Why, Where, and How are Organizations Using Blockchain in their Supply Chains? Motivations, Application areas, and Contingency Factors

Abstract

Purpose

Blockchain is increasingly being considered for deployment in operations and supply chain management. However, evidence from practice is still scarce on why, where, and how organizations seek to apply the technology in the supply chain across different industries. The study develops a comprehensive framework to enhance understanding of the application areas of blockchain technology in the supply chain, as well as organizations' motivations in seeking blockchain solutions and relevant contingency factors influencing applications.

Design/methodology/approach

We investigate 50 use cases of blockchain applications in the supply chain, covering six industries. We apply contingency theory and conduct a detailed qualitative textual and correlation analysis to identify and compare blockchain adoption motivations, application areas and contingency factors across the different sectors.

Findings

The analysis develops an evidence-based framework that captures ten principal motivations in seeking blockchain solutions, three main blockchain application areas along with important application sub-categories, and five clusters of contingency factors that determine blockchain deployment and its success in different industrial sectors.

Research implications

The study expands the limited cross-sectoral research on blockchain applications and motivations in the supply chain. Using contingency theory, we present a comprehensive framework that captures the drivers and factors relating to blockchain adoption in the supply chain in a nomological network. The study lays the foundation for further theoretical perspectives and empirical research to investigate relevant sectoral characteristics and their importance for different types of blockchain applications in the supply chain.

Practical implications

The study informs practitioners about potential supply chain application areas that can be enhanced through blockchain technology, taking account of the specific characteristics of their product, business and manufacturing processes, supply network configuration, industry standards, regulations, and market demand.

Originality/value

The study is the first to provide cross-sectoral evidence on the relevance of organizations' motivations and numerous contingency factors on blockchain application areas in the supply chain.

Keywords: Supply chain, Blockchain, Traceability, Transparency, Sustainability, Industry characteristics, Contingency Theory, Contingency Factors

1. Introduction

A blockchain is a decentralized peer-to-peer network consisting of a chronological chain of blocks that are tamper-proof and cryptographically protected (Crosby *et al.*, 2016). A core characteristic of a blockchain is the creation of an immutable and shared digital record of timestamped transactions. Transactions recorded in a blockchain are validated based on a consensus mechanism that enables a shared truth among the participating nodes in the network. Blockchain technologies have developed rapidly and include numerous types, ranging from public cryptocurrencies to permissioned and private blockchain frameworks such as Hyperledger Fabric (Zhou *et al.*, 2020). The overall functionality of blockchain expanded significantly with the development of 'smart contracts', which are self-executing and deterministic code stored in the blockchain and triggered by predetermined events (Crosby *et al.*, 2016; Wang, Ouyang, *et al.*, 2019). Due to its features of immutability and shared data access, blockchain has been predicted to be a disruptive technology for supply chain management applications (Mann *et al.*, 2018; Papathanasiou *et al.*, 2020).

Blockchain's ability to provide a secure medium for instant information sharing among distributed supply chain partners can help in tackling some of the major challenges in supply chain management related to supply chain visibility, traceability, and transparency (Kshetri, 2018; Li *et al.*, 2018; Queiroz and Wamba, 2019; Schmidt *et al.*, 2021). In particular, blockchain technology has the potential to facilitate secure information sharing across the fragmented structures of global supply networks (Wamba and Queiroz, 2020). The immutable chronological record of transactions facilitates blockchain's use for verifiable traceability and auditability. The autonomous capabilities provided by smart contracts foster the automation of business processes, which may potentially transform many business models and operations (Wamba and Queiroz, 2020). More generally, the technology may promote trust and information sharing (Centobelli *et al.*, 2021). However, despite its manifold potential applications, there is still limited study of actual industry applications that capture the core motivations for blockchain adoption, the main application areas and, critically, the contingency factors that influence its application in the supply chain.

In spite of the numerous potential benefits of blockchain, the extant academic literature still provides only limited insights into why, where and how blockchain technology is and can be applied in practice (Lacity and Van Hoek, 2021; Wang, Han, *et al.*, 2019). Practitioners are ahead of the research community in experimenting with the technology in supply chain and enterprise applications (Ahmed and MacCarthy, 2022a; Kshetri, 2018; Xu *et al.*, 2019). Blockchain has already captured the interest of many leading organizations, start-ups and consortia (Lacity and Van Hoek, 2021; Lacity, 2018), with a growing body of practice literature (Seebacher and Schüritz, 2017; Vadgama and Tasca, 2021). However, the technology is still in the early stages of wide-scale adoption for supply chain applications. Most projects have yet to become commercial or have not been implemented at scale (Wamba and Queiroz, 2020). Furthermore, there is a notable lack of research investigating how blockchain is applied in different supply chain contexts. Supply chains display great diversity in their structures and configuration (Demirel *et al.*, 2019). They are comprised of dispersed economic actors performing different value-adding activities with various forms of ownership, relationships, and power structures, (MacCarthy *et al.*, 2016). Supply chain complexity, an important antecedent of supply chain performance (Chand *et al.*, 2022), varies substantially across different industries (Demirel *et al.*, 2019). Given the diversity of supply chains across industries, there is a need to better understand the factors that influence blockchain applications in different supply chain management contexts to guide future potential application areas.

A number of theoretical lenses have been suggested relating to blockchain technology adoption and applications in supply chain and operations (Kummer *et al.*, 2020; Liu *et al.*, 2022; Sternberg *et al.*, 2021; Treiblmaier, 2018). However, industry evidence is needed to underpin theory-driven research. In this study, we adopt a contingency theory perspective to explore why, where and how blockchain has been applied in the supply chain. We focused our research on analyzing 50 prominent blockchain reported use cases over the last five years across six major sectors - automotive, aerospace, food and beverages, textiles and apparel, pharmaceuticals, and logistics and global shipping industries. The reported applications are analyzed in an objective way to understand why organizations are seeking to apply the technology, where they are seeking to apply it, and if and how these are influenced by contingencies pertaining to product, processes, market and industry characteristics. Specifically, we address the following research questions:

1. Why do companies adopt blockchain in supply chain applications?
2. Where is blockchain applied in the supply chain?
3. How do contingency factors influence the adoption and application of blockchain in the supply chain?

This is an exploratory study in which we examine industrially led blockchain use cases driven by focal firms or supply chain partners that focus on supply chain applications. We use qualitative content analysis of secondary data to address the research questions and to create a comprehensive framework of blockchain motivations, application areas and contingency factors.

The study provides new evidence about the use of blockchain solutions in supply chain applications across different industries. First, our findings confirm some of the motivations identified in the academic literature that are driving blockchain adoption, but we identify new ones that were, largely ignored in previous literature, including customer service, risk management, and quality assurance. Second, we provide a detailed cross-industry analysis of the application specific areas where organizations seek to apply blockchain technology. We identify three principal blockchain application areas in the supply chain - traceability of product information across the supply chain and in aftermarkets, the automation, digitalization, and optimization of business processes, and the enhancement of the customer experience through demonstrating product provenance. We provide further details on each of these applications evident from the data. Third, the study identifies five clusters of contingency factors related to product characteristics, supply network configurations, industry standards and regulations, market and customer demand characteristics and business and manufacturing processes that may affect applications. Fourth, we present an evidence-based framework that is the first to take a cross-industry contingency perspective on blockchain applications in the supply chain to uncover the underlying motivations and contingencies influencing blockchain adoption and applications. The research findings and developed framework provide a strong foundation that can be further investigated and tested using appropriate theoretical perspectives and, by matching industry findings with theoretical propositions, help to further develop and refine existing theory as the rate of adoption of blockchain increases and the application domain matures.

The paper is structured as follows: Section 2 provides a critical appraisal of the academic literature on blockchain in the supply chain to motivate the study. Section 3 describes the research methodology and data analysis methods. Section 4 provides the results from the analysis structured around the emerging themes, specifically, the main motivations for blockchain applications in the supply chain, the key application areas and relevant contingency factors for blockchain applications. Section 5 discusses the analysis results considering the existing literature and presents a comprehensive framework that combines all these factors in a nomological network. Section 6 discusses the theoretical and practical implications of our research as well as the research limitations and future research directions. We provide a conclusion to the study in Section 7.

2. Blockchain in the Supply Chain: An appraisal of previous research

The flow of information across supply chains has been enhanced in the last three decades through the advancement and refinement of information systems, as well as the rapid and continuing development of communication technologies and cloud-based enterprise software (Fazlollahi and Franke, 2018; Peng and Gala, 2014; Sahin and Robinson Jr, 2005; Shou *et al.*, 2019). However, there is a continuing need for technologies that enhance supply chain connectivity, security, and transparency. The increasing pressure to demonstrate and maintain sustainable practices, emanating from both consumers and regulators, is putting pressure on organizations to engage with, and be responsible for their extended supply chains. Most existing information systems such as ERP systems can be tampered with or pose risks in terms of data security. Importantly, they present a fragmented landscape where digital records may be dispersed across globally dispersed organizations with limited access or visibility across the entire chain (Arora *et al.*, 2021; Speier *et al.*, 2011; Tian, 2017). Blockchain technology shows promise in helping to address these issues (Kshetri, 2018; Laforet and Bilek, 2021; Mann *et al.*, 2018; Papathanasiou *et al.*, 2020; Sodhi and Tang, 2021). Consequently, blockchain technology is being trialed and applied increasingly across many industry sectors for supply chain and related enterprise applications (Lacity, 2020; Wang et al., 2021; Vadgama & Tasca, 2021), and even the mere announcements of blockchain deployment may trigger positive stock market reactions (Klöckner *et al.*, 2022; Liu *et al.*, 2022).

Although blockchain emerged for cryptocurrencies in 2009 (and distributed ledger concepts pre-date that), the academic literature on blockchain applications in the supply chain started to emerge only in 2016 (Queiroz *et al.*, 2019). Among the earlier studies, Seebacher and Schüritz (2017) investigated the potential use of blockchain in service systems by facilitating information sharing and collaborative value creation in a trusted and transparent environment. Kshetri (2018) explored how blockchain can affect essential SCM objectives including speed, quality, cost, flexibility, dependability, risk reduction and sustainability and reflected on the different mechanisms by which blockchain could help in meeting these objectives. Janssen et al. (2020) developed a conceptual framework indicating the relationship between the different institutional, technical and market factors that affect blockchain adoption. Sternberg et al. (2021) adopted inter-organizational systems adoption theory to identify the motivations for and against blockchain adoption in a supply chain setting with the use of a single case study. Treiblmaier (2018) identified four theoretical lenses - transaction cost analysis (TCA), principal agent theory (PAT), resource-based view (RBV), and network theory (NT) – that may be relevant to investigate the structural and the managerial aspects of blockchain applications in SCM. His work is one of few studies to consider the range of theoretical perspectives relevant to blockchain in the supply chain.

Many researchers have anticipated the potential benefits of blockchain in the supply chain (Babich and Hilary, 2020; Kshetri, 2018; Li *et al.*, 2018; Queiroz and Wamba, 2019; Tseng *et al.*, 2018). In this regard, Maull et al. (2017) argued that blockchain has the potential to significantly improve supply chain visibility and enable traceability for complex supply networks. Viriyasitavat and Hoonsopon (2019) claimed that blockchain has the potential to disrupt business models and processes through its innovative characteristics that can enable the transparency and automation of business processes. This can help in overcoming SCM challenges resulting from increased globalization (Kshetri, 2018) that have made supply chains more complex and facing high levels of uncertainties (Manuj and Mentzer, 2008). Complex supply networks can suffer from a severe lack of transparency. The immutable distributed ledger provided by blockchain can enable all SC partners to access information to track shipments, deliveries, and progress, which may increase trust among them, eliminate the need for intermediaries, and thereby improve supply chain performance and reduce costs (Kshetri, 2018; Pournader *et al.*, 2020). Blockchain can also be used to secure the storage and transmission of digitally signed documents and can transform the verification and auditing processes to be more efficient and reduce lead time and costs (Chang *et al.*, 2019; Loklindt *et al.*, 2018). Kurpjuweit *et al.* (2021) combined the Delphi method with in-depth interviews to identify numerous potentials for, and barriers to blockchain adoption, but specifically in an additive manufacturing context.

From a market perspective, numerous recent studies underscore the relevance and the potential of blockchain for transforming supply chains through the inclusion of business intelligence, enabling end-to-end visibility and helping to resolve multi-party disputes (IBM, 2020). According to a study from MarketsAndMarkets, the post-COVID 19 worldwide blockchain supply chain market size is expected to grow from USD 253 million (2020) to USD 3,272 million (2026), with a Compound Annual Growth Rate (CAGR) of over 50% (MarketsAndMarkets, 2021). A report from Mordor Intelligence (2020) predicts that further development will be driven by North America with estimates of a CAGR of over 80% over the forecast period 2021 to 2026.

From an industry perspective, researchers have noted the potential for blockchain applications in the supply chain across different sectors, including Automotive (Fraga-Lamas and Fernández-Caramés, 2019; Kuhn *et al.*, 2021; Mann *et al.*, 2018), Aerospace (Aleshi *et al.*, 2019; Eryilmaz *et al.*, 2020; Ho *et al.*, 2021; Lopes *et al.*, 2021; Schyga *et al.*, 2019; Wang and Li, 2019), Food and Beverages (Bechtsis *et al.*, 2019; Malik *et al.*, 2018; Shingh *et al.*, 2020; Tian, 2017), Pharmaceutical (Singh *et al.*, 2020; Sylim *et al.*, 2018; Tseng *et al.*, 2018), Shipping and Logistics (Chang *et al.*, 2019; Loklindt *et al.*, 2018; Tsiulin *et al.*, 2020; Yang, 2019), and Textile and Apparel (Agrawal *et al.*, 2021; Bullón Pérez *et al.*, 2020). However, despite the growing academic interest in investigating blockchain applications across the supply chain, most published academic research consists of isolated studies that focus on a particular application. There is a dearth of research that applies a cross-industry lens to analyze how blockchain adoption and application in the supply chain are contingent on industry characteristics.

Numerous literature review papers have sought to identify the main motivations for blockchain adoption in the supply chain. Wang et al. (2019) reviewed the academic literature and identified five main motivations including (1) improving trust, (2) information security and reliability, (3) supply chain disconnections and complexity, (4) product safety and authenticity, and (5) public safety and anticorruption. Jardim et al. (2021), in their review, identified process automation, cost benefits, transparency, product traceability, data variability and having a single source of data as the main motivations for blockchain adoption in the supply chain. Similarly, Treiblmaier et al. (2022) revealed traceability, trust and transparency, supply chain integration, data security and privacy, and sustainability as the main motivations highlighted in their review of the academic literature.

However, the motivations and drivers identified in the aforementioned studies are mainly based on academic and practitioner literature (Hastig and Sodhi, 2020) or on a small number of quantitative studies where researchers have conducted surveys to understand blockchain adoption behavior (e.g., Queiroz and Wamba, 2019; Wong *et al.*, 2020). Specific evidence to support the motivations behind real blockchain applications has not been presented and a systematic compilation of contingency factors that ultimately determine the success of blockchain in the supply chain is missing from the extant literature. We address these research gaps in this study from a contingency perspective. Contingency theory has a long history in supply chain research to uncover organizations' ability to align their operational and strategic measures and performance with the challenges and changes of external environments (Sousa and Voss, 2008; Stonebraker and Afifi, 2004).

To date, however, very few studies have applied it to better understand those factors that impact blockchain adoption and deployment in the supply chain. A notable exception includes Xiong *et al.* (2021)who investigated the mitigating role of blockchain-enabled supply chains during the COVID-19 pandemic using a logistic regression model. Our study extends previous research considerably by applying a contingency perspective to examine a multitude of factors influencing the adoption and deployment of blockchain in the supply chain from both internal and external perspectives and the diverse application areas that have been reported.

3. Methodology, data collection, and analysis

The application of blockchain technology in supply chain management continues to develop with an increasing number of blockchain projects being announced (Vadgama and Tasca, 2021). To achieve our research aim, we focused on analyzing the announced blockchain projects across six major industries from January 2017 through to August 2021. To capture the diversity in blockchain related supply chain applications across different industrial contexts, the sectors examined were: automotive, aerospace, food and beverages, textile and apparel, pharmaceuticals, as well as logistics and global shipping. Several reasons underpinned the selection of these industries: (1) these sectors are among the top industries experimenting with blockchain (IBM Blockchain, 2021; Lim *et al.*, 2021), (2) they are among the largest sectors contributing to growth in global domestic product (GDP) (U.S. Bureau of Economic Analysis, 2022), and (3) supply chain configuration, product and business process characteristics vary substantially across these sectors, as do the regulatory regimes, and market requirements under which they operate. For example, the aerospace, automotive, food and pharmaceutical industries are highly regulated sectors producing safety critical products (Eryilmaz *et al.*, 2020), the textile and apparel industry is a highly fragmented and highly globalized sector (MacCarthy and Jayarathne, 2013; Pal and Yasar, 2020), and the shipping and logistics is a major sector that is responsible for managing material flows across complex and global supply chains and is subject to various regulations, business processes and product management requirements (Ahmed and Rios, 2022; Yang, 2019) . In targeting these sectors, we also investigated projects that encompass partners from other areas including the mining and consumers luxury goods industries (e.g., ConsenSys, 2019; Volvo Cars, 2019; Wolfson, 2019). We explain the research methods below with respect to data collection and data analysis.

3.1 Data collection

A wide variety of secondary data from media sources and the practice literature have been surveyed, reviewed, and analyzed to gain insights about the current state of blockchain applications across the targeted industry sectors. The use of secondary data sources reduces bias in the collected data and can expand and deepen the understanding of a research topic under investigation (Calantone and Vickery, 2010; Ellram and Tate, 2016; Rabinovich and Cheon, 2011). To begin the data collection process, we reviewed the business and enterprise blockchain news website Ledger Insights[1]. We focused our research on the supply chain news category and we reviewed the title of 587 articles from February 2018 (the appearance of the first relevant article on the Ledger Insights website) to August 2021. We then applied the following exclusion criteria:

- Repeated announcements about the same projects over time
- Announcements that were related primarily to financial aspects such as securing funds
- Announcements that were either government-led or Blockchain technology provider announcements about new developed solutions
- Announcements that were in other sectors not included in the study such as energy and construction.

The initial screening resulted in 218 blockchain announcements in the six sectors targeted. These were then further investigated extensively using other data sources to identify more information about the blockchain application and the organizations engaged in the projects and to ensure data triangulation and validity. These data sources include popular blockchain news providers such as Coin Insider[2], and Coindesk[3], industry specific data sources such as the Maritime Executive, World Coffee Portal, Wine & Spirits Magazine, and Fashion for Good, as well as accredited news providers such as Reuters and Forbes. Similarly, industry reports and publications of industry associations (e.g., Aerospace Industry Association, Innovative Medicine Initiatives), blockchain consortia (e.g., MOBI, TradeLens, SITA) and publications from leading IT and consulting companies (e.g., IBM, Deloitte, Cognizant) have been reviewed to provide insights about industry applications across the different sectors. The broad range of sources used helped us to avoid selection bias by triangulating the data from multiple sources and ensuring that sufficient information was available about the project. Furthermore, we applied the following screening steps to identify our final study sample:

- We considered only blockchain projects that they were industry-led initiatives, which comprises projects led by a focal firm or group of supply chain partners.
- We considered only cases that included sufficient information to identify the following: The motivations for initiating the blockchain project (Why?), the application area(s) for the blockchain project (Where?), and the contingency factors (i.e., industry characteristics) that were relevant in blockchain project selection and initiation (How?)

[1] https://www.ledgerinsights.com/about-us/
[2] https://www.coininsider.com/
[3] https://www.coindesk.com/

- Considering the availability of multiple announcements for the same project in multiple data sources, we relied where available on the project partners' press release or company website information to ensure the accuracy and credibility of the data provided by getting it directly from the source (Rabinovich and Cheon, 2011).

This exhaustive search and screening processes resulted in 50 blockchain use cases that qualified for further analysis. Table I shows the summary details of the use cases with a reference source and the type of each use case (please note that dates in Table 1 refer to the announcement date , some of which pre-date their appearance in Ledger Insights).

Table I: Cases identified for supply chain blockchain applications (2017 to 2021)

	Case Number[4]	Organization[5]	Blockchain application description	Reference	Reference Type
Automotive Industry	1	Hyundai	Automating manual processes to reduce lead time and cost and to facilitate supply chain finance	https://tinyurl.com/yuvtvnby	News Website
	2	Lamborghini	Tracking vehicle history and streamlining vehicle authentication processes	https://tinyurl.com/yc6w54aj	News Website
	3	BMW	Tracing products across the supply chain (front lights)	https://tinyurl.com/yckwdzp6	Press Release
	4	Ford Motors	Tracing products across the supply chain (cobalt)	https://tinyurl.com/2jf8ay44	Forbes News
	5	Volkswagen	Tracing products across the supply chain (cobalt)	https://tinyurl.com/5n6ec36b	Press Release
	6	Volvo	Tracing products across the supply chain (cobalt)	https://tinyurl.com/3vdh56je	Press Release
	7	Ford Motors	Tracing products across their entire life-cycle (lithium-ion batteries)	https://tinyurl.com/26w2rub7	Press Release
	8	Mercedes-Benz	Tracking CO_2 Emissions across the supply chain (cobalt)	https://tinyurl.com/yc6ds3dr	News Website
	9	Mercedes-Benz	Digitalizing and managing suppliers' contracts across the supply chain	https://tinyurl.com/dfeweu64	Company Website
	10	Hyundai Kia Motor	Securing customers' data when using the vehicle smart application	https://tinyurl.com/2p8txz66	Company Website
	11	Volkswagen	Collecting and protecting vehicle odometer data against fraud	https://tinyurl.com/2p85k8jy	News Website
	12	Hyundai	Collecting and protecting vehicle history record data against history counterfeit	https://tinyurl.com/3ntn5e4t	Company Website
	13	Jaguar Land Rover (JLR)	Collecting road conditions and weather data from vehicle and reward customers with cryptocurrencies for data sharing	https://tinyurl.com/mvy5hbn4	Company Website
	14	Daimler AG	Collecting data from vehicle and reward customers with cryptocurrencies to foster eco-friendly driving habits	https://tinyurl.com/bdh65u42	News Website
	15	Porsche	Enabling the traceability of plastics and tracking of CO_2 emissions	https://tinyurl.com/rnsykehn	Press Release
Aeros	16	Airbus and Rolls-Royce	Tracking aircraft parts across the supply chain and managing data	https://tinyurl.com/2eahst7d	Reuters News

[4] Case Number is used in brackets [] throughout the paper to refer a specific use case.
[5] Some organizations may be engaged in more than one blockchain project. These are reported as separate use cases.

	17	Rolls Royce	Managing aircraft assets to reduce engine overhaul time	https://tinyurl.com/42ywysad	News Website
	18	Block Aero	Digitalization of assets and asset data management	https://tinyurl.com/2p956mxk	Company Website
	19	Boeing	Developing technical solutions for urban aerial mobility	https://tinyurl.com/5fbj3jnk	Company Website
	20	SITA MRO Blockchain Alliance Consortium	Maintaining, repairing and overhauling (MRO) engine data management and tracing aircraft parts across the supply chain	https://tinyurl.com/bdekd2rr	Company Website
	21	Aerospace Industries Association (AIA)	Digitalizing the Department of Defense form 250 (DD250) process	https://tinyurl.com/49db9un2	Company Press Release
Logistics and Global Shipping	22	Maersk Group	Digitalization of shipping processes, trade documents and shipping data	https://www.tradelens.com/platform	Company Website
	23	Alibaba and China Merchants Ports	Digitalizing import and export transactions and integrating them into logistics value chain	https://tinyurl.com/2p947fej	News Website
	24	Cargo Smart	Improving shipment documentation management	https://tinyurl.com/2dh5hsjc	Company Website
	25	Port of Rotterdam	Managing and tracking shipments and improving port efficiency	https://tinyurl.com/5n88yrhx	News website
	26	Alibaba Logistics	Standardizing the bill of lading document	https://tinyurl.com/yx53h2ca	News Website
	27	Mediterranean Shipping Company (MSC)	Digitalizing the issuance and exchange of an electronic bill of lading	https://tinyurl.com/2p8bj5yn	Company Press Release
Food and Beverages Industry	28	Chateau Marguax	Tracing products across the supply chain (Wine)	https://tinyurl.com/45k82888	News Website
	29	Walmart	Tracing products across the supply chain (Pork and Mango)	https://www.hyperledger.org/learn/publications/walmart-case-study	Company Website
	30	Alibaba Food	Tracing products across the supply chain (Food)	https://tinyurl.com/y4x55ry2	News Website
	31	Carrefour	Tracing products across the supply chain	https://tinyurl.com/phuweyv2	Press Release
	32	JBS	Enabling traceability in the beef cattle production value chain	https://tinyurl.com/5wbtesu8	Press Release
	33	E-Live Stock Global	Proving the origin and tracking the medical records of cattle	https://tinyurl.com/4uw39cuf	Press Release

	34	Birra Peroni	Providing non-fungible tokens for each batch of beer for better supply chain visibility and efficiency	https://tinyurl.com/c6sxjjnz	Press Release
	35	HEMA	Enabling product traceability across the supply chain (Coffee).	https://tinyurl.com/3wv6fut8	News Website
Pharmaceutical industries	36	Modum	Monitoring and tracking products' ambient condition during transportation	https://tinyurl.com/mse8kcmr	Company Website
	37	Merck (MSD)	Tracing prescribed drugs downstream their supply chain and protect patients	https://tinyurl.com/rttbjdtx	Company Website
	38	Pharmaledger consortium	Ensuring drugs' authenticity, enabling secure development of an eLeaflet, and tracking drugs tracking	https://tinyurl.com/y53uvr37	Company Website
	39	Mediledger consortium	Tracing drugs across the supply chain	https://www.mediledger.com/solution-protocols	Company Website
	40	Moderna	Enabling the traceability of vaccine batches across the supply chain and maintaining digital health passes for individuals	https://tinyurl.com/2nda2v24	Press Release
	41	Tech Mahindra	Monitoring and tracking vaccine distribution and usage in the supply chain	https://tinyurl.com/4uujy6uk	Press Release
Textile and Clothing Industry	42	LVMH	Tracing products across the supply chain	https://tinyurl.com/2p8db3t7	Press Release
	43	Hugo Boss	Tracing products across the supply chain	https://tinyurl.com/2p88batb	News Website
	44	Arianee Consortium	Creating digital certification of valuable assets	https://www.arianee.org/about-arianee	Company Website
	45	Chargeurs Luxury Materials	Ensuring product quality, sustainability and traceability across the supply chain (wool)	https://tinyurl.com/mrx6s2bd	Company Website
	46	Martine Jarlgaard	Tracing products across the supply chain.	https://tinyurl.com/4trt9tse	Company Website
	47	C&A Foundation	Tracing products across the supply chain (organic cotton)	https://tinyurl.com/3zfh3n53	Company Website
	48	Lenzing Group	Tracing products across the supply chain (manmade cellulose fibers)	https://tinyurl.com/2p9ypt9c	Company Website
	49	U.S Cotton Trust	Tracking and verifying the movement of cotton fiber across the supply chain	https://tinyurl.com/y6eds526	Press Release
	50	UK Fashion and Textile Association (UKFT)	Enabling product traceability and improving transparency in the supply chain	https://www.ukft.org/supply-chain-platform/	Press Release

3.2 Data analysis

Data analysis was conducted in three stages:

(1) We initially used the software NVivo 12 from QSR International to conduct a detailed qualitative analysis of the identified reported cases (QSR International, 2021). NVivo enables rigorous content analysis to discover underlying themes and their reoccurrence patterns (Stock and Boyer, 2009). NVivo is also flexible as it enables the analysis of data in various formats including large textual datasets, videos, and pictures. It deploys the following concepts: *nodes* refer to the codes used by the researcher to assign meaning to specific pieces of text in a dataset; a *node tree* is a group of nodes falling under a certain category; *free nodes* are nodes that are not part of any tree (Mani *et al.*, 2018). We used NVivo for textual analysis to identify themes across the 50 use cases related to the three research questions. The coding process included the following coding rules: Rule (1): We coded all statements capturing the "motivations" behind blockchain use that could answer the first research question on why companies adopt blockchain in supply chain applications under the *motivations parent node* and the specific identified motivations as *child nodes* within it. Rule (2): We coded all statements capturing the "application areas" where blockchain was applied in the supply chain under the *application area parent node* and the different identified application areas within it. Finally, Rule (3): We coded all statements as "contingency factors" that could answer the question how various external and internal factors could influence the selection of blockchain application area in the supply chain. These contingency factors were classified into categories (i.e., *parent nodes),* related to product characteristics, supply chain configuration, industry standards and regulations, market and customer demand, and business and manufacturing processes.

Figure 1 shows a snapshot of a typical data source with examples of the coded text using NVivo. This shows the Volkswagen use case [5] in which the statement "Application of blockchain technology to trace minerals" is identified. This statement is coded to the *Traceability* node under the *Motivations* parent node (Rule 1) and to the *Product information* node under *Application Areas* parent node (Rule 2). Similarly, the statement "Focus on responsible sourcing of cobalt" is coded under the *Sustainability* node under Motivations (Rule 1), and the *Product Characteristics* node under *contingency factors* since the blockchain application was specific to a certain mineral due to its *social and environmental impact* (Rule 3). We followed this approach in conducting a thorough coding analysis of each of the identified 50 reports. The coding process led to the identification of sub-themes that provided answers and insights relevant to the research questions and helped analyze and categorize the reported use cases. The use of NVivo facilitated the identification and comparison of emergent themes within and across the sectors. It also laid the foundation for further frequency and contingency analysis that provided rich insights into blockchain applications in the different sectors. We stress that we were seeking to identify explicit evidence that a firm or consortium was seeking to achieve a specific goal in its blockchain application. For instance, an announcement might state a goal of enhancing transparency in supply chain operations.

Transparency may be sought for many reasons (e.g. quality, cost reduction, sustainability etc.). However, unless the announcement explicitly noted a specific goal for seeking transparency (e.g. sustainability), this would be recorded as transparency only.

All authors were involved in the development of the coding themes. The NVivo coding was conducted by the first author and all authors participated in the interpretation of coding results and in the development of the final framework.

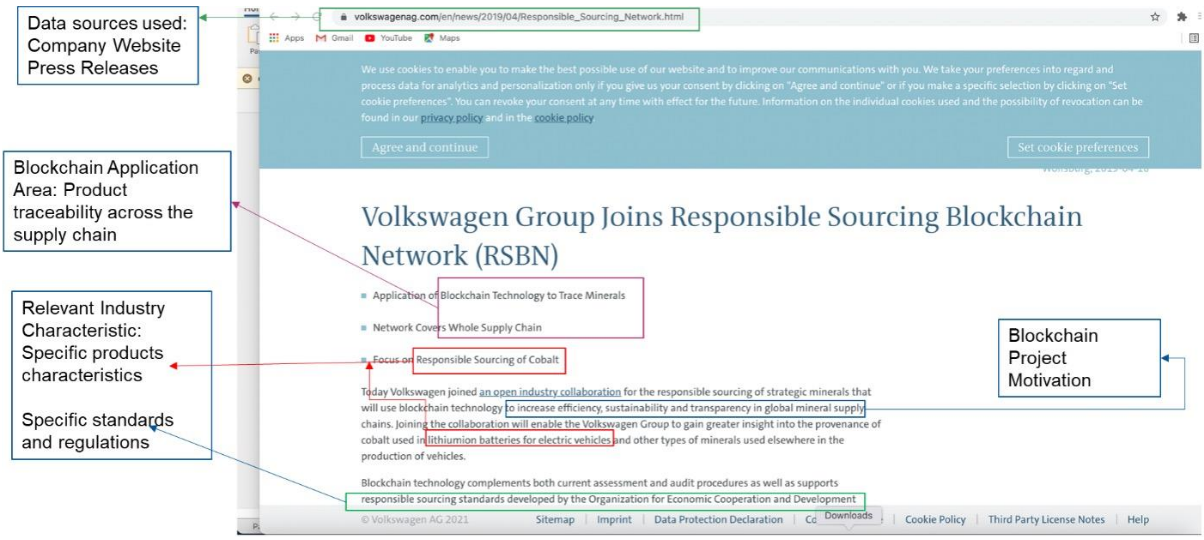

Figure 1: A snapshot of a typical data source

(2) After the coding process, we conducted frequency analysis using NVivo crosstab and word frequency queries to identify and compare across the different sectors, the most frequently cited motivations and application areas of blockchain and the main contingency variables influencing the application area.

(3) We conducted a correlation analysis based on the frequency analysis and calculated the phi correlation coefficient (φ) using the "psych" package in R project for statistical computing[6] to identify the potential associations between the main blockchain application areas and the industry motivations and contingency factors evident across the 50 reported use cases. The correlation analysis helps identify and inform the association patterns that occur more frequently within each use case. The correlation coefficient indicates the strength of the association between the two categories where a value more than 0.3 is non-trivial (Fleiss *et al.*, 2013; Sauer and Seuring, 2017). However, it must be noted that it indicates association only and does not show causality between the categories (Fleiss *et al.*, 2013; Gold *et al.*, 2010). This approach has been adopted by Qian *et al.* (2020) and de Lima *et al.* (2021) in conducting literature reviews. We present the results from the analysis in Section 4.

[6] https://www.r-project.org/

4. Results

4.1 Frequency Analysis Results

The frequency analysis provides descriptive insights about the reported use cases and helps analyze and identify the major themes in the data. Table II presents the 15 most frequent words in the data. The words "blockchain", "supply", "chain", "technology", and "industry" are the most mentioned words, supporting our choice of case selection criteria.

We also present the most frequently cited motivations, application areas, and contingency factors in Table III. The identified motivations include Traceability, Transparency, Process efficiency, Security, Customer service, Sustainability, Risk Management, Product authenticity, Quality, and Cost Reduction. Three specific blockchain application areas are identified in Table III relating to product, business processes and customer experience. Finally, five main contingency variables are highlighted relating to product characteristics, business process characteristics, supply network configuration characteristics, industry standards and regulations, and market and customer demand characteristics. We discuss each of the identified motivations, application areas and contingency factors in detail in Section 5.

Table II: Most frequent words in the reported use cases

Word	Length	Count	Weighted Percentage
blockchain	10	503	2.34%
supply	6	236	1.10%
chain	5	229	1.07%
technology	10	224	1.04%
industry	8	155	0.72%
data	4	144	0.67%
platform	8	105	0.49%
global	6	101	0.47%
traceability	12	97	0.45%
solution	8	90	0.42%
new	3	85	0.40%
transparency	12	84	0.39%
use	3	84	0.39%
based	5	83	0.39%
also	4	78	0.36%

Table III: Results of the qualitative analysis of blockchain reported used cases

	Motivations (Emerged Themes)	Examples of coded cases	Frequency of coding						
			Total	Automotive (15)	Aerospace (6)	Food and Beverages (8)	Textile and Clothing (9)	Shipping and Logistics (6)	Pharmaceutical (6)
Top Motivations	Traceability	Porsche [15]	36	7	4	8	9	2	6
	Transparency	U.S Cotton Trust [49]	33	7	4	6	7	5	4
	Process efficiency	Aerospace Industries Association [21]	24	6	5	3	2	6	2
	Security	Maersk [22]	20	5	3	2	1	6	3
	Customer service	Jaguar Land Rover [13]	17	7	-	4	3	1	2
	Sustainability	Ford Motors [7]	17	8	-	2	7	-	-
	Risk management	Tech Mahindra [41]	13	-	-	4	2	3	4
	Product authenticity	Arianee [44]	12	2	-	3	5	-	2
	Quality assurance	Walmart [29]	11	-	1	4	3	-	3
	Cost reduction	Mediterranean Shipping Company [27]	11	2	2	-	2	5	-
Top Application Areas	Product	Across the supply chain [35], after sale product tracking [2], product monitoring [36].	36	11	2	8	9	1	5
	Business process	To digitalize certain business processes [27], for asset data management [18].	31	9	5	1	5	6	5
	Customer	To secure customer data [10], to reward customers [14].	14	6	-	2	3	1	2
Contingency Factors	Product Characteristics		33	9	4	8	8	0	4
	High social and environmental impact	Cobalt [4,5]	15	7	0	2	6	0	0
	High Value Product	Wine [34]	13	5	3	3	2	0	0
	Safety Critical Product	Drugs [41]	10	1	1	4	0	0	4

	Business and Manufacturing Processes Characteristics		23	7	6	1	1	6	2
	High BP value adding	Certification process [44]	10	1	3	0	0	5	1
	Impact on performance	Documents management [22]	16	4	6	1	0	4	1
	Social and Environmental Impact	Beef production [32]	4	3	0	0	1	0	-
	Supply Network Configuration Characteristics		11	4	2	2	1	1	1
	Geographical Expansion	Global [3]	6	3	0	1	1	1	0
	Supply chain complexity	High complexity [20]	8	3	1	1	1	1	1
	Supply network size	Large size [20]	4	1	2	0	1	0	0
	Industry Standards and Regulations Characteristics		21	4	3	4	5	2	3
	Compliance to existing standards and regulations	OECD [6]	13	3	1	2	3	1	3
	Development of industry-wide standards	Shipping standards [22]	4	1	1	1	0	1	0
	Support for technological developments	DSCSA [37]	4	0	1	1	2	0	0
	Market and Customers Demands Characteristics		25	7	0	5	7	3	3
	Demand for authenticity	Luxury goods [44]	13	3	0	4	3	0	3
	Demand for performance	Shipping document [24]	3	1	0	0	0	2	0
	Demand for provenance	Walmart [29]	8	0	0	4	4	0	0
	Demand for security	Pharmaledger [38]	6	1	0	1	1	2	1
	Demand for sustainability	C&A Foundation [47]	10	3	0	1	5	1	0

4.2. Correlation Analysis Results

Considering the frequencies of each of the identified motivations, application areas, and contingency factors, we calculated the phi correlation coefficient to identify the potential association between the blockchain application, industry motivation and contingency factors, which is presented in Table IV. The contingency analysis shows many significant associations where $\varphi > 0.3$ (in bold). We combined the findings from the correlation and the frequency analysis and our interpretation of the qualitative evidence to propose a cross-sectoral framework that presents the main motivations application areas and contingency factors influencing blockchain adoption in the supply chain in Section 5.4.

Table IV: Correlation analysis results for emerged themes

Phi Coefficient (φ)		Blockchain application areas			Contingency factors influencing blockchain application area				
		Business process	**Product**	**Customer**	**Product Characteristics**	**Business Process Characteristics**	**Supply Network Configuration Characteristics**	**Industry Standards and Regulations**	**Market and Customers Demands**
Main Motivations Behind Blockchain Adoption	Traceability	-0.153	**0.504**	-0.206	**0.493**	-0.184	0.224	0.17	-0.089
	Transparency	0.047	0.019	-0.305	0.109	**0.239**	0.075	0.183	-0.042
	Process efficiency	**0.475**	-0.479	-0.129	-0.325	**0.72**	0.145	**0.318**	-0.32
	Security	**0.387**	-0.4	0.127	-0.534	**0.311**	0.039	-0.199	0
	Customer service	-0.047	-0.108	**0.681**	0.07	-0.408	-0.381	-0.354	**0.296**
	Sustainability	-0.221	**0.354**	-0.165	**0.248**	-0.239	0.128	0.159	0.042
	Risk Management	0.014	0.065	0.138	-0.056	-0.039	0.015	**0.419**	0.046
	Product authenticity	-0.042	**0.246**	**0.275**	**0.304**	-0.237	-0.095	-0.099	**0.375**
	Quality assurance	-0.065	0.089	0.099	**0.279**	-0.393	-0.282	0.1	**0.338**
	Cost reduction	**0.316**	-0.38	-0.009	-0.434	**0.479**	0.184	0.233	-0.048
Contingency factors influencing blockchain application area	Product Characteristics	-0.388	**0.505**	-0.023					
	Business Process Characteristics	**0.441**	-0.318	-0.307					
	Supply Network Configuration Characteristics	-0.08	**0.224**	-0.331					
	Industry Standards and Regulations	-0.109	**0.227**	-0.26					
	Market and Customers Demands	0.041	0.089	**0.267**					

5. Discussion

In the sub-sections below, we discuss the results of the frequency analysis and contingency analysis of the 50 reported use cases with respect to: (1) the principal motivations driving companies to seek blockchain solutions for supply chain applications, (2) the application areas and business processes highlighted, and (3) the contingency factors that influence the deployment of blockchain solutions in the supply chain.

5.1 Industry motivations for blockchain solutions in the supply chain

Table III summarizes the results of the analysis of industry motivations for seeking blockchain solutions in the supply chain. Enabling traceability (highlighted in 72% of the 50 cases) and improving transparency (66%) are the two principal motivations identified for blockchain projects across all industries. The results also show how the principal motivations vary across industries. For example, customer service and sustainability are the dominant motivations identified in the automotive industry, while cost reduction is a major motivation in the shipping and logistics industry. Improving process efficiency and security are frequently mentioned motivations in the aerospace, shipping, and pharmaceutical industries, while ensuring product quality and risk management are among the most frequently cited motivations in the food and beverages and pharmaceuticals industries. Ensuring sustainability and product authenticity are among the principal motivations in the textile and clothing industry.

Our results provide confirmatory evidence from practice for a number of the motivations identified from academic literature reviews conducted by Wang et al. (2019), Jardim et al. (2021), and Treiblmaier et al. (2022). However, the results also highlight the importance of additional important motivations including customer service, risk management, and product quality assurance. Improving process efficiency is a further important motivation from our analysis and is evident in all the industries. The study has also highlighted the relative frequency of each of these motivations across each of the six industries to provide further insights on motivations. We discuss below the ten most frequently cited motivations across all sectors:

Traceability: The use of blockchain for traceability (i.e., the ability to verify the history, location, or application of an item by means of recorded identification (Olsen and Borit, 2013)), has been a major motivation for many blockchain initiatives across many of the sectors as it facilitates the tracking of products across the supply chain and the identification of product provenance (36 cases). Examples include BWM [3] in automotive, the SITA consortium [20] in aerospace, the Port of Rotterdam [25] in global shipping and logistics, JBS [32] in food and beverages, Moderna [40] in pharmaceuticals, and C&A Foundation [47] in textile and apparel industries. It has also been widely recognized in the literature based studies (Agrawal *et al.*, 2021; Eryilmaz *et al.*, 2020; Hastig and Sodhi, 2020). Blockchain architecture supports supply chain traceability by enabling the identification and traceability of a product's transaction history across the supply chain using its immutable and distributed ledger (Ahmed and MacCarthy, 2021).

Transparency: Improving transparency (i.e., the availability of information to those who need it (Sodhi and Tang, 2019)) has been a major motivation for a significant majority of the reported cases (33 cases). Examples include Mercedes-Benz [8] in automotive, Block Aero [18] in aerospace, Alibaba and China Merchants Ports [23] in global shipping and logistics, HEMA [35] in food and beverages, Tech Mahindra [41] in pharmaceuticals, and US Cotton Trust Protocol [49] in the textile and apparel industries. Improving transparency is also one of the most acknowledged potential benefits of blockchain adoption in the academic literature (Aras and Kulkarni, 2017; Cole *et al.*, 2019; Jardim *et al.*, 2021; Kamble *et al.*, 2020; Kshetri, 2018; Maull *et al.*, 2017; Viriyasitavat and Hoonsopon, 2019). Blockchain can provide transparency through its distributed peer-to-peer network, allowing all the nodes in the network to have access to an exact copy of the database, thereby ensuring a single source of truth of supply chain operations and transactions (Treiblmaier, 2020). This can lead to improved supply chain transparency through improved information sharing and an organization's knowledge and visibility of its extended supply chains (Centobelli *et al.*, 2021; Kshetri, 2018).

Process efficiency: Improving process efficiency is highlighted in this study as the third most frequently cited motivation for blockchain applications (24 cases). Examples include Hyundai [1] in automotive, Aerospace Industries Association [21] in aerospace, MSC [27] in global shipping and logistics, Birra Peroni [34] in food and beverages, Mediledger [39] in pharmaceutical, and Hugo Boss [43] in textile and apparel industries. Many researchers have also highlighted blockchain's potential to improve the efficiency and performance of business processes by reducing lead-time, enabling better business planning, and supporting operations with improved processes (Casino et al., 2019; Queiroz et al., 2019). Each of these benefits is facilitated through blockchain's distributed ledger that enables real-time information sharing, eliminating the need for intermediaries, and facilitating the use of smart contracts to allow the digitalization and automation of business processes (Viriyasitavat and Hoonsopon, 2019). Blockchain also has the potential to combine with other technologies to improve business performance, including IoT, RFID, and cloud manufacturing (van Hoek, 2019; Kshetri, 2018).

Security: Enabling security underpins almost all blockchain applications, as immutability is the most powerful characteristic of blockchains. Security has been identified as a motivation in 20 cases across the different industries considered in this analysis. Examples include JBS [32], Moderna [40], Block Aero [18], and SITA [20]. Blockchain provides a technical solution that improves supply chain security through its immutable, transparent, and distributed network, ensuring the reliability of shared information in real-time (Treiblmaier, 2020; Wang, Han, *et al.*, 2019). Furthermore, with the deployment of smart contracts, blockchain can enforce desired policies and procedures in the system through automation and digitalization (Queiroz et al., 2019).

Customer service: Every business seeks to meet customer requirements, expectations, and demands. Although not recognized as an important motivation for blockchain adoption in the academic literature, the analysis of use cases highlights customer service as the fifth most frequently cited motivation for blockchain adoption. Blockchain has been applied in many projects to provide or improve specific customer services (17 cases). Examples include blockchain projects in the food industry to provide customers with information on the product journey [31], in the pharmaceutical industry to share drugs e-leaflets with patients in a secure way [38], and in the textile and apparel industry to provide assurance to customers about the authenticity of luxury products or the use of specific fibers [42, 44]. Additionally, blockchain technology is being used to enable customers to share their information in a secure way to help organizations to provide better services. This is particularly evident in the automotive industry for vehicle data management applications, e.g., Hyundai Kia Motor [10]. Importantly, the number of organizations that are pioneering the application of blockchain in their supply chain to improve customer service indicates a potential opportunity to gain a competitive advantage through the application of blockchain. Researchers have highlighted the increasing demand for guarantees on product provenance and authenticity (Wang, Han, *et al.*, 2019) as well as initiatives to make the customer order management process and operations more efficient (Martinez *et al.*, 2019).

Sustainability: The motive behind seeking a blockchain solution can be to promote sustainability practices (i.e., the ability to maintain processes over time (Brown *et al.*, 1987), typically implemented from a Triple Bottom Line (TBL) perspective including economic development, environmental performance, and social contributions (Treiblmaier, 2019)) through improved supply chain transparency and traceability. By adopting blockchain in processes such as sourcing, organizations can ensure the integrity of their processes and assert their commitment to sustainable practices. This is particularly evident in automotive (8 cases) and in the textiles and apparel (7 cases) industries. In the automotive sector, Ford [4], Volvo [6], and Volkswagen [5] have started to test the technology to ensure the ethical sourcing of Cobalt used in batteries. Sustainability is also a major challenge in the clothing industry (Cognizant, 2018). Hence, several fiber producers and brand retailers have started to experiment with the technology to promote their sustainability practices e.g., Chargeurs Luxury Materials [45] and Lenzing [48]. Sustainability has been recognized as a motivation for blockchain adoption in some academic literature studies across different industries (Cole *et al.*, 2019; Feng *et al.*, 2020; Park and Li, 2021).

Risk management: The use of blockchain for risk management has been recognized in most industries (13 cases) including managing and responding to disruptions in logistics and shipping, e.g., Cargo Smart [24], and managing product recall when critical non-conformance occurs in the food and beverages sector e.g., Walmart [29], and pharmaceutical industry e.g., Merck [37]. Blockchain's immutable distributed ledger enables accessibility to stored information by all relevant SC parties in real-time, which can potentially help in reducing the bullwhip effect, one of the most recognized SC risks (Jardim *et al.*, 2021; Pournader *et al.*, 2020; Wu and Katok, 2006). Blockchain can also reduce cybersecurity risks as it is extremely difficult to successfully hack a blockchain system and relatively easy to identify false participants (Li and Zhou, 2020).

Product authenticity: Our analysis provides evidence showing that ensuring product authenticity has been a major motivation for blockchain application (12 cases), particularly for high-end value products in the automotive industry, e.g., Lamborghini [2], and the textile and apparel e.g., LVMH [42]. It has also been significant in industries such as the agricultural and pharmaceutical sectors where product safety is crucial and fraudulent products can have a high detrimental effect, e.g., Birra Peroni [34] and Pharmaledger [38]. Blockchain can help in guaranteeing the authenticity of products by verifying their provenance and tracking their movements across the supply chain. This is valuable for all parties in the supply chain including customers who are increasingly demanding assurances for product provenance and authenticity (Danese *et al.*, 2021; Wang, Han, *et al.*, 2019). In addition, fighting counterfeit goods is a major challenge in several industries. The use of blockchain to prevent counterfeiting has been recognized in a small number of sectors, including food (Bechtsis *et al.*, 2019), automotive (IBM, 2018), and pharmaceutical (Tseng *et al.*, 2018) but this study underscores the importance of the broader authenticity concept for consumer assurance in some sectors.

Quality assurance: The analysis shows that ensuring quality is a major motivation in the food and beverages [4 cases], pharmaceutical [3 cases], and textile and apparel [3 cases] industries. Ensuring product quality is a significant motivation for blockchain applications especially when non-conformance can have significant human, social, environmental and/or economic implications. As with risk management, this is particularly important in the pharmaceuticals and food and beverages industries where the use of inferior products can affect the health and safety of consumers. Blockchain has been applied with Internet of Things (IoTs) to monitor the ambient conditions of drugs during transportation to ensure the drugs quality e.g., Modum [36]. The use of blockchain to ensure the quality and provenance of beverages like wine has been one of the earliest noted application areas, e.g., Chateau Marguax [28]. For textiles and apparel, it has been a motivation for fiber producers who are keen to ensure the quality of their fibers (e.g., being organic), e.g., Chargeurs wool producer [45], and brand retailer, e.g., C&A Foundation [47].

Cost reduction: Although there is still no clear evidence about the level of cost savings attainable from blockchain adoption, there are many debates about the potential areas where savings may be possible. Our results show that several projects have addressed opportunities for cost reduction through blockchain (11 cases), e.g., Hyundai [1], and Cargo Smart [24], where blockchain is applied to automate manual processes and reduce paperwork. Some researchers have also anticipated the potential financial gains from blockchain adoption by eliminating intermediaries (Cole *et al.*, 2019; Kamble *et al.*, 2020; Saberi *et al.*, 2019), facilitating SC finance (Choi, 2020; Pournader *et al.*, 2020; Tsiulin *et al.*, 2020), and enabling automation and digitalization (Queiroz *et al.*, 2019).

5.2 Blockchain application areas in the supply chain

Beyond the high-level motivations that drive the search for blockchain solutions in the supply chain, the academic literature does not provide evidence on specific blockchain application areas or on the types of information being captured. We used the analysis to gain further insights into the types and specific nature of blockchain applications in practice. The results from the analysis of cases are summarized in Table III. Three generic application areas are evident. Importantly, we highlight specific sub-categories where blockchain technology is being applied in the supply chain. We describe these below.

5.2.1. Blockchain application for effective product tracking and traceability

A high proportion of use cases (around 72%) report the use of blockchain for traceability. The application area in most of these cases is product related and involves the collection and tracking of product information across the supply chain. This includes the majority of cases in the automotive, textile and apparel, and food and beverage industries. Two different perspectives were evident:

- *Product tracking and traceability across the supply chain*: The majority of applications apply blockchain to capture, track, and trace specific information about a product across its value adding stages in the supply chain. Importantly, three distinct types of information are tracked: First is *product provenance and sourcing information*, as, for example, in the automotive industry to ensure the ethical sourcing of products, e.g., Ford Motors [4], and in the textile industry to ensure the sustainability of fibers used in garments and textile products, e.g., Lenzing [48]. Second is *product-related environmental impact information*, including CO_2 emissions, e.g., Mercedes-Benz [8]. Third is information related to *product transportation and storage conditions* to ensure product quality and safety, as is the case when the ambient conditions of drugs are monitored during transportation e.g., Modum [36].
- *After sales product tracking*: This area of application was evident mostly in the automotive industry for the tracking and traceability of vehicle data and its subsequent use in mobility and vehicle servicing applications e.g., Lamborghini [2].

5.2.2. Blockchain applications to enable, support, or improve specific business processes

61% of the report use cases (31 cases) deploy blockchain to improve specific business processes. These processes include internal business processes or external supply chain processes. Two important categories are evident from the analysis:

- *Automation of business processes*: For example, the automation of manual supply chain finance processes, e.g., Hyundai [1] and the automation of quality checks with the use of sensors and smart contracts, e.g., Modum [36].
- *Digitalization and optimization of business processes*: For example, activities such as the digitalization of shipment document handling processes, e.g., Cargo Smart [24], engine data

management in aerospace industry e.g., Block Aero [18] and digitalization and management of supplier contracts e.g., Mercedes-Benz [9].

5.2.3. Blockchain application for an enhanced customer experience

Improving the customer experience is a desired goal for blockchain applications in several industries. The analysis identified 14 reported blockchain projects in this category. Examples include customer reward schemes in the automotive industry, e.g., Daimler AG [14]; the provision of information to customers about a product's journey across the supply chain to guarantee the authenticity and provenance of a product e.g., LVMH [42] in textile and apparel industries, and Carrefour [31] in the food and beverages industries; and the provision of e-leaflets for customers to access specific drug-related information and guarantee drug authenticity e.g., Pharmaledger [38].

5.3 Contingency factors influencing blockchain supply chain applications

We analyzed and clustered the contingency factors in each reported blockchain project to identify five principal characteristics that influence blockchain applications in the supply chain emerging from the analysis (see Table III).

5.3.1. Product characteristics

Product characteristics influence the selection of blockchain application areas. High value and innovative products potentially justify the investment and effort required to adopt an extended blockchain-enabled supply chain solution (e.g., material sourcing concerns in automotive batteries and high-end luxury products). Products that are high risk (e.g., food products), safety critical (e.g., aircraft parts, drugs), and/or with high social and environmental impact (e.g., textile products, mineral raw materials) are seizing the potential for blockchain solutions as organizations seek to provide assurance on the authenticity, quality, traceability and/or sustainability of their products. Examples include: Arianee [44] and LVMH [42], where blockchain is applied for high-end products; the SITA MRO Blockchain Alliance consortium [20] that aims to apply blockchain for the traceability and verification of aircraft parts; and Walmart [29], Merck [37] and Volkswagen [5] in the food, pharmaceutical, and automotive industries, respectively, where blockchain is applied to tackle the social and environmental impacts of the selected products.

5.3.2. Business and manufacturing process characteristics

Business and manufacturing process characteristics in an industry are important factors that influence decisions to exploit blockchain capabilities for specific application areas. The inherent capabilities of blockchain to provide a secure medium for information sharing with data immutability, and enable digitalization and automation, have made the technology attractive for improving those business processes with high security and performance requirements (Ahmed and Rios, 2022). Examples include shipping document management in the shipping industry [25] and asset data management in the aerospace sector [17,18]. For reliable blockchain applications in manufacturing industries, it is critically important to consider the characteristics of the manufacturing processes and how the product is transformed across each process to address traceability (i.e., bill of materials), sustainability (i.e., sustainability impact of the manufacturing processes including CO_2, and waste management) and regulatory requirements (i.e., standards and regulations for manufacturing including testing and verification processes). For example, Mercedes-Benz have applied blockchain to track the CO_2 emissions across its Cobalt supply chain [8], and to digitalize and manage supplier contracts to ensure compliance across the supply chain [9].

5.3.3. Supply network configuration characteristics

The size, complexity and geographical dispersion of the supply network are important aspects that can influence both engagement in blockchain solutions and the target application area. These factors are addressed in multiple blockchain use cases including BMW [3] and SITA MRO Blockchain Alliance [20]. The configuration of the supply network influences decisions regarding the extent of the blockchain application in the supply chain. Some organizations are choosing initially to experiment with blockchain on a smaller or local supply network prior to its implementation at scale, e.g., Martine Jarlgaard [46], and C&A Foundation [47].

5.3.4. Industry standards and regulations

Standards and regulations operating in a sector may support or inhibit blockchain adoption and vary across the different industries (Hughes, 2020; Wang et al., 2016). Regulations to provide proof of product provenance are increasingly prevalent in many sectors. For instance, the food industry has stringent regulations regarding food safety and quality. Organizations in this industry seek blockchain solutions to improve product traceability and product recall processes, e.g., [29, 31]. Other examples include the Merck [37] project with the USA FDA, investigating the use of blockchain for drug traceability to comply with the Drug Supply Chain Security Act (DSCSA) regulations that requires assurance on drug product provenance. Mandated industries like aerospace have stringent regulations regarding their manufacturing processes that encourage the application of blockchain to streamline product verification and maintenance processes, e.g., Block Aero [18].

The pressure exerted by standards organizations and non-government organizations (NGOs) also affects blockchain adoption in the supply chain. Standards organizations and NGOs play an important role in some industries. Their involvement and support are crucial in developing industry-wide blockchain solutions and standards. This is clear in the textile and apparel industry where industry standards are monitored by NGOs. Organizations including Textile Exchange, and Fashion for Good are engaged in blockchain projects in textile and apparel supply chains (Fashion for Good, 2019).

5.3.5. Market and customer demands characteristics

Customer requirements can be a powerful motivation for organizations' investments. The analysis identifies a wide spectrum of customer requirements and desires that may be tackled with blockchain solutions. Customer and market demands have been considered in several blockchain projects across the different industries including demand for performance, e.g., Lamborghini [2], demand for security, e.g., ALIBABA and China Merchants Ports [23], demand for authenticity, e.g., Arianee [44], demand for provenance, e.g., Carrefour [31], and demand for sustainability, e.g., C&A Foundation [47].

5.4. Contingency Framework

The correlation analysis has revealed important associations between the motivations, application areas and contingency factors where the correlation coefficient exceeded 0.3 (see Table IV). Although it does not indicate causality, it shows how frequently the associated variables are evident in each case. For example, there is a strong association between the application of blockchain in a business process, the blockchain motivations to improve process efficiency and security and reduce costs, and the contingency factors related to the business processes characteristics. Figure 2 shows the contingency factors evident from the analysis. We consider that the contingency factors may have both direct effects (shown as direct arrows) and/or indirect effects (not shown in the framework to avoid clutter) on blockchain application areas in the supply chain, which can be investigated in future studies. Such types of associations have also been considered in studies in other management domains (e.g., Grötsch *et al.*, 2013; Williams *et al.*, 2017).

In synthesizing the results from the correlation and frequency analysis and their implications, we have developed the conceptual framework presented in Figure 2. The left-hand side of the framework shows the ten most common industry motivations driving organizations to consider blockchain-enabled applications in the supply chain. Each of the identified motivations may be interpreted as a challenge that needs to be addressed in a specific industry context (e.g., tackling lack of transparency, limited current traceability, known inefficiencies and/or high costs, etc.). These motivations may be influenced by both the internal characteristics of a specific industry's supply chain (i.e., product characteristics and business processes), and the external environment (i.e., industry standards and regulations, government standards and regulations, sustainability requirements, market conditions, prevalent risks, etc.). Both the industry motivations and inherent sectoral characteristics can influence the specific blockchain application areas in the supply chain. We identified three main application areas indicating where blockchain has been applied in the supply chain, including: (1) blockchain application for recording product information across the supply chain and/or after sales, (2) blockchain application for customer experiences, including customer service processes, reward programs and/or provision of product/process information, and (3) blockchain application to digitalize, automate and/or optimize business and supply chain processes. The right hand-side of the framework shows five clustered contingency factors and specific sub-characteristics considered in blockchain applications in the supply chain, which were identified from the analysis of the reported use cases. These characteristics influence the specific supply chain challenges addressed and the types of application area tackled in the different industries. For example, product characteristics (i.e., contingency factors) such as value, safety or social/environmental impact influence which information needs to be recorded across the supply chain (i.e., application area).

The framework shows associations between specific industry motivations, application areas, and related contingency factors. Three broad associations are summarized in the discussion below.

- **First broad association:** Blockchain can be applied to enable a product's traceability and ensure its sustainability by capturing relevant information across the supply chain. This is particularly important for products of high value, high social and environmental impact, or for safety critical products. It is also influenced by the size, complexity, and geographical spread of the product's supply network configuration and the existing or emerging industry standards and regulations.
- **Second broad association:** Blockchain can be applied to customer-related processes to improve customer experience. This may include providing quality assurance, ensuring product authenticity or seeking to improve or deliver specific customer services or information. It is also strongly influenced by the market and customer demand characteristics, e.g. whether it is a demand for authenticity, security, performance, sustainability and/or proof of provenance.
- **Third broad association:** Blockchain can be applied for internal business processes or external supply chain processes for different reasons, including improving transparency, efficiency, and security of these processes, managing risks, and/or reducing costs. Process-related blockchain applications are influenced by the business process characteristics including the significance of the value adding stage, the impact on performance, and/or social and environmental impact. It may also be subject to, or affected by existing or developing industry standards and regulations.

We stress that these associations from the framework are not exhaustive nor are they necessarily exclusive with regard to the associations between the identified motivations, application areas, and contingency factors. Blockchain application areas can also be inter-related. For example, customer-related applications may benefit from, or even require, blockchain implementation in specific product-related or business processes application areas to provide end customers with product information or with improved customer service.

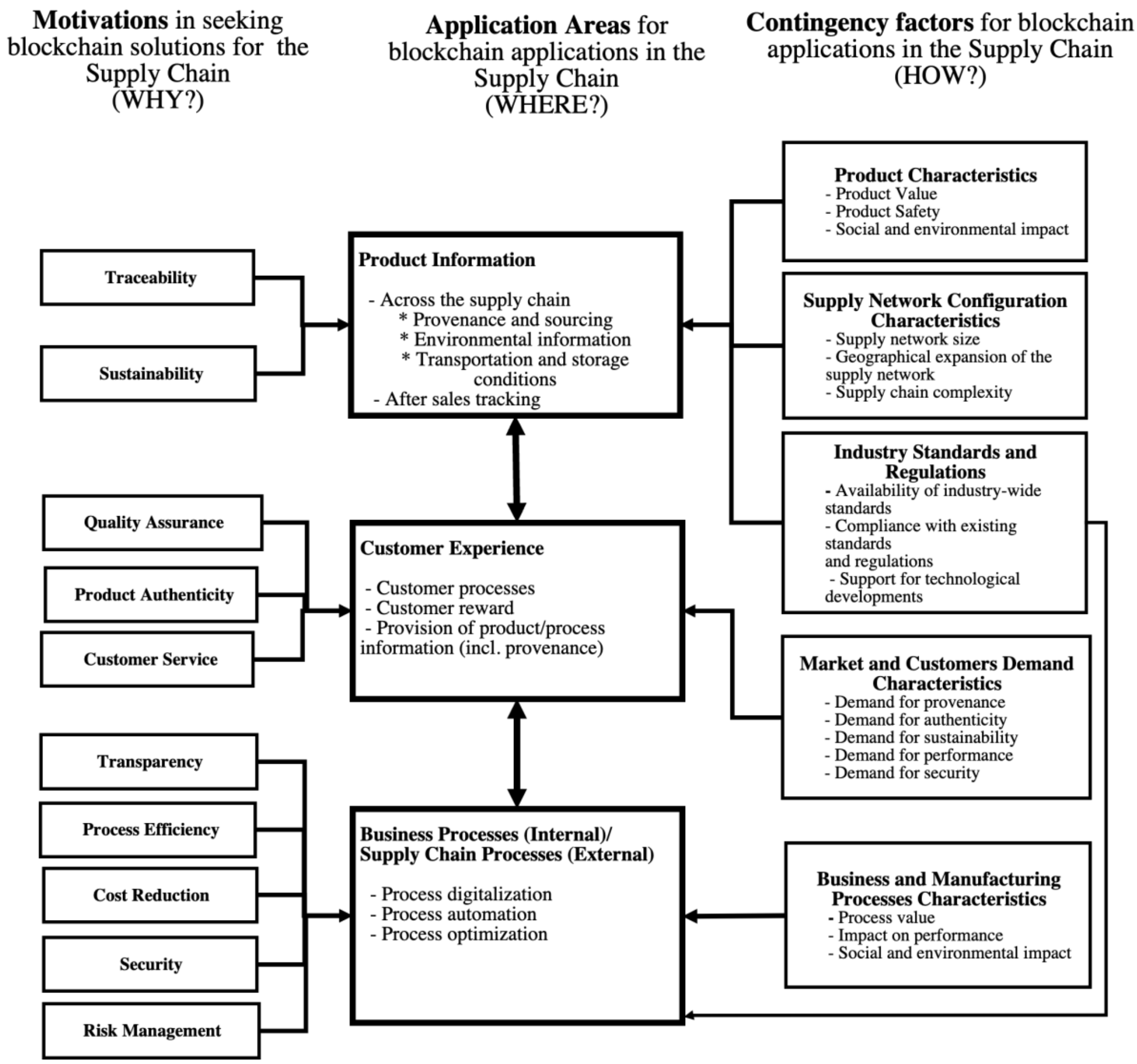

Figure 2: The main motivations and contingency factors influencing blockchain application areas in the supply chain

Table V summarizes the empirical findings, highlighting relevant contingency factors for each industry, the main blockchain application areas, ongoing projects, and notes relevant academic literature. The automotive industry is characterized by a highly dynamic environment that faces many pressures from technological change, complex processes, increasingly demanding consumers, and the need for regulatory compliance. In this regard, blockchain can not only help to track and trace product but can also help to support business processes related to data management and improve the emerging new mobility services offered to automotive customers. The aerospace industry faces the challenge of increasingly complex supply networks, which may impede or inhibit compliance with the strict regulations and high-quality standards that characterize this sector. Blockchain applications are mainly being used for product traceability and the improvement of business processes. The shipping industry is one of the first sectors to fully acknowledge the potential of blockchain. It benefits from the immutable data property of blockchain as well as shared data access in facilitating the complicated and involved processes that accompany the shipment of goods that cross borders (many of which are still paper based). Compliance with customs regulations is one of the major benefits that blockchain-based applications have to offer in this sector. The demands of the food and beverage industry in many cases mimic those of the shipping industry, but problems are aggravated due to the perishability factor that demands rapid flow of both goods and information. Additionally, blockchain in this sector can be used to improve the customer experience by integrating consumers in the supply chain and enabling them to access potentially important information on product sourcing and provenance. Companies in the pharmaceuticals industry operate in a highly regulated environment and frequently face the issue of counterfeit products, which may be ineffective, harmful or even worse, lethal. Hence, blockchain-enabled product traceability that is particularly appealing to this industry and it may also support it in regulatory compliance. Finally, the textiles and apparel industry benefits from blockchain applications by helping it to trace products and to improve the customer experience. This is especially important for a sector that faces constant pressure from the public pertaining to production standards and the sourcing of raw material. In this regard, blockchain can help to create trust and to provide evidence that regulatory and sustainability standards have been met.

Table VI: Contingency factors influencing blockchain projects in six industries

Industry	Main Application Areas	Main Contingency Factors	Examples of Reported Blockchain Projects	Relevant Academic Literature
1. Automotive	Mobility services (Customer Experience)	• Highly innovative • Technology focused • Improved customer experience	JLR [13] Daimler AG [14]	Fraga-Lamas and Fernández-Caramés, (2019); Singh and Kim, (2018)
	Automotive battery (Product Traceability)	• Complex supply network • High social and environmental concerns related to raw materials and manufacturing processes • OECD Guidelines for ethical sourcing of minerals	Ford Motors [4] Volkswagen [5] Volvo [6]	Chohan, (2021); Mann et al. (2018) Fraga-Lamas and Fernández-Caramés, (2019); Kuhn et al. (2021)
	Vehicle data management (Business Process)	• Subject to tampering and fraud • Manual and scattered information • Lengthy verification process	Hyundai [1] Lamborghini [2] Mercedes-Benz [9]	Abbade *et al.* (2020); Chen *et al.* (2020)
2. Aerospace	Aircraft parts tracking (Product Traceability)	• Complex supply networks • High quality standards requirements • Regulated manufacturing processes • Required product certification by regulations (back to birth) • Stringent requirement for engine maintenance, repair and overhaul (MRO) processes	SITA MRO Blockchain Alliance [20] Block Aero [18]	Eryilmaz et al. (2020) ; Ho et al. (2021); Wang and Li, (2019)

	Aircraft engine maintenance record (Business Process)	• High security requirements for MRO transactions records.		Aleshi et al., (2019); Schyga et al. (2019)
3. Logistics and Shipping Industry	Shipping data management (Business Process)	• Manual Paper based processes • Lengthy and costly processes (Letter of credit processes) • Compliance to customs regulations	Cargo Smart [24] Port of Rotterdam [25] Maersk Group [22]	Chang et al. (2019); Loklindt et al., (2018); Tsiulin et al., (2020); Yang, (2019)
4. Food and Beverages	Products traceability across the supply chain ((Product recall (Business Process) Product Story (Customer Experience)	• Different levels of complexity • High sustainability concerns related to product sourcing and use of chemicals • Stringent regulations regarding food safety	Carrefour [31] Walmart [29]	Bechtsis et al. (2019); Malik et al. (2018); Shingh et al. (2020); Tian (2017)
5. Pharmaceutical industry	Drugs traceability and monitoring across the drug supply chain (Product traceability)	• Complex supply network • Highly regulated industry • High quality standards requirements • Stringent regulations regarding drug safety and traceability (DSCSA)	Pharmaledger [38] Merck [37] Modum [36]	Singh et al. (2020); Sylim et al. (2018); Tseng et al. (2018)
6. Textiles and Apparel	Products traceability across the supply chain (Product Traceability/Customer Experience)	• Complex supply network • High social, ethical and environmental concerns related to raw materials and production processes • Pressure from sustainability organizations (i.e. Textile Exchange, Canopy Planet)	Martine Jarlgaard [46] Lenzing [48]	(Agrawal *et al.*, 2021; Bullón Pérez *et al.*, 2020)

6. Research implications and future research

We scrutinize our findings from a theoretical perspective to provide guidance for future academic research and discuss the implications of our framework from an industry perspective.

6.1 Theoretical implications

The multidisciplinary nature of blockchain applications and their impact (Casino *et al.*, 2019; Centobelli *et al.*, 2021; Queiroz *et al.*, 2021; Saberi *et al.*, 2019) has led to calls for the consideration of numerous theoretical perspectives to develop a better understanding of the technology, its capabilities, and its implications, particularly given its early stage of industrial deployment (Ahmed and MacCarthy, 2022b). Some previous research has noted that existing theories could be applied and modified to describe, explore, and predict the changes that may accompany the introduction of blockchain (Sternberg *et al.*, 2021; Treiblmaier, 2018). Kummer et al. (2020) identified six theories including information theory, agency theory, transaction cost analysis, institutional theory, resource-based view theory, and network theory as the main organizational theories that could be adopted in blockchain research in the supply chain. Saberi et al. (2019) argued for the use of Grounded Theory when studying blockchain technical features, adoption and applications to provide opportunities to develop new theoretical perspectives that advance the emerging multidisciplinary body of knowledge. Other studies have suggested information systems theories including the technology acceptance model (TAM), the unified theory of acceptance and use of technology (UTAUT), Task-technology fit and information system success models to investigate blockchain adoption behavior in the supply chain (Fosso Wamba *et al.*, 2020; Kamble *et al.*, 2019; Queiroz *et al.*, 2021; Queiroz and Wamba, 2019; Wong *et al.*, 2020).

However, the growing yet limited understanding, adoption and scalability of blockchain in practice hinders the effective use of theory-testing research that requires more real evidence to investigate the impact of blockchain adoption that should emerge in future years as the blockchain technology landscape matures. Therefore, to fully capture and explain the disruptive potential of blockchain, we have argued here for the application of contingency theory as a broad framework that helps identify factors that can influence the applicability of blockchain projects in important business and industry sectors (Sousa and Voss, 2008; Stonebraker and Afifi, 2004). In this study, we have analyzed current applications of blockchain in the supply chain, and how they are contingent on motivations for seeking blockchain solutions and the industry characteristics influencing them. In this respect, our findings do not displace the use of other theoretical approaches, but rather, as more evidence emerges of blockchain adoption in practice, call for further theoretical refinements that incorporate the idiosyncrasies of blockchain deployment depending on the respective sector of the industry. We especially postulate that future research needs to jointly consider the motivations for seeking a blockchain solution in the supply chain (answering the WHY? question), identify and analyze in detail further important application areas in which blockchain can provide actual business value (the WHERE? question) and further refine the contingency factors that influence blockchain deployment and application (the HOW? question). This study lays the foundation for further theory development and theory testing research as the field matures and more evidence comes to light (Ahmed and MacCarthy, 2022).

6.2 Practical implications

The granularity of our findings and the differentiation into various industry sectors yield important implications for practitioners. We have analyzed the information provided by 50 reported blockchain use cases across a number of critically important industries. A qualitative analysis yielded three main application areas for blockchain deployment in supply chains relating to (1) product information, (2) customer experience and (3) operational processes (both business and supply chain-related). Additionally, we identified the motivations that drive the search for blockchain solutions and classified the contingency factors that can play an important role in whether a blockchain deployment will ultimately be successful.

In contrast to previous studies, our findings present a detailed list of considerations that may play an important role in a blockchain adoption decision. The findings can be used by managers as a blueprint for internal discussions on blockchain's relevance and applicability and, critically, foster communication with external stakeholders that are essential participants in a blockchain supply chain initiative. The motivations allow for an enhanced understanding of why different collaborators prefer blockchain solutions while the application areas provide a better understanding of where the actual business value will arise. A careful scrutiny of the contingency factors provides managers with awareness of the external factors that can play an important role in blockchain deployment. Blockchain deployment requires active participation from multiple stakeholders across a supply chain. Our comprehensive framework can facilitate discussions among all stakeholder to ensure that critical issues relating to product, process and supply chain configuration are considered.

6.3 Limitations and future research directions

The analysis of reported use cases, in combination with the framework and identified associations, contribute significant new evidence to the emerging body of literature on blockchain applications in the supply chain. Given that this is a rapidly developing field, the research findings can be extended through further case study research and through longitudinal studies to identify additional supply chain and sectoral characteristics that affect the adoption and the application of the technology.

The findings are necessarily limited by the sample selected which, albeit large and comprehensive, can be extended as the field develops by including more blockchain use cases from the targeted sectors as well as other industry sectors that we have not considered. The different potential associations identified in the framework can lay the foundation for future research directions. Numerous research propositions can be derived from the framework (considering the different combinations of motivations, application areas, and contingency factors), that can be tested in future research. Examples of potential propositions from this study that provide a basis for valuable future research include:

> Proposition 1: Firms with high value products have a higher tendency to apply blockchain in their supply chain to enable the tracking and tracing of product information. (Alternatively, 'high value' may be replaced by 'safety critical' or 'high social and environmental impact')
>
> Proposition 2: As the size, complexity and geographical spread of supply chains expand, the application of blockchain will help ensure product traceability and sustainability.
>
> Proposition 3: Firms apply blockchain to securely digitalize business and supply chain processes that have a high impact on operational performance. (Alternatively: 'impact on operational performance' may be replaced by 'process value' or 'social and environmental impact').
>
> Proposition 4: The availability of industry-wide standards positively impacts firms' decisions to apply blockchain for product traceability and/or business processes digitalization in their supply chain. (Alternatively, 'industry-wide standards' may be replaced by 'regulatory compliance requirements' or 'support for technological development')
>
> Proposition 5: Firms can apply blockchain in their supply chain to enhance customer experience by providing quality assurance, ensuring product authenticity, and delivering customer services in response to specific customer demands.

The gathering of primary data, which can be done via in-depth interviews, direct observations or cross-sectional survey studies, will provide additional insights regarding the relative importance of the identified contingency factors for different industries and the strength of the relationships identified here. Furthermore, future research can investigate (1) how the different product characteristics, supply network configuration characteristics and/or industry standards and regulations influence blockchain application areas and the type of collected blockchain data to enable products' traceability and ensuring their sustainability across the different sectors, (2) how the different business and manufacturing processes can benefit from blockchain application and the role of industry standards and regulations in deriving blockchain-enabled digital transformation to existing processes across the different sectors, (3) the impact of customers' demand and market characteristics on the motivations of blockchain adoption and application areas across the different sectors, and (4) how organizations can materialize and operationalize the benefits of blockchain, as well as the implications of different industries' idiosyncrasies on the need and benefits of blockchain, blockchain design and implications on performance.

We also argue for a combination of theoretical perspectives that can contribute to the refinement and further advancement of theory-based research on why, where, and how blockchain is being applied in different industries for supply chain applications. In this regard, future research will especially benefit from a strong theoretical foundation, which allows for incremental and rigorous results that are integrated with and tested against findings from industry to ensure the practical applicability of research. Specifically, the framework outlines numerous research propositions that warrant further investigation. This study provides a comprehensive foundation that summarizes industry findings in a framework that can be used to refine, test and enhance existing theory.

7. Conclusions and further research

The study has provided valuable insights on the motivations driving current blockchain adoption in the supply chain, the specific types of application being developed, and the contingency factors that influence the desire for seeking particular blockchain solutions. The analysis has highlighted and detailed three main application areas for blockchain technology in the supply chain - enabling product tracking and traceability, supporting or improving specific business processes, and enhancing customer experience. The contingency framework encompasses the main motivations behind seeking blockchain solutions and the main contingency factors that determine the respective application areas - product characteristics, business processes characteristics, supply network configuration, industry standards and regulations, and market and customer demand. The research findings has strong implications for research and practice and lay the foundation for future empirical and theory-driven research.

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