl. 2018. “Blockchain and Trust: Refuting Some Widely-held Misconceptions.” In *Thirty Ninth International Conference on Information Systems*. San Francisico.

Avital, M., R. Beck, J. King, M. Rossi, and R. Teigland. 2016. "Jumping on the Blockchain Bandwagon: Lessons of the Past and Outlook to the Future." *ICIS 2016 Proceedings*.

Bakos, J. Y., and E. Brynjolfsson. 1993a. "From Vendors to Partners: Information Technology and Incomplete Contracts in Buyer-Supplier Relationships." *Journal of Organizational Computing* 3 (3):301–328.

———. 1993b. "Information Technology, Incentives, and the Optimal Number of Suppliers." *Journal of Management Information Systems* 10 (2):37–53.

Bakos, J. Y., and M. E. Treacy. 1986. "Information Technology and Corporate Strategy: A Research Perspective." *MIS Quarterly* 10 (2):107–119.

Balakrishnan, K., U. Mohan, and S. Seshadri. 2008. "Outsourcing of Front-end Business Processes: Quality, Information, and Customer Contact." *Journal of Operations Management* 26 (2):288-302.

Banker, R. D., J. Kalvenes, and R. A. Patterson. 2006. "Research Note: Information Technology, Contract Completeness, and Buyer-Supplier Relationships." *Information Systems Research* 17 (2):180–193.

Barratt, M., T. Y. Choi, and M. Li. 2011. "Qualitative Case Studies in Operations Management: Trends, Research Outcomes, and Future Research Implications." *Journal of Operations Management* 29 (4):329-342.

Batra, G., R. Olson, P. Shilpi, N. Santhanam, and H. Soundararajan. "Blockchain 2.0: What's in Store for the Two Ends— Semiconductors (Suppliers) and Industrials (Consumers)?", Accessed 27 January 2019. https://www.mckinsey.com/industries/advanced-electronics/our-insights/blockchain-2-0-whats-in-store-for-the-two-ends-semiconductors-suppliers-and-industrials-consumers?cid=other-eml-alt-mip-mck&hlkid=a728082b2e1d4a339cc104aba3aa9c64&hctky=10075197&hdpid=701f32cf-37f8-47da-95f1-56df2a47d262.

Beck, R., and C. Müller-Bloch. 2017. "Blockchain as Radical Innovation: A Framework for Engaging with Distributed Ledgers." In *Hawaii International Conference on System Sciences (HICSS-50), 2017*, 5390–5399. AIS Electronic Library (AISeL).

Blossey, G., J. Eisenhardt, and G. Hahn. 2019. "Blockchain Technology in Supply Chain Management: An Application Perspective." In *52nd Hawaii International Conference on System Sciences*. Maui.

Camek, V., and J. F. Mills. 2004. "The Risks, Threats and Opportunities of Ddisintermediation: A Distributor's View." *International Journal of Physical Distribution & Logistics Management* 34 (9):714-727.

Casey, M. J., and P. Wong. "Global Supply Chains Are About to Get Better, Thanks to Blockchain." Harvard Business Review. https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain.

Casson, M. 1997. "Institutional Economics and Business History: A Way Forward?" *Business History* 39 (4):151-171.

Catalini, C. 2018. "How Blockchain Applications Will Move Beyond Finance." Harvard Business Review, Accessed 27 August 2018. https://hbr.org/2017/03/how-blockchain-applications-will-move-beyond-finance.

Catalini, C., and J. S. Gans. 2016. "Some Simple Economics of the Blockchain." In *MIT Sloan School Working Paper 5191-16*, edited by MIT Sloan School of Management.

Clemons, E. K., R. M. Dewan, R. J. Kauffman, and T. A. Weber. 2017. "Understanding The Information-based Transformation of Strategy and Society." *Journal of Management Information Systems* 34 (2):425–456.

Clemons, E. K., S. P. Reddi, and M. C. Row. 1993. "The Impact of Information Technology on the Organization of Economic Activity: The "Move to the Middle" Hypothesis." *Journal of Management Information Systems* 10 (2):9–35.

Clemons, E. K., and M. C. Row. 1993. "Limits to Interfirm Coordination Through Information Technology: Results of a Field Study in Consumer Packaged Goods Distribution." *Journal of Management Information Systems* 10 (1):73–96.

Crook, T. R., J. G. Combs, D. J. Ketchen, and H. Aguinis. 2013. "Organizing Around Transaction Costs: What Have We Learned and Where Do We Go from Here?" *Academy of Management Perspectives* 27 (1):63–79.

Davidson, S., P. De Filippi, and J. Potts. 2018. "Blockchains and the Economic Institutions of Capitalism." *Journal of Institutional Economics* 14 (4):639-658.

Dolgui, A., and D. Ivanov. "Call for Paper: Exploring Supply Chain Structural Dynamics: New Disruptive Technologies and Disruption Risks." Accessed 26 January 2019. https://www.journals.elsevier.com/international-journal-of-production-economics/call-for-papers/call-for-paper-exploring-supply-chain-structural-dynamics.

Dubois, A., and L.-E. Gadde. 2002. "Systematic Combining: An Abductive Approach to Case Research." *Journal of Business Research* 55 (7):553-560.

Eisenhardt, K. M. 1989. “Building Theories from Case Study Research.” *Academy of Management Review* 14 (4):532-550.

Gerring, J. 2004. “What Is A Case Study And What Is It Good For?” *American Political Science Review* 98 (02):341–354.

Goldsby, T. J., and J. A. Eckert. 2003. “Electronic transportation marketplaces: a transaction cost perspective.” *Industrial Marketing Management* 32 (3):187-198.

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

Gupta, V. 2017a. “A Brief History of Blockchain.” *Harvard Business Review* 95 (1).

———. 2017b. “The Promise of Blockchain Is a World Without Middlemen.” *Harvard Business Review* 95 (2).

Hawlitschek, F., B. Notheisen, and T. Teubner. 2018. “The Limits of Trust-free Systems: A Literature Review on Blockchain Technology and Trust in the Sharing Economy.” *Electronic Commerce Research and Applications* 29:50-63.

Higginson, M., M.-C. Nadeau, and K. Rajgopal. 2019. “Blockchain’s occam problem.” McKinsey & Company, Accessed 20.02.2019. https://www.mckinsey.com/industries/financial-services/our-insights/blockchains-occam-problem.

Hitt, L. M. 1999. “Information Technology and Firm Boundaries: Evidence from Panel Data.” *Information Systems Research* 10 (2):134–149.

Holcomb, T. R., and M. A. Hitt. 2007. “Toward a Model of Strategic Outsourcing.” *Journal of Operations Management* 25 (2):464–481.

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

Ivanov, D., A. Dolgui, and B. Sokolov. 2018. “The Impact of Digital Technology and Industry 4.0 on the Ripple Effect and Supply Chain Risk Analytics.” *International Journal of Production Research* 57 (3):1-18.

Kamble, S., A. Gunasekaran, and H. Arha. 2018. “Understanding the Blockchain Technology Adoption in Supply Chains-Indian Context.” *International Journal of Production Research*:1-25.

Ketokivi, M. 2006. “Elaborating the Contingency Theory of Organizations: The Case of Manufacturing Flexibility Strategies.” *Production and Operations Management* 15 (2):215-228.

Ketokivi, M., and T. Choi. 2014. “Renaissance of Case Research as a Scientific Method.” *Journal of Operations Management* 32 (5):232–240.

Kovács, G., and K. M. Spens. 2005. “Abductive Reasoning in Logistics Research.” *International Journal of Physical Distribution & Logistics Management* 35 (2):132–144.

Kshetri, N. 2018. “1 Blockchain’s Roles in Meeting Key Supply Chain Management Objectives.” *International Journal of Information Management* 39:80-89.

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

Malone, T. W., J. Yates, and R. I. Benjamin. 1987. “Electronic Markets and Electronic Hierarchies.” *Communications of the ACM* 30 (6):484–497.

Marr, B. “Is This the End of Blockchain.” Forbes, Accessed 22 December 2018. https://www.forbes.com/sites/bernardmarr/2018/12/10/is-this-the-end-of-blockchain/#5261a1c35cf3.

Marshall, D., L. McCarthy, P. McGrath, and F. Harrigan. 2016. “What's Your Strategy for Supply Chain Disclosure?” *MIT Sloan Management Review* 57 (2):37–45.

Mayer, R. C., J. H. Davis, and F. D. Schoorman. 1995. “An Integrative Model Of Organizational Trust.” *Academy of Management Review* 20 (3):709-734.

McIvor, R. 2009. “How the Transaction Cost and Resource-based Theories of the Firm Inform Outsourcing Evaluation.” *Journal of Operations Management* 27 (1):45-63.

Morgan, T. R., R. G. J. Richey, and A. E. Ellinger. 2018. “Supplier Transparency: Scale Development and Validation.” *The International Journal of Logistics Management* 29 (3):959-984.

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

Nærland, K., C. Müller-Bloch, R. Beck, and S. Palmund. 2017. Blockchain to Rule the Waves: Nascent Design Principles for Reducing Risk and Uncertainty in Decentralized Environments. Paper presented at the Thirty Eigth International Conferernce on Infromation Systems (ICIS).

Ortiz-Ospina, E., D. Beltekian, and M. Roser. “Trade and Globalization ”, Accessed 24 April 2018. https://ourworldindata.org/international-trade.

Ostern, N. 2018. "Do You Trust a Trust-Free Technology? Toward a Trust Framework Model for Blockchain Technology." In *Thirty Ninth International Conference on Information Systems*. San Francisco.

Rao, S., C. P. Senthilkumar, J. Patton, and Y. E. Rhodes. "Call for Papers - Blockchain: Applications and Strategies for Supply Chain Research and Practice." Wiley, Accessed 19 April 2018. https://wol-prod-cdn.literatumonline.com/pb-assets/assets/21581592/Block_Chain_Applications_and_Strategies_for_Supply_Chain_Research_and_Practice-1509470804000.pdf.

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

Saberi, S., M. Kouhizadeh, J. Sarkis, and L. Shen. 2018. "Blockchain Technology and Its Relationships to Sustainable Supply Chain Management." *International Journal of Production Research*:1-19.

Seebacher, S., and R. Schueritz. 2017. "Blockchain Technology as an Enabler of Service Systems: A Structured Literature Review." In *International Conference on Exploring Services Science*, 12–23. Cham: Springer.

Seidel, M.-D. L. 2018. "Questioning Centralized Organizations in a Time of Distributed Trust." *Journal of Management Inquiry* 27 (1):40–44.

Shapiro, C., and H. R. Varian. 1998. *Information Rules: A Strategic Guide to the Network Economy*: Harvard Business Press.

Slocum, H. "IBM Food Trust Expands Blockchain Network to Foster a Safer, More Transparent and Efficient Global Food System." Accessed 10 October 2018. https://newsroom.ibm.com/2018-10-08-IBM-Food-Trust-Expands-Blockchain-Network-to-Foster-a-Safer-More-Transparent-and-Efficient-Global-Food-System-1.

Sternberg, H., and G. Baruffaldi. 2018. Chains in Chains – Logic and Challenges of Blockchains in Supply Chains. Paper presented at the HICSS, Waikoloa, Hawaii.

Subramani, M. 2004. "How Do Suppliers Benefit from Information Technology Use in Supply Chain Relationships?" *MIS Quarterly* 28 (1):45–73.

Suri, H. 2011. "Purposeful Sampling in Qualitative Research Synthesis." *Qualitative Research Journal* 11 (2):63-75.

Swan, M. 2015. *Blockchain: Blueprint for a New Economy*. Sebastopol, CA: O'Reilly Media, Inc.

TradeIX. "Rewiring Trade Finance." Accessed 05 February 2018. https://tradeix.com/.

Trujillo, J. L., S. Fromhart, and V. Srinivas. "Evolution of Blockchain Technology." Accessed 27 January 2019. https://www2.deloitte.com/insights/us/en/industry/financial-services/evolution-of-blockchain-github-platform.html.

Underwood, S. 2016. "Blockchain Beyond Bitcoin." *Communications of the ACM* 59 (11):15–17.

Van de Ven, A. H. 2007. *Engated Scholarship: A Guide for Organizational and Social Research*. Oxford, UK: Oxford University Press.

Wheeler, M. 2018. "The Woman Whose Mum Inspired Her to Track Ethical Food." http://www.bbc.com/news/business-38773878.

Williamson, O. E. 1975. *Markets and Hierarchies: Analysis and Antitrust Iimplications; A Study in the Economics of Internal Organization*. 3. [print.] ed. New York NY: Free Press [u.a.].

———. 1985. *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*. 2. print ed. New York NY u.a.: Free Press.

———. 2008. "Outsourcing: Transaction Cost Economics and Supply Chain Management." *Journal of Supply Chain Management* 44 (2):5–16.

Wüst, K., and A. Gervais. 2017. "Do You Need a Blockchain?" *IACR Cryptology ePrint Archive* 375:1-7.

Yin, R. K. 2014. *Case Study Research: Design and Methods*. 5. edition ed. Los Angeles; London; New Delhi; Singapore; Washington, DC: SAGE.

Zipkin, P. 2012. "A Reply to Williamson's "Outsourcing …"." *Production and Operations Management* 21 (3):465-469.

Curriculum vitae

Dominik Röck, born on February 14, 1991, in Buehl, Germany.

Education

Since 04/2017	**University of St.Gallen**, St. Gallen, Switzerland Doctoral Student and Research Associate at the Institute of Supply Chain Management
04/2015 – 03/2017	**Karlsruhe Institute of Technology (KIT)**, Karlsruhe, Germany Master of Science (MSc), Industrial Engineering and Management
10/2011 – 03/2015	**Karlsruhe Institute of Technology (KIT)**, Karlsruhe, Germany Bachelor of Science (BSc), Industrial Engineering and Management
09/2001 – 07/2010	**Windeck High School**, Buehl, Germany Secondary School

Published Research Papers

1. Huang L, Roeck D, Murray A & Hofmann E (2019): **modum.io: Funding a Blockchain-based Start-Up's Supply Chain Solution**. Harvard Business School Case 420-006.
2. Roeck D, Sternberg HS & Hofmann E (2020): **Distributed Ledger Technology in Supply Chains – A Transaction Cost Perspective**. International Journal of Production Research, 58(7), p. 2124–2141 (doi: 10.1080/00207543.2019.1657247).
3. Sternberg HS, Hofmann E & Roeck D (2020): **The Struggle is Real: Insights from a Supply Chain Blockchain Case**. Journal of Business Logistics (published online, doi: 10.1111/jbl.12240).
4. Huang L, Roeck D, Murray A & Hofmann E (2020): **modum.io: Funding a Blockchain-based Start-Up's Supply Chain Solution**. Harvard Business School Teaching Note 420-007.

Submitted Research Papers Under Review

1. Roeck D, Hofmann E & Rogers DS (2020): **Decomposition of Transparency in Supply Chains: An Information Processing Perspective**. Submitted to Journal of Supply Chain Management.
2. Roeck D (2020): **Distributed Ledger Technology in Supply Chains: A Taxonomy of Applications**. Submitted to Journal of Business Logistics.

Bock Chapters

1. Roeck, D, Schoeneseiffen F, Greger M & Hofmann E (2020): **Analyzing the Potential of Distributed Ledger Based Applications in Smart Factories**. *Blockchain and Distributed Ledger Technology Use Cases* Edited by Treiblmaier H, Sillaber C & Clohessy T.
2. Roeck D, Hofmann E & Stoelzle W (2020): **Management von Supply Chains**. *Betriebswirtschaft für Führehungskräfte*. Edited by: von Colbe WB, Coenenberg AG, Kaijueter P, Linnhoff U & Pellens B (in press).

Management Articles

1. Roeck D, Burkhart D & Hofmann E (2019): **Enhanced Transparency by Blockchain – The Potential of Applying Blockchain in the Pharmaceutical Industry**. In: CHEManager 10/2019, p. 27-28.
2. Hofmann E, Wetzel P & Roeck D (2018): **Blockchain Can Solve the Pain Points of Trade and Supply Chain Finance**. In: B2B Fintech: Payments, Supply Chain Finance and E-invoicing Market Guide 2018, p. 50-51.
3. Stoelzle W & Roeck D (2018): **Logistics in the Digital Age**. In: International Transport Journal, p 19.

Academic Conferences (Full paper incl. Proceedings)

2020 **80th Annual Meeting of the Academy of Management**, Vancouver, Canada

- Proceedings: *'Enhancing transparency in the supply chain: An information processing perspective'*.

2020 **29th IPSERA Conference**, Knoxville; USA

- Proceedings: *'Determinants of transparency in supply chains: A frame to assess the influence of digital technologies on transparency'*

2020 **53rd Hawaii International Conference on System Sciences**, Wailea, USA

- Presentation and Proceedings: *'The Foundation of Distributed Ledger Technology for Supply Chain Management'* – Best Paper Nomination

2019 **50th Annual Conference of the Decision Sciences Institute**, New Orleans, USA

- Presentation and Proceedings: *'Mastering the Onboarding Challenge – The Case of Information Processing in Distributed Ledgers in Supply Chains'*

2019 **31st Annual Conference of the Nordic Logistics Research Network (NOFOMA)**, Oslo, Norway

- Presentation and Proceedings: *'Distributed Ledger Technology in Supply Chains – An Information Processing View'*

2018 **CSCMP Edge Academic Research Symposium**, Nashville, USA

- Presentation: *'Chains in Chains – Impact of Blockchain Technology on Supply Chain Transactions'*

2018 **30th Annual Conference of the Nordic Logistics Research Network (NOFOMA)**, Kolding, Denmark

- Presentation and Proceedings: *'Theorizing Distributed Ledger Technology – A Supply Chain Management Perspective'*

2018 — **1st Workshop on Value and Competitiveness in Logistics**, Copenhagen, Denmark

- Presentation: *'Uncovering the Challenges of Distributed Ledger Technologies in Supply Chain Management'*

Research Projects

Since 04/2017 — **University of St.Gallen**, St. Gallen, Switzerland

Project Manager for the following research projects:

- **'Blockchain and IoT-based Supply Chain-Transparency and Automation'**. An application-oriented research project funded by the Innosuisse – Swiss Innovation Agency (since 04/2019) – Acquisition and Project Management
  With: Vifor Pharma, Hilcona, SAP, Grieshaber Logistics Group, GS1 Switzerland
- **'Swiss SCM 4.0-Roadmap & Toolsets'**. An application-oriented research project funded by the Innosuisse – Swiss Innovation Agency (07/2018 – 12/2018) – Acquisition and Project Management
  With: ABB, Coca-Cola, PostFinance, Arviem, Hemro, Hocoma
- **'Foundation of Distributed Ledgers in Supply Chain Management: Theory Development, Practical Applicability and Critical Reflection'**. A research project funded by the Swiss National Science Foundation (since 06/2018) – Acquisition and Project Management
- **'HEMRO Lab for Digital Innovation'**. Industrial project (09/2017 – 12/2018) – Project Management

Corporate Internships

09/2016 – 02/2017 — **Trumpf GmbH & Co. KG**, Stuttgart, Germany

Master Thesis, Simulation, and Process Planning

04/2016 – 07/2016 — **Porsche Consulting GmbH**, Stuttgart, Germany

Visiting Associate, Site Planning

12/2014 – 04/2015 — **Robert Bosch GmbH**, Buehl, Germany

Bachelor Thesis, Layout Planning and Material Flow Design

08/2014 – 11/2014 — **Robert Bosch GmbH**, Buehl, Germany

Internship, Assistant to Plant Management

09/2013 – 03/2014 — **Bosch Rexroth Corp.**, Bethlehem, USA

Internship, Production Planning, Layout Planning, and Material Flow Design