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Distributed ledger technology in supply chains: a transaction cost perspective

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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 (Marshall et al. 2016; Slocum 2018; Wheeler 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. Saberi et al. 2018; Blossey, Eisenhardt, and Hahn 2019) see reducing (transaction) costs as the short-term benefit of DLT in supply chain management (SCM). Long term, the

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technology is seen as a radical (Beck and Müller-Bloch 2017) or disruptive innovation (Casey and Wong 2017; Saberi et al. 2018). 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 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 2018).

- *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. Swan 2015; Avital et al. 2016).

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, 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, 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, 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 effort 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. Malone, Yates, and Benjamin 1987; Hitt 1999; Balakrishnan, Mohan, and Seshadri 2008). 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, 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). Figure 1 illustrates the abductive case study approach, including case design, selection and sampling, data collection and data analysis.

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

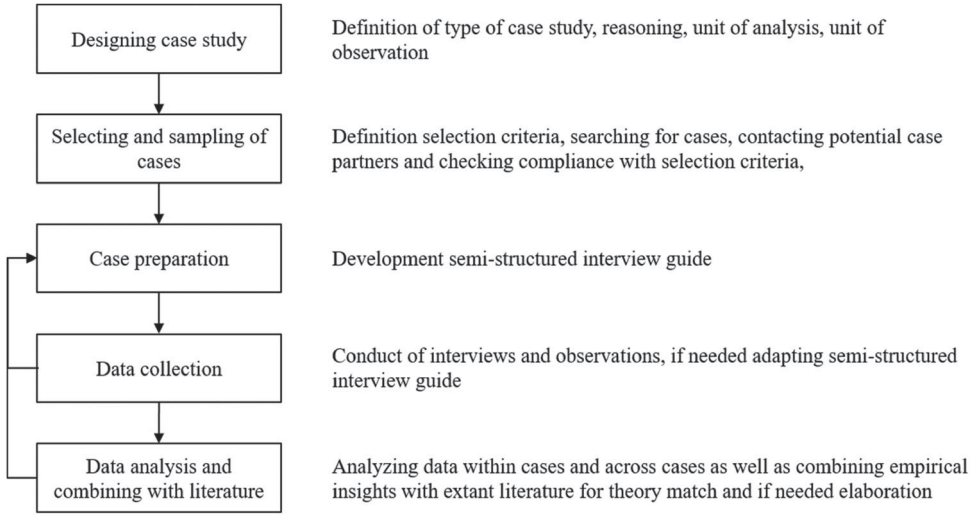

Figure 1. Case study process.

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

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, 960). Table 1 provides an overview of the five cases.

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 h 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 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

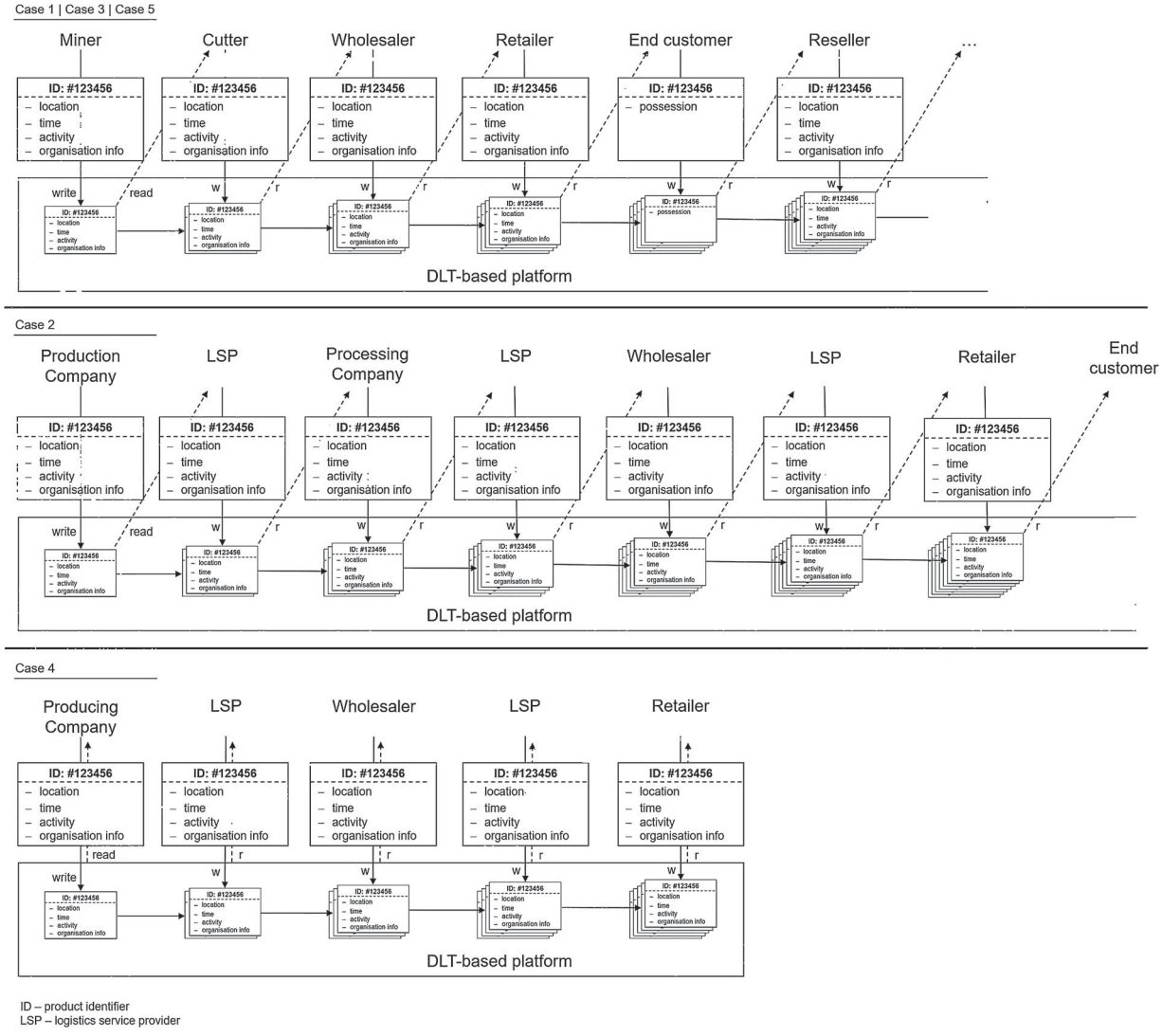

Figure 2. Description of the solutions of the empirical cases.

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

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 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).

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 exemplified 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 supply chain 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 met.

> 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

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.

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

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	Disintermediation
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 scale-pan effect	Cost reduction (increase) effect due to equalised (reinforced) information asymmetry	Expanding	D + +	–	–
	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 segregation effect	Cost reduction due to facilitated searching for transaction partners	Expanding	D + +	–	–
	DLT-enhanced automation 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
D Direct
I Indirect
– Not related

Strength of relation
+ + Very strong influence (appearance in all cases, multiple codes)
+ Strong influence (appearance in all cases, one code)
0 Weak influence (appearance in some cases).

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. Further 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.

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Appendix 1.

A.1. 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