Beyond the hype: how blockchain affects supply chain performance

Sven Markus and Paul Buijs
Deparment of Operations, University of Groningen, Groningen, The Netherlands

Abstract

Purpose – This paper aims to contribute to the debate about the value of blockchain for supply chain management by assessing empirical evidence on the relationship between blockchain and supply chain performance.

Design/methodology/approach – The authors conducted a structured review of the academic literature to identify and assess papers providing empirical insight on operational blockchain applications. The authors complement the findings from this review with primary empirical data from 11 interviews with blockchain providers, users and experts involved in four recent projects.

Findings – The paper presents an integrated research framework that illustrates the impact of blockchain on supply chain performance. The findings highlight that blockchain can affect supply chain performance directly – via one of its core technological features – and indirectly via the broader business project through which blockchain technology is implemented.

Practical implications – Insights from this paper should provide managers with a more nuanced understanding of how blockchain technology can be leveraged to address important supply chain management challenges.

Originality/value – Prior research addressing the relationship between blockchain and supply chain performance mostly discusses potential performance effects of blockchain, presents individual blockchain applications and/or provides little explanation for how the core technological features of blockchain affect supply chain performance. This paper systematically assesses the ways in which blockchain can affect supply chain performance. In doing so, it goes beyond the initial hype around blockchain technology while countering some of the more recent critiques.

Keywords Blockchain, Supply chain management, Empirical study, Information systems

Paper type Research paper

1. Introduction

While still in its infancy, blockchain has been described as the biggest innovation in computer science (Tapscott *et al.*, 2016) and as a possible disruptor of supply chain processes around the world (Kamble *et al.*, 2020; Treiblmaier, 2018). Several papers discuss the potential of blockchain to positively affect supply chain performance (Cole *et al.*, 2019; Hald and Kinra, 2019; Nandi *et al.*, 2020; Sheel and Nath, 2019; Wang *et al.*, 2019b). Recently, a few papers have also presented cases of operational blockchain applications, empirically showing supply chain performance improvements from blockchain in terms of transparency, quality and efficiency (Danese *et al.*, 2021; Rogerson and Parry, 2020; Stranieri *et al.*, 2021). Based on this broadly shared positivity, it may not come as a surprise that supply chains are seen as the most popular domain for exploring the application of blockchain technology (Pawczuk *et al.*, 2018). However, blockchain has proven difficult to implement (Kharif, 2018). Some claim because supply chain managers lack an understanding of blockchain technology (Queiroz *et al.*, 2020; van Hoek, 2020a; Wang *et al.*, 2019a); others indicate that companies pushing ahead with pilot tests are scaling back their ambitions due to a gap between promised benefits and reality (Kharif, 2018). Indeed, up to 2016, only 8% of the blockchain applications were still operational one year later (Trujillo *et al.*, 2017). Due to the low success rate, skeptics have accused blockchain of being an "amazing solution for almost nothing" (Frederik, 2020) and argued that companies can get most of the benefits attributed to blockchain also from traditional software solutions (Catalini and Michelman, 2017; Levine, 2017; Madnick, 2017).

These opposing views on blockchain lead to fascination and confusion (Hanebeck *et al.*, 2019) and emphasize that a better understanding of the impact of blockchain on supply chain performance is needed. To grasp this impact, first, it is important to understand what blockchain is exactly. Blockchain is often referred to as a specific solution. However, there is no such thing as the blockchain, just like there is no such thing as the car. Cars come in different shapes, can be bought privately or shared publicly and have different engines, of which the first were not very fuel-efficient. Just like cars, blockchain technology comes in different types, such as

The current issue and full text archive of this journal is available on Emerald Insight at: **https://www.emerald.com/insight/1359-8546.htm**

Supply Chain Management: An International Journal
27/7 (2022) 177–193
Emerald Publishing Limited [ISSN 1359-8546]
[DOI 10.1108/SCM-03-2022-0109]

Received 18 March 2022
Revised 6 June 2022
2 August 2022
Accepted 5 August 2022

public and private. And, like the first inefficient petrol engine, Bitcoin – the very first protocol that was deployed on blockchain technology (Nakamoto, 2008) – is very energy inefficient. Nowadays, blockchain technology includes many protocols, each leveraging different features to achieve different business goals (Chang and Chen, 2020). Second, it is important to understand how blockchain can improve supply chain processes. Blockchain is often part of a broader business project (Lacity and van Hoek, 2021), involving other activities such as process mapping, digitizing paper-based processes and data analysis. These other activities are likely to impact supply chain performance too, without being directly related to blockchain technology. As blockchain technology comes in different types and is often part of a larger project, a nuanced relationship between blockchain and supply chain performance is to be expected.

Thus far, studies addressing the relationship between blockchain and supply chain performance either discuss the potential impact of blockchain and/or provide little theoretical explanation for how the different features of blockchain affect supply chain performance. The work of Nandi *et al.* (2020), for example, argues that blockchain leads to cost reductions, better quality compliance, process improvements and enhanced flexibility. However, these findings are based on news articles of companies "attempting to implement blockchain" (Nandi *et al.*, 2020, p. 841). Others conclude that blockchain leads to improved traceability, integrity, transparency (Hew *et al.*, 2020), adaptability, agility, alignment (Sheel and Nath, 2019), supply chain visibility, information sharing and other operational improvements (Wang *et al.*, 2019b). While these findings are based on empirical data, the underlying studies rely on surveys with managers that did not yet have first-hand experience with blockchain. A few recent studies did analyze operational blockchain applications. The studies of Danese *et al.* (2021), Rogerson and Parry (2020) and Stranieri *et al.* (2021), for example, show that blockchain leads to improved transparency in food supply chains. However, these studies do not provide a detailed discussion about the core features of blockchain technology or the activities in the broader business project that led to the observed performance improvements.

Owing to these limitations in the literature, this study aims to assess how blockchain technology affects supply chain performance, both directly and indirectly, in operational blockchain applications. To this end, our study analyzes blockchain applications in a supply chain context from the academic literature and complements insights from this analysis with primary empirical data from interviews with blockchain providers, users and experts in The Netherlands. Overall, we include four primary and 24 secondary cases and classify the elements of blockchain that affect supply chain performance as part of the underlying blockchain technology or the broader business project. This results in a framework explaining how the different elements of blockchain connect to different supply chain performance indicators. The framework contributes to the supply chain management literature by distinguishing the direct impact of blockchain technology on supply chain performance from the indirect impact of the other activities that can be part of the broader business project.

2. Background

Blockchain is a distributed ledger technology. Basically, this technology is a specific type of database in which the technological features relate to data immutability, shared ownership of data and the automatic execution of smart contracts. To help explain the direct and indirect impact of blockchain on supply chain performance, this paper distinguishes between blockchain technology and the broader business project by means of which blockchain is implemented.

2.1 Blockchain technology

Blockchain technology comes in different types and with different core technological features.

2.1.1 Types

Broadly, there are two types of blockchain, namely, private and public, which are distinct in terms of permissions for users to read and write data on the blockchain (O'Leary, 2017). Permission to read gives a user access to data stored on the blockchain, whereas permission to write means a user is allowed to add data to the blockchain, for example, by making or approving transactions. Private blockchains are permissioned by definition. Only authorized users can read or write information on the blockchain. Therefore, a private blockchain is also referred to as a closed blockchain. Public blockchains are open to read for everybody and can be unpermissioned or permissioned in terms of writing. Unpermissioned public blockchain users do not have restrictions in terms of writing. In permissioned public blockchains, only authorized users can add or approve data. Some blockchains are called hybrid and leverage elements of both the private and public types to meet business requirements, for example, by using the high throughput performance of a private blockchain while using cryptocurrencies (i.e. a public blockchain) for enabling payments (Xiao *et al.*, 2020).

2.1.2 Core features

The core features of blockchain technology are enabled by combining mathematical and computational techniques, such as cryptography, shared databases and automation. Whereas these technological features have a larger, independent history (Bos *et al.*, 2007; Hammer, 1990), the innovative nature of blockchain stems from combining them in a single system, leading to the development of an *immutable* and *shared* ledger that can automatically deploy *smart contracts*.

A common feature across the different types of blockchain is data *immutability*. Blockchain gets its name from a list of blocks, where each block contains transaction data and a timestamp (Xu *et al.*, 2017). As transactions occur, the chain grows by adding new blocks to it (Zheng *et al.*, 2017). By means of a cryptographic mechanism, each block is given a unique key (i.e. hash) that corresponds to the entire chain. When a transaction occurs, the hash of the chain is recalculated to check whether the data has been tampered with. If not, the hash of the newly appended block will be calculated. Hence, tampering with the data would require a simultaneous attack on all previous blocks stored across multiple servers, which makes it practically impossible (Lyasnikov *et al.*, 2020).

Data on a blockchain is *shared*. It is stored across different servers (i.e. distributed) and not owned or controlled by a central authority (i.e. decentralized). Traditional transaction processing systems often rely on a centralized database, creating a single-point-of-failure (Zhao *et al.*, 2019). Data stored on a blockchain, by contrast, is shared across users, which makes blockchain a distributed ledger technology (Lai and Lee Kuo Chuen, 2018). Because data on blockchains can be added and accessed by multiple, potentially anonymous users, trust in the data is not self-evident. Therefore, blockchain technology requires a consensus mechanism (Kumar *et al.*, 2020). The two most common consensus mechanisms select users in the network to approve transactions based on their computational power (i.e. Proof of Work) and their wealth (i.e. Proof of Stake). The first public blockchain was invented as a truly decentralized system to transfer money without a central authority and relied on a consensus mechanism based on Proof of Work (Nakamoto, 2008). This computationally extensive consensus mechanism limits operational efficiency (Wang *et al.*, 2019b) and scalability (Lee, 2019) due to its time and energy consumption. Within private blockchains, all users are known, which ensures trust more inherently. Therefore, consensus can be based on predetermined authorizations of the users.

The deployment of *smart contracts* is another core feature of blockchain technology, although not every blockchain protocol supports the execution of smart contracts. A smart contract is a computer protocol that can be automatically executed when certain conditions are met, for example, for immediate and automatic trade payments when contractual conditions within the supply chain are satisfied (Babich and Hilary, 2020). In addition, smart contracts can be programmed to automatically retrieve data from external data sources – such as from traditional databases – when needed. As smart contracts use the automation of processes in a transparent, immutable and decentralized way, smart contracts are seen as promising new means of automation (Eggers *et al.*, 2021).

2.2 Blockchain and its broader business project

Over 30 years ago, Hammer (1990) noticed that breakthroughs in performance cannot be achieved by merely automating existing operational processes but require a more extensive approach in which those processes are optimized. Yet, prior research on blockchains in a supply chain context has not made a distinction between the direct impact of blockchain technology – stemming from its core features described above – and the potential indirect impact of applying blockchain in a broader business project. In our study, we consider the broader business project to include all activities and tools that are part of the process of implementing blockchain technology.

One of these activities is process mapping, which may result in the identification and elimination of bottlenecks before any automation occurs (Lie and Kusumastuti, 2021). Blockchain is a digital technology to store and share data (Helo and Shamsuzzoha, 2020) and hence can only work when paper-based processes are digitized. Even though blockchain is described as an emerging digitization technology, the need for digitizing paper-based processes is not exclusive to blockchain and has been part of the implementation of several traditional software solutions (Gupta *et al.*, 2021). Benefits from digitizing paper-based processes can therefore not be attributed to blockchain directly. In a similar vein, the data that is stored on the blockchain can be used for data analysis. Improvements based on the analysis of data that is stored on a blockchain should be seen as a potential spin-off from implementing blockchain technology and not be confused with the direct benefits of the blockchain itself (Babich and Hilary, 2020). In sum, we consider *process mapping*, *digitization* and *data analysis* as part of the broader business project and not of the core features of blockchain technology.

2.3 Supply chain performance

Prior studies have discussed the potential of blockchain to positively affect supply chain performance in terms of several indicators (Hald and Kinra, 2019; Nandi *et al.*, 2020; Sheel and Nath, 2019; Wang *et al.*, 2019b). In our study, we consider five generic supply chain performance indicators based on Slack and Lewis (2017):

Speed refers to doing things fast. It can be measured as the time between the beginning and the end of a process. The scope of this process may involve all operational steps, from the arrival of a customer order to the final delivery of the product or service (i.e. order lead time) or only one or a few steps (e.g. production lead time).

Quality refers to doing things right. More specifically, it relates to how well a process can yield products or services that meet customer specifications. Quality also refers to the ability of processes to deliver products or services reliably and consistently according to specifications.

Cost refers to doing things cheaply. It involves all financial inputs required for designing and operating the processes that produce products or services.

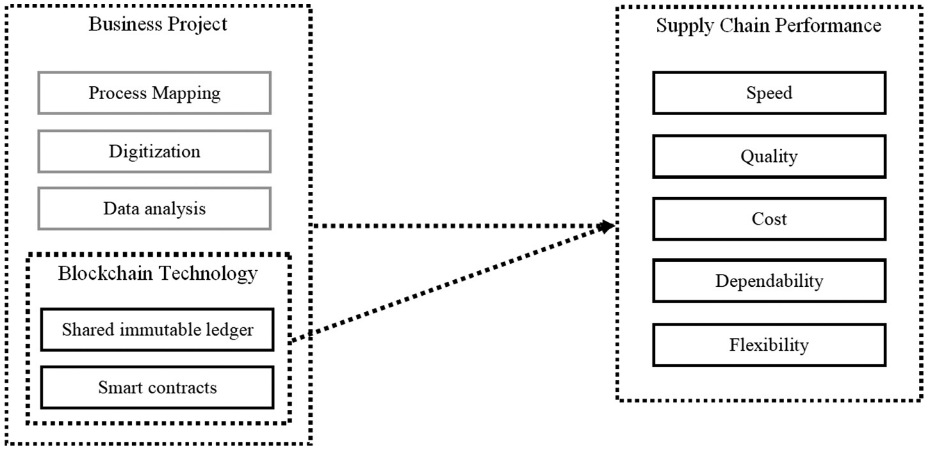
Dependability refers to keeping promises. These promises can be related to the right quantity, at the right place, at the right time. Dependability may concern the delivery of products and services but also of information related to the product or service, or to intermediary process steps in creating the product or service.

Flexibility refers to being able to change. This can be broadly divided into range flexibility and response flexibility. Range flexibility concerns the extent to which a process can be changed. Response flexibility relates to how fast the process can be changed. Processes can be flexible in terms of product mix, volume and/or delivery.

2.4 Conceptual framework

The aim of our study is to provide a better understanding of the effects blockchain can have on supply chain performance – either directly via the core technological features of blockchain, or indirectly via the elements of the broader business project involved with implementing blockchain. This relationship can be conceptualized according to the framework presented in Figure 1. The aim of our study is to first identify the direct linkages between individual elements of blockchain technology and the project (i.e. on the left-hand side of the framework) and supply chain performance indicators (i.e. on the right-hand side of the framework) and then provide detailed explanations for each of these linkages.

Figure 1 Conceptual framework



3. Research design

Research on the use of blockchain in supply chains is still in its infancy. Therefore, this research is exploratory in nature. Our aim is to explore how blockchain affects supply chain performance. To this end, our research design includes several blockchain cases selected by means of a structured literature review (SLR) and interviews with blockchain providers, users and experts. The inclusion of multiple cases enables a cross-case analysis, which improves the generalizability of the research findings (Eisenhardt, 1991). The goal of the SLR is to extract relevant data on blockchain applications in supply chain processes in a timely manner. The subsequent interviews are conducted to complement the secondary empirical data from the literature. By triangulating between different methods, we could systematically assess several blockchain applications and reflect upon the findings from the literature review during the interviews.

3.1 Structured literature review

In line with methodological guidelines presented by Tranfield *et al.* (2003), our SLR consists of the five steps described below:

1. *Identification.* To explore as many papers on blockchain applications as possible, we used both Scopus and Web of Science for identifying academic papers. The search string we used was related to blockchain and supply chain or operational performance and is further specified in Table 1. Papers included in the SLR are written in English and published between 2016 and March 2021. This time span was selected to capture the

Table 1 Procedural steps and selection criteria of the SLR

Step		**Description (number of papers)**
1. Identification	*Search engine*:	Scopus and Web of Science (550)
	Search string in paper title and abstract:	Blockchain AND Supply chain performance (37)
		*Blockchain AND Supply AND Chain AND Performance AND Case (38)
		*Blockchain AND Performance AND Case (314)
		Blockchain AND Operational performance (15)
		*Blockchain AND Operations AND Management AND Case (119)
	Inclusion criteria:	*Language*: English
		Time span: 2016–March 2021
		**Source type*: Journal
		**Document type*: Article
	Exclusion criteria:	Duplicates (217)
2. Screening	*Title and abstract examination*	
	Exclusion criteria:	1. No blockchain/blockchain not being the main topic (16)
		2. No empirical cases (proposals) (205)
		3. No supply chain performance indicator mentioned (33)
3. Reading	*First full text reading*	
	Exclusion criteria:	1. No empirical cases (proposals) (38)
		2. Supply chain performance mentioned but not studied (18)
4. Case selection	*Second full text reading*	
	Inclusion criteria:	To some extent explaining how blockchain affects supply chain performance (8)
5. Data analysis		Coding based on quotes on 24 cases from the selected papers (8)

most recent applications of blockchain technology in supply chain processes before starting our primary data collection. Due to the diversity of academic disciplines studying and writing about blockchains (Hald and Kinra, 2019), all academic, peer-reviewed journals were considered. In this first step of the SLR, we identified 550 papers, of which 217 were duplicates.

2. *Screening*. The identification phase resulted in 333 unique papers. We then screened the titles and abstracts of these papers and included those that indicated that the study was about blockchain cases applied in supply chain processes. Due to the limited number of empirical cases, all possible business processes in which one or more supply chain performance indicators could be of importance were included. In this step, 254 papers were excluded due to blockchain not being the main topic of the paper but a mere part of discussing emerging technologies more generally not discussing an operational blockchain application; and/or not mentioning supply chain performance. An example of a paper that was excluded in the screening phase is the work of Kalla *et al.* (2020), in which the authors "identify potential use cases" and "present a high-level view of how blockchain can be leveraged and discuss the expected performance" (p. 85). Interestingly, 79.4% of the papers that were excluded from the SLR discussed potential use cases – similar to the work of Kalla *et al.* (2020).
3. *Reading*. The screening phase resulted in 79 papers that were then read in full. In this step, another 56 papers were excluded because they do not discuss an empirical case and/or do not address any supply chain performance indicator, despite the promising abstracts. An example of a paper that was excluded in the reading phase is the work of Schmidt and Wagner (2019). The abstract of this paper includes a statement that blockchain enables more efficient and transparent transactions, but upon reading the full paper, we realized the study does not present empirical cases to substantiate this claim.
4. *Case selection*. Out of the remaining 23 papers, eight were selected for further inclusion in our study. The other 15 papers were excluded during the selection of cases because they do not discuss any specific relation between blockchain and supply chain performance. The eight selected papers do – at least to some extent – discuss how blockchain affects supply chain performance in the process(es) under study. Collectively, these eight papers provide data on 24 different cases, called secondary cases from hereon, in various supply chain industries: food, health, trade finance and accounting, manufacturing and automotive. The selected papers are published in the journals: *Sustainability* (3), *International Journal of Operations and Production Management* (2), *Supply Chain Management* (1), *Food Control* (1), *Corporate Social Responsibility and Environmental Management* (1) and *Computers and Industrial Engineering* (1). An overview of the selected papers is presented in the Online Supplement (Table A1).
5. *Data analysis*. The result of the SLR is a research framework indicating identified linkages – both direct and indirect – between blockchain and supply chain performance indicators. These linkages are identified and substantiated based on quotes from the selected papers. To this end, we first copied all relevant quotes concerning the impact of blockchain on supply chain performance to Excel. We then coded each quote based on a feature of blockchain technology or an element of the broader business project on the one hand, and one or more supply chain performance indicator(s) on the other hand. Explanations for the linkages between the blockchain elements and performance indicators have been identified in multiple rounds of coding. The resulting coding tree is shown in the Online Supplement (Table B1).

3.2 Case study

To explore the impact of blockchain on supply chain performance in more depth, we complemented our findings from the SLR with interviews related to four empirical cases. These interviews allowed for richly describing empirical phenomena (Yin, 2009), which is valuable since there are only a few existing case studies on this topic (Chang and Chen, 2020). All the cases, called primary cases from hereon, consider a blockchain application in a supply chain process that has been in operation for at least four months so that the interviewees have insights into the actual impact of blockchain on supply chain performance.

3.2.1 Sampling

A mixed strategy was used to find cases to approach for interviews (Seawright and Gerring, 2008). First, existing relations in the industry were contacted to identify companies that provide or use blockchain technology. Additionally, blockchain users and providers were identified via the internet and contacted by e-mail or via LinkedIn. Second, snowball sampling was used by asking interviewees if they knew other companies involved in blockchain initiatives in a supply chain context. This process resulted in 11 interviews across four cases, with two interviewees per case, as presented in Table 2.

3.2.2 Data collection

Semistructured interviews form the main source of primary empirical data. The participants include employees of blockchain providers, users and experts. Blockchain providers are responsible for the technical implementation of the blockchain application. They were mainly questioned about the features of their implemented blockchain application. Blockchain users are the clients applying blockchain in their supply chain process. Their interview questions were mainly related to the impact of these applications on their process. The interview protocols for blockchain providers and blockchain users are enclosed in Online Supplement (Tables C1 and C2). Blockchain experts have been consulted to reflect on the research findings of the SLR and the preliminary analysis of the interview data. A short overview of these results was followed by an unstructured interview to let the experts freely comment and share their experiences related to our findings thus far.

Supply Chain Management: An International Journal
Volume 27 · Number 7 · 2022 · 177–193

Table 2 Overview of the interviews

No.	Case	Interviewee	Code	Duration (in min.)	User	Provider	Expert
1	1	Project Manager	User 1	48	X		
2		Project Manager	User 1	41	X		
3		Founder	Provider 1	81		X	
4	2	Project Manager	User 2	66	X		
5		Founder	Provider 1	45		X	
6	3	Founder	Provider 3a	46		X	
7		Business Developer	Provider 3b	86			X
8	4	Product Owner	Provider 4a	89		X	
9		Product Development Manager	Provider 4b	62			X
10	–	*Blockchain Expert*	Expert 1	60			X
11	–	*Blockchain Expert*	Expert 2	58			X

3.2.3 Data analysis

The interviews were conducted using Google Meet and lasted between 41 and 89 min. All interviews were recorded and transcribed with permission of the interviewees. The transcripts of the interviews have been coded using the same coding strategy as for the SLR. In the first two cases, the quotes from the blockchain users were used for coding the relationship between blockchain and supply chain performance. The interviews with the provider within these cases were used for the understanding of the blockchain application and to assess whether the experienced impact by the users is due to blockchain technology or its broader project. The resulting coding tree is presented in the Online Supplement (Table B2). The quotes related to the third and fourth cases were based on interviews with the blockchain providers because the blockchain users were unavailable for an interview. To discuss the impact of their blockchain application on supply chain performance, questions were asked related to their experiences with clients in pilots and applications. The interviews with the experts yielded practical insights into the preliminary findings. To avoid misinterpretation, all transcripts have been either discussed in a follow-up meeting or sent to the interviewees for feedback.

3.2.4 Research context

Here, we briefly discuss the context of each of the four primary cases.

The first case is an internal supply chain process of a manufacturing company that produces adhesives. Their production process starts with order intake, which is followed by preparation in the lab, a production phase and quality assurance, and ends at the transportation phase. The goal of applying blockchain to this process is to have more insight into their orders and to reduce the number of rejected products by performing a uniform process. This blockchain project started two years ago. At the time of writing, the blockchain is operational for the third time after processing some requested adjustments after a first launch in 2020 and a second launch in 2021.

The second case is the preliminary design process within a construction company. This process deals with the administrative steps required before constructing a building, such as inspections and requesting a permit from the municipality and from other parties to be allowed to build. The goal of applying blockchain is to have a real-time overview of the process, not forget steps in the process and improve efficiency. The blockchain project is in its pilot phase – launched in January 2021 – and is evaluated at the time of writing. In both the first and the second case, blockchain technology is implemented as part of an intraorganizational workflow management system based on the protocol of Corda.

The third case is the administration process of returnable transport items. This process deals with the transportation and registration of crates and trolleys in which retail products are stored and moved. The goal of applying blockchain is to ensure simple and fast administration and registration of these items. In September 2020, the first external pilots started, and in January 2021, the platform went live for operational users. At the moment of writing, the platform is being used by pilot users and operational users.

The fourth case is related to the logistics process of finished cars. This process involves all logistical activities performed from the moment a car is fully produced by an original equipment manufacturer to the final customer of the car. This process is complex due to the many stakeholders involved. The goal of applying blockchain is to improve visibility, reduce fraud and accelerate deliveries. Multiple pilots have been conducted with the blockchain application over the previous two years and is ready to be fully operationalized at the moment of writing. Whereas the first and second cases involve an intraorganizational workflow management system based on Corda, the third and fourth cases involve an interorganizational platform based on the Hyperledger protocol (Table 3).

4. Analysis of secondary cases

We begin the presentation of our research findings with the results from the analysis of the secondary cases identified as part of the SLR. Table 4 provides an overview of the 24 secondary cases with blockchain applications in supply chain processes across different industries. With 14 out of the 24 cases, food supply chains are most widely covered, followed by trade finance and accounting (6) and health (2). The other cases are set in the context of manufacturing (1) and the automotive industry (1). The blockchain types that are identified from the papers are public (9), private (6) and hybrid (1). In eight cases, across three papers, the type of blockchain could not be identified because it was not mentioned in the paper or the cases were anonymous.

Table 3 Overview of primary cases

Case No.	1	2	3	4
Setting	Adhesive company	Construction company	Retail consortium	Logistics consortium
Industry	Manufacturing	Construction	Retail	Automotive
Process	Production	Design	Administration	Logistics
Goal	Improve traceability and quality of orders	Improve traceability, quality and efficiency	Ensure simple and fast administration and registration	Improve visibility, reduce fraud and accelerate deliveries
Scope	Intraorganizational	Intraorganizational	Interorganizational	Interorganizational
Blockchain	Private (Corda)	Private (Corda)	Private (Hyperledger)	Private (Hyperledger)
Stage	Operational	Pilot	Operational	Pilot

Table 4 Selected papers from the SLR

Paper(s)	Data source	#Cases	Industry	Blockchain type
A. Rogerson and Parry (2020)	Interviews	4	Food	Private (1) and Public (3)
B. Danese *et al.* (2021)	Interviews	5	Food	Public
C.Azzi *et al.* (2019)	Archival data	2	Food and Health	Hybrid and Public
D.Stranieri *et al.* (2021)	Interviews	3	Food	Unknown
E. Tseng and Shang (2021)	Interviews	3	Health, accounting and food	Unknown
F. Chang *et al.* (2020)	Archival data	5	Trade finance	Private (3) and Unknown (2)
G. Luchoomun *et al.* (2020)	Empirical case	1	Automotive	Private
H. Martinez *et al.* (2019)	Empirical case	1	Manufacturing	Private

Because we identified great similarities across different cases within the same industry, the discussion below presents insights from the secondary cases at an industry level. The results per paper are presented in the Online Supplement (Section D).

4.1 Food

All the cases in food supply chains suggest that blockchain improves dependability due to better accessibility of information across the supply chain. Azzi *et al.* (2019), Danese *et al.* (2021), Rogerson and Parry (2020), Stranieri *et al.* (2021) and Tseng and Shang (2021) describe blockchain applications that enable consumers to trace their food back into the supply chain. This is made possible via radio frequency identification tags or quick response codes that can be scanned by the consumer. With an application programming interface (API) connection to the blockchain, consumers can view where their product originated and which process steps it has undergone. The depth of information that consumers are allowed to see depends on the permissions that are provided to them. In cases with a public blockchain, all data that is stored on the blockchain is readable for the consumer. Stranieri *et al.* (2021) explain how "blockchain enabled transparency and gave consumers the possibility to increase the understanding of the product quality" (p. 6), and in doing so, increased the quality of products. Blockchain enables data to flow "with less impediment," which, in turn, increases access to timely supply chain data and "reduces unfair practices and allows a better management of opportunistic behavior" (Stranieri *et al.*, 2021, p. 6). Finally, Stranieri *et al.* (2021) describe how cost-effectiveness is affected by a "sharp increase in sales' and a 'better management of production costs" (p. 5). While the cases within food supply chains suggest that blockchain can lead to improved dependability, quality and cost-effectiveness, the papers do not detail which elements of the blockchain or its broader business project are affecting these performance indicators – hence the dotted lines in Figure 2.

4.2 Health

Similar to the cases in the food industry, Azzi *et al.* (2019) and Tseng and Shang (2021) point to the ability of blockchain to improve dependability in the health-care industry by providing better accessibility of timely information. In addition, supply chain performance benefits stem from patients being able to access information on the blockchain that is collected by means of other technologies, such as barcodes and smartphone applications (Azzi *et al.*, 2019; Tseng and Shang, 2021). Tseng and Shang (2021) elaborate that "all medical referral processes are paperless," which enables "the directness of data sharing" and so "the speed and error rate of data transmission can be improved" (p. 10). This suggests that digitizing the referral process enables improved information sharing, which, in turn, improves the speed and quality of the process. It seems these improvements can be attributed to the digitization of transactions that were previously paper-based. Since digitization is not an inherent technological feature of blockchain, the arrows from digitization to speed and quality in Figure 3 are depicted in gray.

4.3 Trade finance and accounting

The papers discussing cases in trade finance and accounting indicate that digitizing processes increases speed and reduces cost (Chang *et al.*, 2020; Tseng and Shang, 2021). For example, Chang *et al.* (2020) state that "using blockchain technology as a substitute for traditional trade documents, reduces transaction time from 10 days to less than three hours" (p. 9). In turn, "the high cost of administrative procedures and high volume of paperwork is greatly reduced" (Chang *et al.*, 2020, p. 7). No further explanation is given about how this is

Figure 2 Framework based on reported cases in the food industry

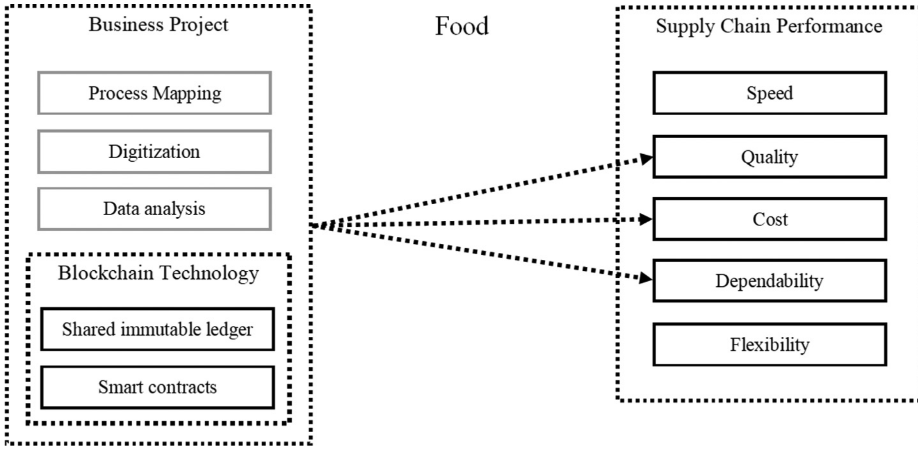
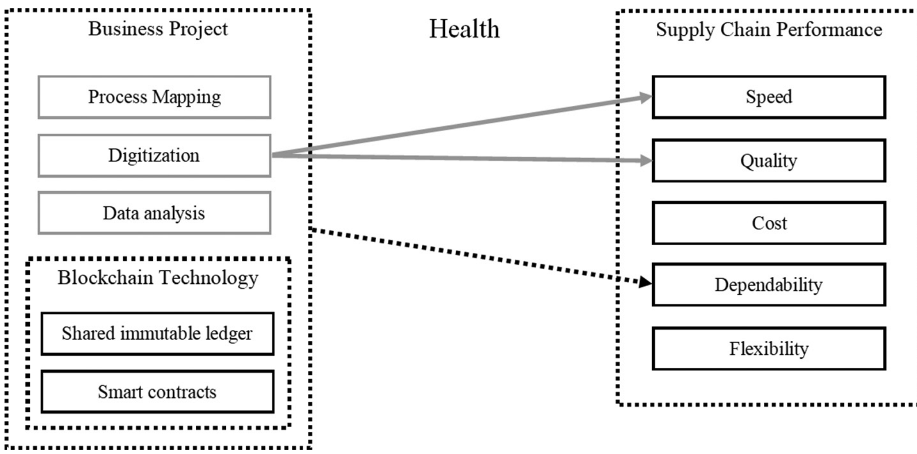


Figure 3 Framework based on reported cases in the health industry



related to the core features of blockchain technology. Hence, we characterize the improvements in speed and cost as being the result of substituting paper-based processes – that is, through digitization. Additionally, Chang *et al.* (2020) report that "blockchain is utilized as a shared ledger to store trading documents" and that, therefore, "participating parties, including banks and trading counterparties, are able to access on-chain data to track the flow of information and goods" (p. 6). The relation between the shared immutable ledger – as a core feature of blockchain technology – and dependability is included in Figure 4.

4.4 Automotive

Luchoomun *et al.* (2020) discuss the implementation of a blockchain application within the process of vehicle import, sales and registration. They state that "falsification of mileage and other frauds are mitigated through the adoption of blockchain technology for the automotive industry" and that "the application offers the ability for transactions or processes to be more efficiently through streamlining and automating" (Luchoomun *et al.*, 2020, p. 76). Yet, the authors do not discuss precisely how data quality is ensured or whether streamlining and automation have a direct relation to the core features of blockchain technology. What is clear, however, is that having a shared immutable ledger improves dependability: "the transaction histories of the vehicle are more transparent through the use of blockchain technology where distributed ledger is shared among all network participants" (Luchoomun *et al.*, 2020, p. 76). Therefore, we included the link between the shared immutable ledger and dependability in Figure 5.

4.5 Manufacturing

Martinez *et al.* (2019) discuss the implementation of a blockchain application within a manufacturing company. Blockchain is implemented for the customer order process, which used to be time-consuming and costly. Martinez *et al.* (2019) indicate that after implementation, "the visibility of data has been increased and safely opened to [the company's] employees, and its customers' employees in the supply chain" (p. 1008). The level of visibility is limited based on the predetermined access rights for viewing and writing information on the blockchain. Additionally, the "traceability of orders improved" as "the company never had this open and detailed traceability available for all its transactions in the past

Figure 4 Framework based on reported cases in the trade finance and accounting industry

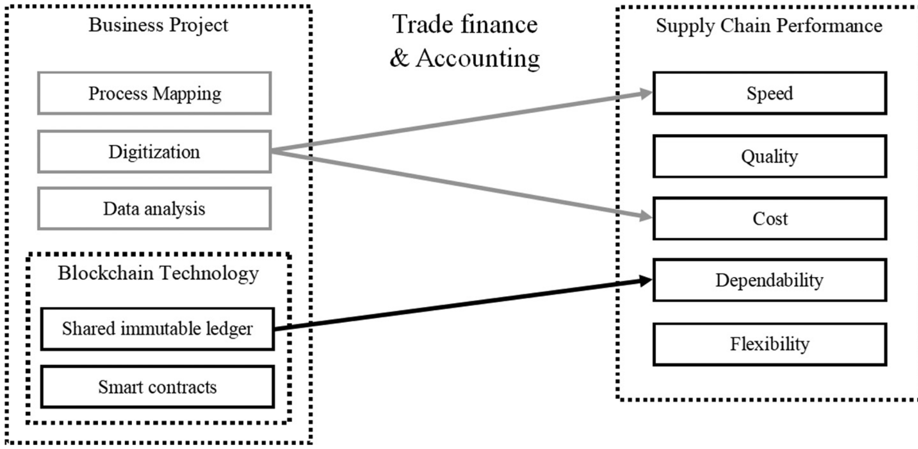
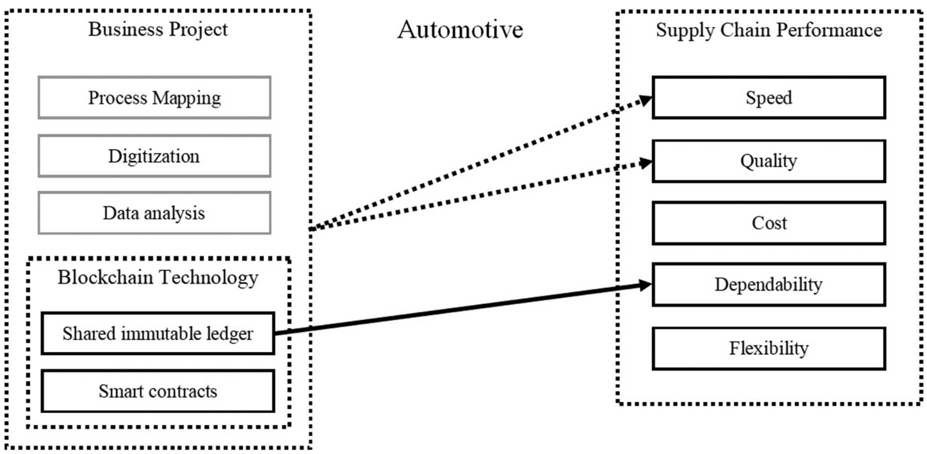


Figure 5 Framework based on reported cases in the automotive industry



[...] Now it is impossible for someone to alter previous transactions" (Martinez *et al.*, 2019, p. 1008). Based on these quotes, improvements in dependability seem to stem from the shared immutable ledger of blockchain. In addition, Martinez *et al.* (2019) mention that "the blockchain solution considerably improved processing time. While normally it would take two to four days for an order or modification to be processed and approved, the blockchain solution leads to instantaneous, automatic approval times (including the verification time against set rules) and a reduction in the amount of griefs, which improved efficiency – from two to four days to less than 1 min" (p. 1007). This quote relates to smart contracts, being protocols that are automatically executed against a set of predetermined rules. Overall, blockchain, in this case, improves dependability – through the introduction of a shared immutable ledger technology – and improves speed, quality and cost – through smart contracts – as illustrated in Figure 6.

Based on the secondary empirical data retrieved from the selected papers, the conceptual framework introduced in the Background Section of this paper is updated with more detail in Figure 7. When looking at the core technological features of blockchain, the shared immutable ledger technology is linked to improved dependability as a result of the timely sharing of information among actors in supply chains (Chang *et al.*, 2020; Luchoomun *et al.*, 2020). The automation of processes by means of smart contracts can lead to supply chain performance improvements in terms of speed, quality and cost. Smart contracts reduce the number of mistakes, which improves quality. They also cut down the average time of processing orders, which improves speed and reduces the workload (Martinez *et al.*, 2019), which allows processes to be performed more cost-effectively. When looking at the business project more broadly, digitization efforts can lead to improved speed by substituting paper-based processes (Chang *et al.*, 2020; Tseng and Shang, 2021). In turn, the cost of administrative procedures can be reduced greatly (Chang *et al.*, 2020). Digitization can also result in improved quality due to a reduced error rate, which is a result of the directness of paperless data sharing (Tseng and Shang, 2021).

5. Analysis of primary cases

We continue the presentation of our research findings with insights from the primary cases based on interviews with blockchain providers, users and experts involved in four recent

Figure 6 Framework based on reported cases in the manufacturing industry

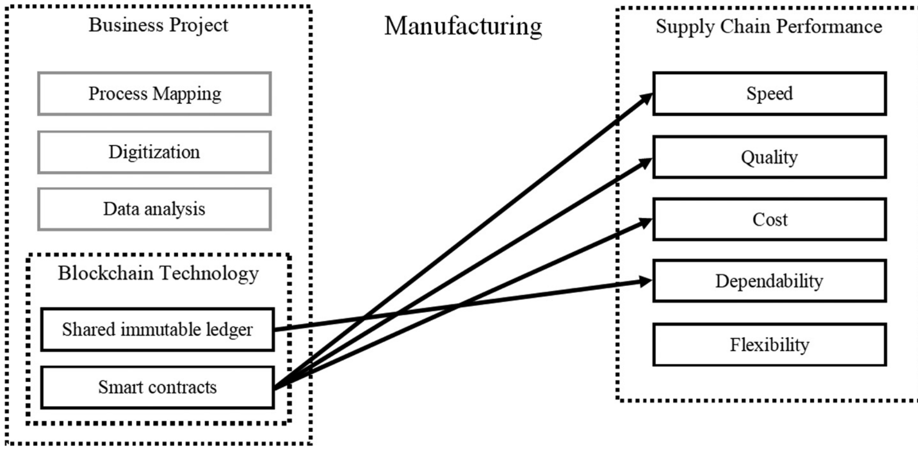
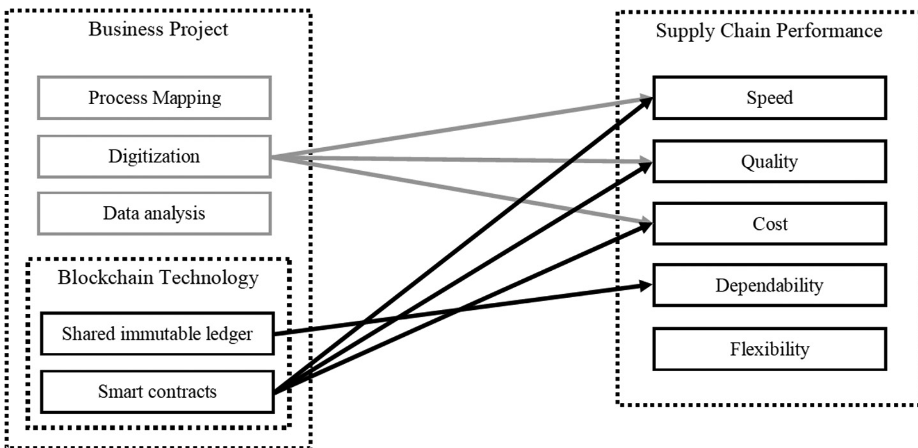


Figure 7 Research framework based on secondary cases



blockchain projects in The Netherlands. After a first within-case analysis of the interview transcripts, Case 1 appeared to share similarities with Case 2, and so did Case 3 with Case 4. Therefore, we discuss these cases in pairs. The results per case are presented in the Online Supplement (Section E).

5.1 Intraorganizational blockchain applications

Cases 1 and 2 address the intraorganizational application of blockchain. In both cases, the shared immutable ledger technology and smart contracts came forward as having an impact on supply chain performance. In addition, these cases suggest all three elements of the broader blockchain project affect supply chain performance (Figure 8).

5.1.1 Shared immutable ledger

Due to the immutability of the data on the ledger, every activity in the process can be traced, which leads to improved dependability. "One can see which person at which moment made a mistake that led to rejected products" (User 1). As indicated by both Users 1 and 2, when faced with audits, the auditors can see how the process was conducted due to a tamperproof audit trail of the process steps. However, to build an audit trail, the workflow management systems in both cases need to be fed with information, either automatically from other systems or manually. When other systems are not integrated with the blockchain solution, this could lead to extra manual handling, as indicated by User 2.

5.1.2 Smart contracts

Smart contracts have two main functions in these cases to automate manual process steps and to guide employees through the process. For example, "product certificates are automatically sent [to the customer] and indicated in the system as such" (User 1). Due to the automated logic, smart contracts are executed when certain conditions are met. So, when an employee has finished a certain activity in the process, the certificates related to the product are sent automatically to the customer. Simultaneously, the workflow system jumps to the next task, automatically handing over all relevant information. The use of smart contracts thus reduces the number of simple manual steps, such as e-mailing certificates or process handovers, which improves the speed of the process. Moreover, because all steps in the process are formalized in smart contracts, employees cannot deviate from the predetermined business logic, which decreases the error rate. In Case 1, for example, the cleaning of the adhesive tank is a formalized process step that is enforced by means of a smart contract. As a result, the production employee is reminded of performing this task and is less likely to skip it. Similarly, User 2 mentioned, "the system automatically reminds you of the next step. In this way, you will not forget steps." This improves the quality of the final product. Finally, the fact that smart contracts make the process less prone to errors also reduces the cost. "Decreasing the error rate leads to increased speed and reduced cost since solving problems requires a lot of time" (User 1).

Notwithstanding the benefits described above, some employees experienced reduced flexibility because of the rigid protocols enforced by smart contracts. This was indicated by both users. For new employees, a rigid protocol with automatic reminders about process steps may come in handy, but for more experienced employees, it may feel forced and reduce their freedom, which negatively impacts range flexibility. As flexibility may be negatively impacted, this relation is depicted by a red arrow in Figure 8.

5.1.3 Process mapping

User 1 stated that one of the reasons for implementing blockchain was to enable a thorough mapping of the processes. In addition, User 2 explained how the blockchain project started by drawing the process in a flowchart so that bottlenecks could be identified and eliminated. Due to these activities, the processes in Case 2 are now described more clearly and in more detail. Previously, one could not indicate specifically at which stage the process was since it only contained five generically described stages. Now that the process has been mapped, 55 detailed process steps have been identified, which enables the possibility to state the exact status of the process at any time. During the process mapping activities, bottlenecks were identified and removed from the process, which improved process speed.

5.1.4 Digitization

Both in Cases 1 and 2, the planning was previously discussed via phone, e-mail or during meetings. Now, the planning and real-time status of the process are visible in a blockchain application. User 1 explained that "the planning is visible on the blockchain for everybody, which should reduce communication between departments." Additionally, "one can react faster when real-time insights in bottlenecks are available. In this way, the process will speed up." (User 2). The digitization of the workflow has resulted in improved quality because the users are able to see and act faster upon mistakes. In addition, digitized processes are less prone to errors "since paperwork can be lost or unreadable" (User 1). Even though the correctness of information depends on what is inserted by the users, digitization may also result in better data quality and therefore improved dependability: "I believe that there is more consciousness since you can actually see the data. There is an extra set of eyes that can watch, track, and solve errors faster. In this way, we can check one another." (User 1).

5.1.5 Data analysis

Aside from the insights into the real-time workflow, performance dashboards can be generated based on historical data stored on the blockchain. Both users indicated that the speed of the process can be improved by analyzing key performance indicators, such as throughput rate and sales performance. In this way, "one can look at the source of why a process was slow. From a process optimization perspective, this is a very effective solution." (User 1). Although these insights were previously unavailable for both cases, blockchain technology itself does not directly play a role in analyzing data. In principle, such analyses could also be performed on data stored in any other type of database.

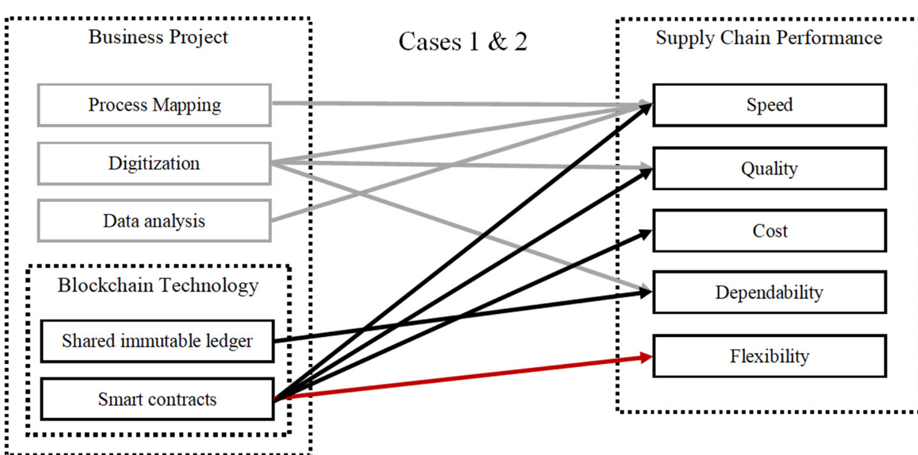
5.2 Interorganizational blockchain applications

Cases 3 and 4 address the interorganizational application of blockchain. They point to the role of shared immutable ledger technology, process mapping and digitization toward improved supply chain performance Figure 9.

5.2.1 Shared immutable ledger

Users in both Cases 3 and 4 can directly share information with their trading partners via the blockchain. Provider 4a explained how this was not possible with electronic data interchange (EDI) technology. EDI enables communication messages between actors in the supply chain based on information in the separate transaction processing software systems of those actors. When entering information about a transaction into

Figure 8 Framework based on intraorganizational workflow management system cases



those systems, some mistakes and delays are inevitable. "As supply chains become longer or more complex such messaging becomes like the telephone game" (Provider 4a), where information becomes increasingly unreliable as it is passed along from actor to actor. The shared immutable ledger technology requires direct information input and enables secure sharing of that information across actors in the supply chain. As a result, all actors in the supply network have a shared view on the state of the process, which improves dependability. In a similar vein, shared ledger technology enhances the focus on the quality of the process. As the information stored on the blockchain is shared directly, possible discrepancies can be detected and solved more quickly. According to Provider 3b, the responsible actor who is not returning the packing product can thereby be held accountable. Moreover, "processes can be simplified and unnecessary communication can be eliminated" (Provider 4a). There is "no more need to work in different administration systems like web portals and Excel sheets" (Provider 3a). This improves process speed. Finally, because shared ledger technology automatically and securely aggregates data, "non-value-adding activities can be eliminated by disintermediation of parties that perform data aggregation activities" (Provider 4a), which reduces cost.

5.2.2 Process mapping

Provider 4a stated their solution "is like a large value stream map in which all shared processes are laid along the line and analyzed for waste." Before implementing the blockchain, processes in Case 4 were mapped to identify and eliminate unnecessary processes, improving speed. Provider 3a mentioned that a large advantage of their approach is that the current processes of customers are being mapped, carefully evaluated and streamlined where possible. However, "process mapping has its pros and cons for us. Some clients might say, we have mapped and optimized it so well, from here onwards we will take care of it ourselves" – that is, before actually implementing blockchain (Provider 3a).

5.2.3 Digitization

Digitized information can be shared faster and is often richer compared to paperwork. For example, Provider 3a explained how the digitization of processes in Case 3 enabled users to add photos of a shipment. Digitizing paperwork in Case 4 resulted in office employees not having to wait for the paperwork to arrive physically. This more timely sharing of richer information results in fewer post hoc discussions about what went wrong in executing the process, which, in turn, improves the quality of the process.

Cases 3 and 4 do not reveal performance effects from smart contracts or data analysis. Providers 3a and 4a stated that smart contracts could play a more significant role in the future, for example, when they would be used to automatically perform existing business rules and enable (payment) agreements between actors in the supply chain. In both cases, however, the users first wanted to scale up at a transactional level and improve data quality before automating the process. "So first the groundwork, from there we can simplify things, and when that has been done, we can automate processes from the network" (Provider 4a). In terms of data analysis, Provider 3a stated: "Sharing information between supply chain partners may lead to better collaboration, but it is up to the users to do the right things with the data".

6. Research framework and interpretation

We developed an integrated research framework by combining insights from the secondary cases identified through the SLR with insights from the primary cases collected via interviews with blockchain users, providers and experts. After presenting the individual elements of this framework, as well as the relations between them, we discuss the broader implications of how blockchain technology can affect supply chain performance.

6.1 Integrated research framework

The integrated research framework presented in Figure 10 depicts all the direct and indirect relations between different elements of blockchain and supply chain performance indicators that emerged from our analysis.

6.1.1 Speed

Our empirical data suggest that speed can be improved not only directly – via the core features of blockchain technology – but

Figure 9 Framework based on interorganizational communication platform cases

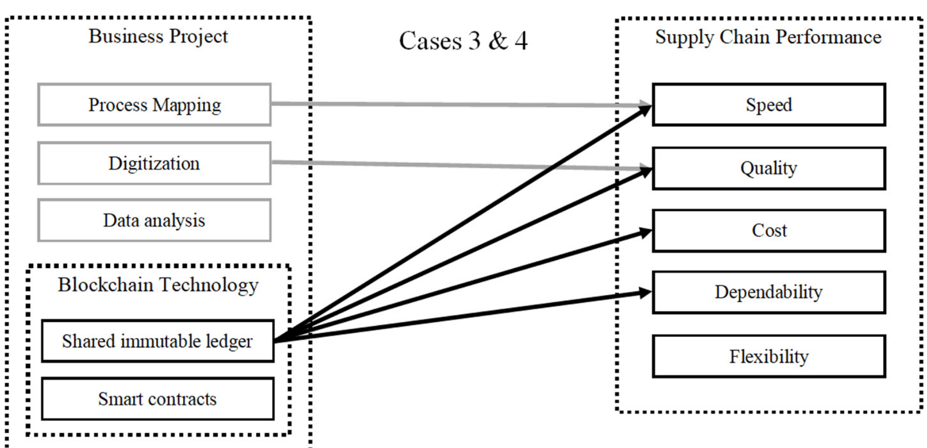
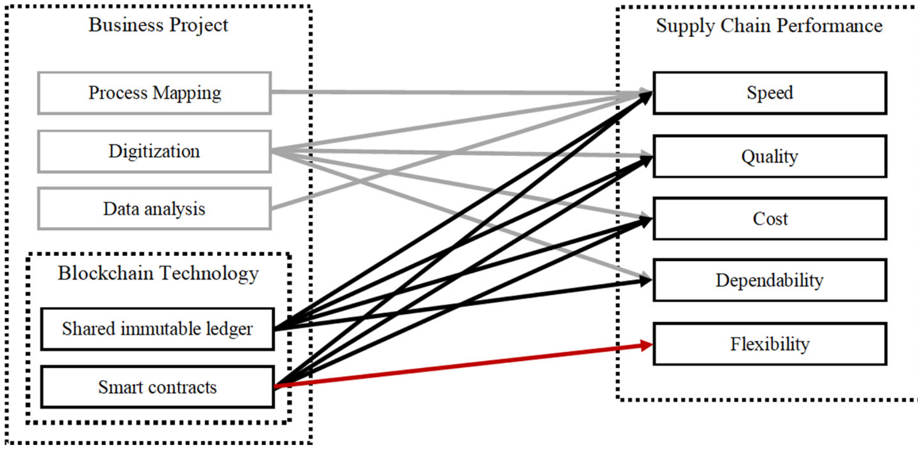


Figure 10 Integrated research framework based on primary and secondary cases



also indirectly via process mapping, digitization and data analysis.

Looking at how speed can be affected by the core features of blockchain technology, having a shared immutable ledger enables the elimination of unnecessary communication among actors in the supply chain because they all have access to the same, secured information in real-time. Additionally, there is no need to work in different portals or systems, and parties performing nonvalue-adding activities can be disintermediated. While, in principle, supply chain process simplification could also be established via the implementation of a centralized database, Cases 3 and 4 clearly point to the role of shared immutable ledgers. Typical supply networks lack a single party that could act as a trusted central authority. Therefore, a decentralized solution – such as blockchain, where no actor has to give up its autonomy – can be better suited. Speed can also improve as a result of the execution of smart contracts. The case described in Martinez *et al.* (2019) shows how smart contracts can reduce processing time by limiting the number of griefs. Our findings related to Cases 1 and 2 show how smart contracts are substituting manual activities, such as process handovers.

Aside from the direct impact of blockchain technology, speed is also positively affected by activities in the broader business project. Process mapping plays an important role in all four primary cases but was not mentioned in any of the secondary cases. Process mapping enables the identification and elimination of sources of waste before the implementation of blockchain technology. The fact that some clients even discontinue the blockchain project when the process is mapped suggests the indirect impact of process mapping may be more important than applying the actual blockchain technology itself. The secondary cases mostly focus on the impact of digitization. Cases in health and trade finance and accounting, for example, show how digitization reduced processing times by removing paperwork (Chang *et al.*, 2020; Tseng and Shang, 2021). This is in line with the empirical findings from Cases 1 and 2, which indicate that by digitizing planning processes communication between departments is reduced. Data analysis came forward as another means to improve speed, especially in Cases 1 and 2, where dashboards were generated aimed at analyzing performance to improve speed.

6.1.2 Quality

Both the primary and secondary cases suggest quality can be improved by blockchain directly – via the introduction of shared immutable ledgers and the application of smart contracts – and indirectly through digitization. Considering how the core technological features of blockchain can improve quality, Cases 1 and 2 show how smart contracts can be used to automatically remind employees when certain process steps should be performed and not allow deviations from the predefined process steps. As indicated in the secondary case of Martinez *et al.* (2019), a series of advanced rules predefined in the smart contracts can be leveraged to reduce the need for manual handling, which, in turn, makes the process less prone to errors and improves quality. Cases 3 and 4 reveal how shared immutable ledger technology improves the quality of the process because information stored on the ledger is shared timelier, enabling the detection and addressing of quality issues more quickly. A shared immutable ledger was an important prerequisite for data sharing in these cases because individual actors in the supply networks were reluctant to share data with a centralized third party.

Tseng and Shang (2021) explain how paperless data sharing reduces the error rate and enhances the speed of data transmission compared to paper-based data sharing. While this case presents a blockchain solution, it provides no reasons for why the reported improvements were related strictly to any of the core features of blockchain technology or why the context would necessitate blockchain. Rather, the quality improvements seem to be the result of digitizing paper-based processes more generally. Overall, a considerable part of the quality improvements identified in our study is the result of such broader digitization activities. Our primary cases – and especially Cases 1 and 2 – point to a similar relationship between digitization and quality.

6.1.3 Cost

Our data suggest blockchain can reduce cost in several ways. First, blockchain can reduce costs by eliminating the need for paperwork throughout the supply chain. In more complex supply networks, this requires shared immutable ledger technology, while in other situations, these cost benefits can be achieved through digitization. Second, the use of smart contracts can reduce processing time and improves process quality, which, in turn, reduces cost. Third, blockchain can reduce cost by the disintermediation of third parties that perform nonvalue-adding activities, such as aggregating data, which can be automatically performed with data stored on a shared immutable ledger.

6.1.4 Dependability

Our study reveals that blockchain can improve dependability by improving the quality of information and timeliness of information sharing. Cases 3 and 4 show how directly sharing information with multiple actors in the supply network improves the timeliness and quality of information, and thus, dependability along the supply chain. It is important to note that data in blockchain settings is often still entered as part of some manual effort, and can therefore contain mistakes. Provider 4a stressed, however, that because all actors in the supply network have access to the same information about the transactions they are involved in, wrong information about the process uploaded by one actor would be easily spotted by others – which helps prevent wrong information from being uploaded in the first place. In a similar vein, the quality of data improved in Cases 1 and 2. The fact that data is accessible for all employees involved in the process, increases the focus of employees entering that data on doing so accurately. In addition, there are also extra sets of eyes checking the data. Chang *et al.* (2020) and Luchoomun *et al.* (2020) discuss how the application of shared ledger technology leads to improved transparency of transactions among partners in a network. Cases 1 and 2 provide more insight on how such transparency can improve dependability. Shared immutable ledger technology enables every process activity to be traced, which improves the availability of process data that can be used, for example, when a company is faced with audits.

6.1.5 Flexibility

Smart contracts can be used to strictly enforce protocols, which, in turn, can improve several supply chain performance indicators. The flip side is that these protocols are rigid and thus limit how much employees can deviate from the formalized processes. Cases 1 and 2 show how smart contracts result in improved efficiency and quality, but at the same time, hamper range flexibility. It, therefore, is important to find the right balance between smart logic and flexibility. "You should not put too much smart logic in the system, since this will factually turn into one large central application, but then implemented 22 times, with the same rigid protocol" (Provider 4a).

6.2 Managerial implications

While our focus was on systematically assessing how blockchain can affect supply chain performance, the four operational blockchain applications studied as part of our primary data collection also provided some broader insights that may be relevant for managers when implementing blockchain in a supply chain context. In line with lessons from early blockchain adopters (Lacity and van Hoek, 2021; van Hoek, 2020a), our study sheds light on the steps involved with implementing blockchain, including some barriers that need to be overcome before supply chains can benefit from blockchain technology.

As a first step, managers should carefully determine which supply chain challenge needs addressing. The second step is then to initiate a broader business project in which different (software) tools and activities can be leveraged to address that challenge. These may include process mapping, digitization and data analysis. Blockchain should only be part of the project if its core technological features have value in relation to the challenge. Otherwise, more traditional transaction processing software would do the job – and probably at lower cost. Or, as one of the experts aptly put it: "One does not jump into a go-kart to find out a jeep would have been more appropriate for the safari tour" (Expert 2).

Blockchain seems particularly valuable when there is a need for trustworthy and transparent data sharing across a complex network of actors that simultaneously cooperate and compete. In those settings, the core technological features of blockchain enable actors to cooperate on a need-to-know basis. Blockchain can "go against the tendency of shifting towards a platform economy, where all information of all actors in the supply network needs to be shared with one or more powerful third parties via EDI and APIs" (Expert 2). Instead, the content of each transaction can be encrypted so that it can only be viewed by the actors that have the public-private key needed to decrypt its content. In this way, "blockchain enables discussions about, for example, the standardization of processes that would theoretically have been possible before, but now have the potential to be actually adopted" (Provider 4b).

Paradoxically, the more salient barriers to successful blockchain implementation – in terms of governance, technology and financing – also appear when applied in complex supply networks. Important benefits of blockchain materialize precisely because it enables standardization and transparency across a larger ecosystem of actors. An important third step in implementing blockchain, therefore, is to determine which existing actors, information systems and other stakeholders to include within the scope of the broader business project. A lesson highlighted by our cases is that it takes time to get the critical actors on board and to agree to the scope and rules of the broader business project. Step four involves deciding on how the different elements of existing processes and information systems can be integrated into a blockchain application and new business processes. The cases in our study confirm that providers and users opt for pilots to validate the application before fully operationalizing the blockchain application (van Hoek, 2020a).

Scalability can be an important concern when implementing blockchain. First, scalability relates to the ability to process a growing number of transactions (throughput) without significantly increasing processing time (latency). Blockchain is a monotonically growing ledger and scalability decreases as data is fully replicated over all nodes in the network. In response, all four primary cases carefully considered the trade-off between performance and transparency of the transaction data. The blockchain applications in these cases log the transactions, while most data related to those transactions is kept at the source, in traditional databases. The blockchain applications in Cases 1 and 2 also make use of sharing, a technique to only store transactions relevant for a user on the node of that user. Second, scalability may refer to the software development required to rollout blockchain technology.

Supply Chain Management: An International Journal
Volume 27 · Number 7 · 2022 · 177–193

Currently, blockchain applications are often still largely custom-built. Expert 1 stressed that, as blockchain software is developed for more application domains, future applications can increasingly rely on existing ones, which will speed up development and reduce cost. Provider 1 explained how developers can now leverage software compiler technology to write blockchain code.

7. Conclusions and discussion

This paper builds on the pioneering research that discussed potential use cases for blockchain technology (Hald and Kinra, 2019; Hew *et al.*, 2020; Nandi *et al.*, 2020; Sheel and Nath, 2019; Wang *et al.*, 2019b) by systematically assessing the impact of blockchain on supply chain performance based on the analysis of 28 empirical cases. Twenty-four of those cases were retrieved from the academic literature by means of a structured review. Four new cases were built from primary empirical data collected through 11 interviews with blockchain providers, users and experts. Our empirical data highlights that there is no such thing as the blockchain. Blockchain relies on several technological features – resulting in the ability to keep a shared and immutable ledger that can automatically deploy smart contracts – and is part of a broader business project that includes other activities, such as process mapping, digitization and data analysis. The core features of blockchain technology can affect supply chain performance directly. Yet, our study reveals that several of the supply chain performance improvements ordinarily attributed to blockchain, in fact, follow indirectly from activities in the broader business project.

7.1 Implications for theory

The contradiction between blockchain as "the biggest innovation in computer science" (Tapscott *et al.*, 2016) and as an "amazing solution for almost nothing" (Frederik, 2020) could not be larger. A first important contribution of our study stems from presenting a more nuanced understanding of blockchain by systematically assessing its impact on supply chain performance. It does so by distinguishing the direct impact of blockchain on supply chain performance from the indirect effects. Prior studies have attributed improvements in, for example, production cycle time to blockchain generally (Nandi *et al.*, 2020; Wang *et al.*, 2019b) – that is, without specifying whether it stems directly from the core technological features of blockchain or indirectly from other activities that are part of the broader business project. We show that several performance effects stem from the core technological features of blockchain. Others result indirectly from activities in the broader business project, for example, by eliminating unnecessary process steps identified after carefully mapping the entire process (Hammer, 1990; Lie and Kusumastuti, 2021). Our analysis also points to ways in which blockchain technology can hamper supply chain performance, for example, when smart contracts enforce rigid protocols that limit the perceived flexibility of employees. This insight taps into an interesting debate, where some argue that the use of smart contracts in a supply chain reduces flexibility (Hald and Kinra, 2019) while others anticipate improved flexibility (Sheel and Nath, 2019).

This paper also contributes to the debate about the operations and supply chain contexts best suited for blockchain technology (Dobrovnik *et al.*, 2018; van Hoek, 2020b). Our cases suggest that the core technological features of blockchain can be particularly valuable in complex supply networks (Braziotis *et al.*, 2013; Cole *et al.*, 2019), especially when characterized by coopetition (Wilhelm and Sydow, 2018). That is, in supply networks where actors collaboratively execute consecutive process steps for some customers while competing for others. In such coopetitive supply networks, the core technological features of blockchain can enable the encryption of transactions and/or the assurance that the specific content of a transaction can only be accessed by the actors involved in that transaction. This observation also relates to the discussion about the role of trust in the use of blockchain technology. Cole *et al.* (2019) clearly summarize the current state of that discussion, in which some argue that blockchain removes the need for trust, due to the shared and immutable nature of data stored on the blockchain (Babich and Hilary, 2020), while others argue that blockchain can, in fact, enhance trust (Rogerson and Parry, 2020). Our study shows that, when applied to coopetitive supply networks, blockchain can facilitate data sharing because individual actors do not need to trust a third party to host a completely centralized database.

7.2 Limitations and implications for future research

The findings of our study should be interpreted in light of some limitations. First, due to the nascent stage of blockchain applications in supply chains, we ended up studying both fully operational blockchain applications as well as pilot projects. Moreover, the empirical data are partially retrieved from secondary cases and partially from primary cases. While these methodological choices enabled a broader view on the many linkages between blockchain and supply chain performance indicators, some of these linkages may have been based on first signs of performance changes rather than being structural. Also, it was difficult to assess the magnitude of the performance changes because most cases involved an early stage blockchain application. As many blockchain projects are terminated within one year (Trujillo *et al.*, 2017), more reliable and generalizable insights on the relationship between blockchain and supply chain performance can be derived from studying long-lasting blockchain applications in future research.

Another limitation of our study is related to the interviews. For two cases, our findings are based on the blockchain provider alone. Since the blockchain providers may have a bias toward success, our study can have missed important downsides of blockchain technology in these cases. However, in the other two cases, we did interview the blockchain users, and we discussed the preliminary analysis – from both the primary and secondary cases – with blockchain experts who broadly confirmed our findings and elaborated with insights from other projects. As time evolves, developments in blockchain will continue, and so, we encourage future scholars to build upon our proposed research framework, for example, by identifying new blockchain elements or performance indicators and by further explaining the many linkages that exist or emerge between them.

References

Azzi, R., Chamoun, R.K. and Sokhn, M. (2019), "The power of a blockchain-based supply chain", *Computers & Industrial Engineering*, Vol. 135, pp. 582-592.

Babich, V. and Hilary, G. (2020), "Distributed ledgers and operations: what operations management researchers should know about blockchain technology", *Manufacturing & Service Operations Management*, Vol. 22 No. 2, pp. 223-240.

Bos, N., Zimmerman, A., Olson, J., Yew, J., Yerkie, J., Dahl, E. and Olson, G. (2007), "From shared databases to communities of practice: a taxonomy of collaboratories", *Journal of Computer-Mediated Communication*, Vol. 12 No. 2, pp. 652-672.

Braziotis, C., Bourlakis, M., Rogers, H. and Tannock, J. (2013), "Supply chains and supply networks: distinctions and overlaps", *Supply Chain Management: An International Journal*, Vol. 18 No. 6, pp. 644-652.

Catalini, C. and Michelman, P. (2017), "Seeing beyond the blockchain hype", *MIT Sloan Management Review*, Vol. 58 No. 4, pp. 17-19.

Chang, S.E. and Chen, Y. (2020), "When blockchain meets supply chain: a systematic literature review on current development and potential applications", *IEEE Access*, Vol. 8, pp. 62478-62494.

Chang, S.E., Luo, H.L. and Chen, Y. (2020), "Blockchain-enabled trade finance innovation: a potential paradigm shift on using letter of credit", *Sustainability*, Vol. 12 No. 1, p. 188.

Cole, R., Stevenson, M. and Aitken, J. (2019), "Blockchain technology: implications for operations and supply chain management", *Supply Chain Management: An International Journal*, Vol. 24 No. 4, pp. 469-483.

Danese, P., Mocellin, R. and Romano, P. (2021), "Designing blockchain systems to prevent counterfeiting in wine supply chains: a multiple-case study", *International Journal of Operations & Production Management*, Vol. 41 No. 13, pp. 1-33.

Dobrovnik, M., Herold, D.M., Furst, E. and Kummer, S. (2018), "Blockchain for and in logistics: what to adopt and where to start", *Logistics*, Vol. 2 No. 3, p. 18.

Eggers, J., Hein, A., Weking, J., Böhm, M. and Krcmar, H. (2021), "Process automation on the blockchain: an exploratory case study on smart contracts", *Proceedings of the 54th HI International Conference on System Sciences*, pp. 5607-5616.

Eisenhardt, K.M. (1991), "Better stories and better constructs: the case for rigor and comparative logic", *The Academy of Management Review*, Vol. 16 No. 3, pp. 620-627.

Frederik, J. (2020), "Blockchain, the amazing solution for almost nothing", *The Correspondent*, available at: https://thecorrespondent.com/655/blockchain-the-amazing-solution-for-almost-nothing/86649455475-f933fe63

Gupta, H., Kumar, S., Kusi-Sarpong, S., Jabbour, C.J.C. and Agyemang, M. (2021), "Enablers to supply chain performance on the basis of digitization technologies", *Industrial Management and Data Systems*, Vol. 41 No. 13, pp. 1-33.

Hald, K.S. and Kinra, A. (2019), "How the blockchain enables and constrains supply chain performance", *International Journal of Physical Distribution & Logistics Management*, Vol. 49 No. 4, pp. 376-397.

Hammer, M. (1990), "Reengineering work: don't automate, obliterate", *Harvard Business Review*, Vol. 68 No. 4, pp. 104-112.

Hanebeck, H.C., Hewet, N. and McKay, P.A. (2019), *Inclusive Deployment of Blockchain for Supply Chains: Part 3 – Public or Private Blockchains: Which One is Right for You*?, World Economic Forum.

Helo, P. and Shamsuzzoha, A.H.M. (2020), "Real-time supply chain – a blockchain architecture for project deliveries", *Robotics and Computer-Integrated Manufacturing*, Vol. 63, p. 101909.

Hew, J.J., Wong, L.W., Tan, G.W.H., Ooi, K.B. and Lin, B. (2020), "The blockchain-based halal traceability systems: a hype or reality?", *Supply Chain Management: An International Journal*, Vol. 25 No. 6, pp. 863-879.

Kalla, A., Hewa, T., Mishra, R.A., Ylianttila, M. and Liyanage, M. (2020), "The role of blockchain to fight against COVID-19", *IEEE Engineering Management Review*, Vol. 48 No. 3, pp. 85-96.

Kamble, S.S., Gunasekaran, A. and Sharma, R. (2020), "Modeling the blockchain enabled traceability in agriculture supply chain", *International Journal of Information Management*, Vol. 52, p. 101967.

Kharif, O. (2018), "Blockchain, once seen as a corporate Cure-All, suffers slowdown", *Bloomberg*, available at: www.bloomberg.com/news/articles/2018-07-31/blockchain-once-seen-as-a-corporate-cure-all-suffers-slowdown

Kumar, A., Liu, R. and Shan, Z. (2020), "Is blockchain a silver bullet for supply chain management? Technical challenges and research opportunities", *Decision Sciences*, Vol. 51 No. 1, pp. 8-37.

Lacity, M. and van Hoek, R. (2021), "What we've learned so far about blockchain for business", *MIT Sloan Management Review*, Vol. 62 No. 3, pp. 40-46.

Lai, R. and Lee Kuo Chuen, D. (2018), "Blockchain-From public to private", in *Handbook of Blockchain, Digital Finance, and Inclusion*, *2*, pp. 145-177.

Lee, A. (2019), "How to position blockchain platforms to increase adoption", Gartner, available at: www.gartner.com/en/documents/3909078

Levine, M. (2017), "Cargo blockchains and Deutsche bank", *Bloomberg*, available at: www.bloomberg.com/opinion/articles/2017-03-06/cargo-blockchains-and-deutsche-bank

Lie, S.R. and Kusumastuti, R.D. (2021), "Process improvement using value stream mapping and lean methodology: a case study application in batch chemical process industry", *IOP Conference Series: Materials Science and Engineering*, Vol. 1072 No. 1, p. 12015.

Luchoomun, K., Pudaruth, S. and Kishnah, S. (2020), "Implementation of a proof of concept for a blockchain-based smart contract for the automotive industry in Mauritius", *International Journal of Advanced Computer Science and Applications*, Vol. 11 No. 3, pp. 71-81.

Lyasnikov, N.V., Smirnova, E.A., Nikiporets-Takigawa, G., Deeva, T.V. and Vysotskaya, N.V. (2020), "Blockchain technology: supply chain management", *The IIOAB Journal*, Vol. 11 No. 3, pp. 1-7.

Madnick, S. (2017), "Blockchain isn't as unbreakable as you think", *MIT Sloan Management Review*, Vol. 61 No. 2, pp. 66-70.

Martinez, V., Zhao, M., Blujdea, C., Han, X., Neely, A. and Albores, P. (2019), "Blockchain-driven customer order management", *International Journal of Operations & Production Management*, Vol. 39 Nos 6/7/8, pp. 993-1022.

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

Nandi, M.L., Nandi, S., Moya, H. and Kaynak, H. (2020), "Blockchain technology-enabled supply chain systems and supply chain performance: a resource-based view", *Supply Chain Management: An International Journal*, Vol. 25 No. 6, pp. 841-862.

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 and Management*, Vol. 24 No. 4, pp. 138-147.

Pawczuk, L., Massey, R. and Schatsky, D. (2018), "Breaking blockchain open", Deloitte's 2018 global blockchain survey, available at: www2.deloitte.com/content/dam/Deloitte/us/Documents/financial-services/us-fsi-2018-global-blockchain-survey-report.pdf

Queiroz, M.M., Telles, R. and Bonilla, S.H. (2020), "Blockchain and supply chain management integration: a systematic review of the literature", *Supply Chain Management: An International Journal*, Vol. 25 No. 2, pp. 241-254.

Rogerson, M. and Parry, G.C. (2020), "Blockchain: case studies in food supply chain visibility", *Supply Chain Management: An International Journal*, Vol. 25 No. 5, pp. 601-614.

Schmidt, C.G. and Wagner, S.M. (2019), "Blockchain and supply chain relations: A transaction cost theory perspective", *Journal of Purchasing and Supply Management*, Vol. 25 No. 4, p. 100552.

Seawright, J. and Gerring, J. (2008), "Case selection techniques in case study research: a menu of qualitative and quantitative options", *Political Research Quarterly*, Vol. 61 No. 2, pp. 294-308.

Sheel, A. and Nath, V. (2019), "Effect of blockchain technology adoption on supply chain adaptability, agility, alignment and performance", *Management Research Review*, Vol. 42 No. 12, pp. 1353-1374.

Slack, N. and Lewis, M. (2017), *Operations Strategy*, Pearson Education Limited, New York, NY.

Stranieri, S., Riccardi, F., Meuwissen, M.P.M. and Soregaroli, C. (2021), "Exploring the impact of blockchain on the performance of agri-food supply chains", *Food Control*, Vol. 119, p. 107495.

Tapscott, D., Tapscott, A. and Kirkland, R. (2016), "How blockchains could change the world", *McKinsey & Company*, available at: www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/how-blockchains-could-change-the-world

Tranfield, D., Denyer, D. and Smart, P. (2003), "Towards a methodology for developing evidence-informed management knowledge by means of systematic review", *British Journal of Management*, Vol. 14 No. 3, pp. 207-222.

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*, Vol. 23 No. 6, pp. 545-559.

Trujillo, J.L., Fromhart, S. and Srinivas, V. (2017), "Evolution of blockchain technology insights from the GitHub platform", *Deloitte Insights*, available at: www2.deloitte.com/us/en/insights/industry/financial-services/evolution-of-blockchain-github-platform.html

Tseng, C.T. and Shang, S.S.C. (2021), "Exploring the sustainability of the intermediary role in blockchain", *Sustainability*, Vol. 13 No. 4, p. 1936.

van Hoek, R. (2020a), "Developing a framework for considering blockchain pilots in the supply chain – lessons from early industry adopters", *Supply Chain Management: An International Journal*, Vol. 25 No. 1, pp. 115-121.

van Hoek, R. (2020b), "Unblocking the chain – findings from an executive workshop on blockchain in the supply chain", *Supply Chain Management: An International Journal*, Vol. 25 No. 2, pp. 255-261.

Wang, Y., Han, J.H. and Beynon-Davies, P. (2019a), "Understanding blockchain technology for future supply chains: a systematic literature review and research agenda", *Supply Chain Management: An International Journal*, Vol. 24 No. 1, pp. 62-84.

Wang, Y., Singgih, M., Wang, J. and Rit, M. (2019b), "Making sense of blockchain technology: how will it transform supply chains?", *International Journal of Production Economics*, Vol. 211, pp. 221-236.

Wilhelm, M. and Sydow, J. (2018), "Managing coopetition in supplier networks–a paradox perspective", *Journal of Supply Chain Management*, Vol. 54 No. 3, pp. 22-41.

Xiao, Z., Li, Z., Yang, Y., Chen, P., Liu, R.W., Jing, W., Pyrloh, Y., Sotthiwat, E. and Goh, R.S.M. (2020), "Blockchain and IoT for insurance: a case study and cyberinfrastructure solution on fine-grained transportation insurance", *IEEE Transactions on Computational Social Systems*, Vol. 7 No. 6, pp. 1409-1422.

Xu, X., Weber, I., Staples, M., Zhu, L., Bosch, J., Bass, L., Pautasso, C. and Rimba, P. (2017), "A taxonomy of blockchain-based systems for architecture design", in *2017 IEEE International Conference on Software Architecture*, pp. 243-252.

Yin, R.K. (2009), *Case Study Research: Design and Methods*, Sage Publications, Thousand Oaks, CA.

Zhao, G., Liu, S., Lopez, C., Lu, H., Elgueta, S., Chen, H. and Boshkoska, B.M. (2019), "Blockchain technology in agri-food value chain management: a synthesis of applications, challenges and future research directions", *Computers in Industry*, Vol. 109, pp. 83-99.

Zheng, Z., Xie, S., Dai, H., Chen, X. and Wang, H. (2017), "An overview of blockchain technology: architecture, consensus, and future trends", in *2017 IEEE International Congress on Big Data*, pp. 557-564.

Supplementary material

The supplementary material for this article can be found online.

Corresponding author

Paul Buijs can be contacted at: p.buijs@rug.nl