

The use of distributed ledger based smart contracts in supply chains - A socio-technical view

Dissertation

zur Erlangung des akademischen Grades

doctor rerum politicarum (Dr. rer. pol.)

der Wirtschafts- und Sozialwissenschaftlichen Fakultät

der Universität Rostock

vorgelegt von

Wieland Müller

aus Würzburg

Rostock, 2025

Gutachter:

Prof. Dr. Michael Leyer, Universität Marburg, Fachbereich Wirtschaftswissenschaften

Prof. Dr. Christian Brock, Universität Rostock, Institut für Betriebswirtschaftslehre

Einreichung: 26.09.2024

Verteidigung: 12.05.2025

Table of Content

List of Figures	VI
List of Tables	VII
List of Abbreviations	VIII
1 Synopsis	1
1.1 Introduction	1
1.2 Research Background.....	3
1.2.1 Positioning in supply chain management research	3
1.2.2 Positioning in information systems research	4
1.2.3 Distributed ledger and smart contract technology	4
1.2.4 Smart contracts in supply chains	5
1.3 Research Design	6
1.3.1 Research Philosophy: Pragmatism	6
1.3.2 Research Paradigm: Behavioural science	8
1.3.3 Research Framework: Socio-technical systems theory	9
1.3.4 Research Process	10
1.3.5 Research design and methods	12
1.4 Research Results.....	16
1.4.1 Understanding the role of distributed ledger based smart contracts in the supply chain: A literature review on theoretical implications and research agenda	16
1.4.2 Employees' intention to use smart contracts in supply chains: The important role of performance expectancy	17
1.4.3 Smart contracts as enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis	18
1.4.4 Metaverse, ubiquitous? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse	18
1.5 Research Discussion.....	19
1.6 Research implications.....	21
1.6.1 Theoretical implications	21
1.6.2 Practical implications.....	22
1.7 Limitations.....	23
1.8 Future research	24
1.9 References	24
2 Understanding the role of distributed ledger based smart contracts in the supply chain: A literature review on theoretical implications and research agenda.....	32
2.1 Introduction	33
2.2 Fundamentals.....	34
2.2.1 Distributed ledger and smart contract technology	34
2.2.2 Use of smart contracts in the supply chain	34
2.2.3 Theories of supply chain management	34
2.3 Research Method.....	36

2.3.1	Search Strategy	36
2.3.2	Study Selection	36
2.4	Results	38
2.5	Discussion and Research Agenda.....	42
2.5.1	Considerations for theory and research	42
2.5.2	Considerations for conception and implementation	44
2.6	Conclusion.....	45
2.6.1	Theoretical implications	45
2.6.2	Practical implications.....	45
2.6.3	Limitations and research.....	46
2.7	References	46
3	Employees' intention to use smart contracts in supply chains: The important role of performance expectancy	51
3.1	Introduction	52
3.2	Theoretical Background	53
3.2.1	Distributed ledger based smart contracts	53
3.2.2	Smart contracts in supply chain networks	53
3.2.3	State of the art of smart contracts in supply chains	54
3.2.4	Distributed ledger and smart contract usage intention	54
3.2.5	Research model.....	55
3.2.6	Hypothesis development.....	56
3.3	Research Method.....	58
3.3.1	Questionnaire.....	58
3.3.2	Sample	58
3.3.3	Statistical tests	59
3.4	Results	60
3.4.1	Descriptive results	60
3.4.2	Test of hypotheses	60
3.5	Discussion	62
3.6	Conclusion.....	63
3.6.1	Theoretical contribution.....	63
3.6.2	Practical contribution.....	64
3.6.3	Limitations	65
3.6.4	Future research.....	65
3.7	References	66
3.8	Appendix	71
4	Smart contracts as enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis	72
4.1	Introduction	73
4.2	Theoretical Background	74
4.2.1	Trust in supply chain networks.....	74
4.2.2	Models of trust.....	74

4.2.3	Distributed ledger-based smart contracts and trust.....	74
4.3	Study 1: Model of trust dimensions	75
4.3.1	Model conceptualisation.....	75
4.3.2	Research Method	76
4.3.2.1	Questionnaire	76
4.3.2.2	Distribution and Sample.....	77
4.3.2.3	Statistical analysis	77
4.3.3	Results.....	77
4.3.3.1	Descriptive results	77
4.3.3.2	Hypotheses results.....	78
4.3.4	Summary Study 1	79
4.4	Study 2: Integrative model of trust towards smart contracts.....	80
4.4.1	Model conceptualisation and hypotheses	80
4.4.2	Research Method	82
4.4.2.1	Questionnaire	82
4.4.2.2	Distribution and Sample.....	82
4.4.2.3	Statistical analysis	82
4.4.3	Results.....	83
4.4.3.1	Descriptive results	83
4.4.3.2	Hypotheses results.....	83
4.4.4	Summary Study 2	84
4.5	Discussion	84
4.6	Conclusion.....	85
4.6.1	Theoretical contribution.....	85
4.6.2	Practical contribution.....	86
4.6.3	Limitations.....	87
4.6.4	Future research.....	87
4.7	References	88
4.8	Appendix	92
5	Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse.....	93
5.1	Introduction	94
5.2	Related Work.....	95
5.2.1	The Metaverse	95
5.2.2	Blockchain in the Metaverse	95
5.2.3	Smart Contracts in Metaverses	95
5.2.4	Transaction Cost Theory.....	96
5.3	Research Method.....	97
5.4	Results	98
5.5	Discussion	99
5.6	Research Agenda.....	99
5.6.1	Technical Perspective	100

5.6.2 Organizational perspective	100
5.6.3 User perspective.....	101
5.7 Conclusion.....	102
5.8 References	102

List of Figures

Figure 1: Functionality of Smart Contracts.....	5
Figure 2: Distributed ledger-based smart contracts in a supply chain.	6
Figure 3: Socio-technical systems theory (Trist, 1981).	9
Figure 4: Research process.....	11
Figure 5: The "research onion" according to Saunders et al. (2007).	13
Figure 6: The selection process of articles adapted from Page et al. (2021).....	37
Figure 7: Research model adapted from Venkatesh et al. (2003) and hypotheses.	56
Figure 8: Research model adapted from Venkatesh et al. (2003) and results (Notes: + $p < .1$; * $p < .05$; ** $p < .01$; *** $p < .001$).	61
Figure 9: Dimensions of trust towards smart contracts based on Hoff and Bashir (2014) and Lemieux et al. (2019).....	76
Figure 10: Theoretical integrative model of trust towards smart contracts based on the findings following Mayer et al. (1995), Hoff and Bashir (2014), Lemieux et al. (2019), Stuck et al. (2021), Lee and See (2004) and results of Study 1.....	81
Figure 11: Results regarding the research model (Note: * $p < .05$; ** $p < .01$; *** $p < .001$; one-tailed).	83

List of Tables

Table 1: Research assumptions	7
Table 2: Research design of “Understanding the role of distributed ledger based smart contracts in the supply chain: A literature review on theoretical implications and research agenda”	13
Table 3: Research design of “Employees’ intention to use smart contracts in supply chains: The important role of performance expectancy”	14
Table 4: Research design of “Smart contracts as enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis”	15
Table 5: Research design of “Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse”	15
Table 6: Comparison of supply chain theories (adopted from Treiblmaier (2018))	36
Table 7: Results of the literature search regarding the principal agent theory	38
Table 8: Results of the literature search regarding the transaction cost analysis	39
Table 9: Results of the literature search regarding the resource-based view	40
Table 10: Results of the literature search regarding the network theory.	41
Table 11: Demographic data and role of companies in the supply chain.	59
Table 12: Descriptive statistics and correlations among variables	60
Table 13: Tests of Hypotheses	60
Table 14: Descriptive results	77
Table 15: Rotated factor matrix: Confirmatory factor analysis using maximum likelihood.	78
Table 16: Dimensions of trust towards smart contracts	79
Table 17: Descriptive statistics.	83
Table 18: Comparison of the analyzed virtual worlds.	97
Table 19: Comparison of transaction costs in virtual worlds	98

List of Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
AVE	Average variance extracted
CFA	Confirmatory factor analysis
DAO	Decentralized Autonomous Organizations
DLT	Distributed ledger technology
E.g.	exempli gratia
Et al.	et alia
HTMT	Heterotrait-monotrait
IoT	Internet of Things
IS	Information Systems
IT	Information Technology
IoT	Internet of Things
MSP	Metaverse Service Provider
MU	Metaverse User
NFT	Non Fungible Token
NT	Network theory
PAT	Principal-Agent Theory
PLS-SEM	Partial Least Squares Structural Equation Modelling
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
RBV	Resource-based view
SCM	Supply Chain Management
SCT	Social Cognitive Theory
STS	Socio-technical Systems
TAM	Technology Acceptance Model
TCA	Transaction Cost Analysis
TCT	Transaction Cost Theory
TPB	Theory of Planned Behaviour
UTAUT	Unified Theory of Acceptance and Use of Technology
VR	Virtual Reality

1 Synopsis

1.1 Introduction

Distributed ledger technology (DLT) is considered a future key technology with the potential to change the organisation and collaboration in economy, society, and industry (Sunyaev, 2020). Using distributed ledger-based automated digital agreements, known as smart contracts, the technology can automate economic processes and make them more flexible and less intermediary (Sun & Huang, 2018). DLT-based smart contracts can be used in various industries, such as banking, government and law, healthcare, insurance, and transportation (Tsvetkov & Kostadinov, 2019). In supply chains, smart contracts can improve the traceability and origin of products throughout the extended supply chain, automatically execute agreements between the actors involved or enable the automatic release of payments upon satisfactory delivery (Tsarsitalidis et al., 2021). Furthermore, DLT and smart contracts can improve the trustworthiness of companies within the supply chain, ensure the accuracy of data-driven operations and migrate existing supply chain management processes from a linear to a fully circular economy (Asante et al., 2021).

Existing research shows that the implementation of DLT is already gaining popularity in additional supply chain management (Fiore et al., 2023; Papathanasiou et al., 2020) or also digital supply chains as they exist in virtual worlds (Dolgui & Ivanov, 2023). However, many aspects of the actual smart contracts use and implementation are not or only insufficiently considered in existing literature (Wu et al., 2022). Even more recent research is still revealing various implementation challenges (Grida & Mostafa, 2023). Furthermore, most of the existing literature takes a conceptual approach without relying on empirical findings and an actual implementation (Azevedo et al., 2023; Bandhu et al., 2023; Naqvi et al., 2023).

The consensus among previous research indicates that incorporating smart contracts can enhance the efficiency and transparency of supply chain processes while fostering increased trust among involved parties. Smart contracts offer benefits such as improved product tracking and tracing (Kumar & Chopra, 2022), automation of inventory management tasks like reordering and restocking (Ahmad et al., 2021), reduction of errors in documents and databases (Bingzhang & Zirianov, 2021; Chen et al., 2022), lowered transaction costs through the mitigation of paperwork in supply chain operations (Raj et al., 2022), and the shortening of information paths through decentralisation (Kajikawa et al., 2010).

Examples of the real-world use of smart contracts in supply chains are still limited, but the first applications have existed since the beginning of blockchain and distributed ledger development. This includes e.g. a food safety monitoring system that Walmart has developed in collaboration with IBM. In this system, food is labelled with smart tags; intelligent sensors can detect damage caused by excessive sunlight and improve food traceability throughout the supply chain (Kamath, 2018). Everledger uses smart contracts to track and manage the lifecycle of diamond production from the mines to the end customer (Thakker et al., 2020). The blockchain-based eChain ecosystem can also detect counterfeits in the electronic supply chain by enabling tracking and traceability (Vashistha et al., 2022).

There is a growing interest in the literature utilising DLT to address various challenges in traditional and digital supply chain management (SCM), including transparency, traceability, and trust. However, several research gaps exist since previous findings are mainly conceptual. Theoretical analyses and empirical studies are only limited available. Also, most current findings only refer to technical specifications or solutions. However, it is essential to not only consider the technological aspects of information systems (IS), but also sociological aspects (Silva, 2019). This allows a better understanding of behavioural impacts, user acceptance, ethical considerations or collaboration and trust building in the supply chain. While the impact of smart contracts on different supply chain processes has been already investigated in previous studies, there is a lack of an overview that summarises the existing results and uncover gaps in research.

To fill the existing research gaps, this first research question for this work is derived from the need to understand the influence of distributed ledger-based smart contracts on supply chain networks: *What are the implications of implementing distributed ledger-based smart contracts within supply chains according to fundamental supply chain theories?* Building on this, following research question will be

addressed: *How will the introduction of smart contracts change the way supply chains operate?* By examining these aspects, this work aims to provide a comprehensive understanding of the socio-technical implications of implementing smart contracts in supply chain management and to propose a research agenda that presents aspects requiring further detailed exploration. The following research questions were developed based on the findings from the research agenda and aim to understand the current readiness of employees towards these DLT-based smart contracts: *How is the intention of employees to use distributed ledger-based smart contracts in supply chains?* and *What factors influence the intention to use distributed ledger-based smart contracts in supply chains?* The aim of this is to explore the socio-psychological factors that affect employees' intention to use smart contracts and to provide actionable recommendations for improving the adoption of smart contracts by considering the human factors in their implementation. The next research question arises from the need to understand the role of trust towards smart contracts, which typically plays an important role in the introduction of new technologies in organisations (Nienaber et al., 2020): *How can a trust model for trust towards smart contracts be realised that takes into account the multidimensionality of the trust construct?* The aim is to develop a theoretical foundation to understand and empirically test how trust influences the decision-making processes of actors in the supply chain in order to facilitate the wider adoption of smart contracts. Also, based on the findings from the scoping review, a need was also identified to analyse the actual transaction costs associated with smart contract applications. Given the relevance of digital applications of smart contracts, the final study focuses on the use of smart contracts in a virtual world with the following research question: *How can smart contracts be designed in the metaverse to optimise transaction costs?* The aim is to provide recommendations on how smart contracts should be designed and optimised from a technical, organisational and user perspective.

By answering the different research questions, this thesis overall aims to shed light on the socio-technical aspects of the implementation of smart contracts in supply chains, helps to better understand the impact of smart contracts, the role of people in organisations towards the implementation of smart contracts in supply chains and to determine the applicability from a cost perspective. In addition to creating an overview on existing knowledge, the aim is to identify specific research gaps and address some of these.

In this work, socio-technical systems (STS) theory serves as the underlying theory and its assumptions about how information systems represent themselves. It considers the social and technical perspective of an information system and offers a more holistic and realistic view (Trist, 1978). The STS is useful as an underlying theory as it provides a more general understanding of the interactions between social and technical components and thus provides a broad foundation for the analysis of smart contracts in supply chains. More specific theories such as the Unified Theory of Acceptance and Use of Technology (UTAUT), the Resource-Based View (RBV) and Transactional Cost Analysis (TCA) can then be used in a more focussed and specific approach to answer detailed research questions in line with the concept of STS.

The research questions are addressed using a mixed methods approach. A scoping review using a qualitative analysis with the PRISMA 2020 framework examines the existing literature on the implementation of smart contracts to answer the first research question. This is followed by an empirical study with a deductive approach and a survey of supply chain employees based on UTAUT (Unified Theory of Acceptance and Use of Technology). The findings are analysed by Partial Least Squares Structural Equation Modelling (PLS-SEM) and should answer the research questions concerning the intention to use smart contracts. In addition, a mixed-methods confidence model combining abductive, inductive and deductive approaches is developed. A structured quantitative questionnaire, analysed using confirmatory factor analysis and PLS-SEM, investigates employee trust in smart contracts, the last research question of this work. Additionally, a transaction-cost-theory-based conceptual analysis is conducted to examine transaction costs associated with smart contracts in virtual worlds, further expanding the methodological portfolio. Overall, this approach allows to comprehensively understand socio-technical factors in implementing smart contracts in supply chains.

This work has theoretical contributions on several levels. First, this work adds value to the field of information systems by deepening the understanding of the introduction and evaluation of new technological innovations and expanding existing theoretical models and concepts. Second, in the field

of supply chain management, it offers important insights into the transformative impact of smart contracts, pointing to their influence on information symmetries, transaction costs, competitiveness and network dynamics. Third, more specifically, it contributes to the development of a multidimensional trust model for smart contracts and shows how trust towards the future technology smart contracts influences risk behaviour. Furthermore, this work contributes to the understanding of transaction cost theory in the context of blockchain-based metaverses and provides insights into the design and implementation of smart contracts in virtual worlds. These findings are of great importance for the successful integration of smart contracts in various application areas and contribute to the further development of theories and models. From a practical perspective, this research provides valuable insights for developers, policy makers and managers to navigate the complexity of integrating smart contract technology and to understand the factors that influence the adoption and efficiency of smart contracts in both traditional and virtual supply chains and supply networks.

The structure of this work is as follows: This introduction is followed by a positioning of the research topic in the field of information systems research, followed by an explanation of DLT and smart contract as well as their use in supply chains. The subsequent chapter explains the research design of this work. Here the chosen philosophy of pragmatism is explained, as well as behavioural science as research paradigm and the STS theory as fundamental framework on which this thesis is based. It also provides a detailed description of how the individual studies of this cumulative work were designed. The results of the four studies are then summarised and discussed, and, in addition to theoretical and practical implications, limitations and future research opportunities are presented. Finally, the four studies, which constitute the core of this work, are presented in total length.

1.2 Research Background

1.2.1 Positioning in supply chain management research

The beginnings of SCM research can be traced back to the 1980s, when the focus was primarily on internal logistics and the optimisation of transport and warehousing processes within individual companies. This early phase of SCM focussed on improving the efficiency of internal processes without taking a detailed look at the entire supply chain (Cooper et al., 1997). With the increasing influence of globalisation and technological development, the focus of research has expanded from an isolated consideration of internal processes to a holistic view that encompasses all actors along the supply chain. This paradigm shift was driven by the realisation that integrated and networked supply chains can represent a significant competitive advantage (Chen & Paulraj, 2004; Mentzer et al., 2001).

In addition to traditional supply chains, recent advances have led to the emergence of digital and virtual supply chains in virtual worlds such as the metaverse. The metaverse represents a new frontier where physical and digital realities converge, creating unique opportunities for supply chain management. Metaverse supply chains integrate cyber-physical systems, digital twins and cloud supply chains to improve visibility, collaboration and decision-making in a virtual environment. This integration enables joint demand forecasting, digital inventory allocation and integrated production planning between the physical and virtual worlds, providing significant benefits in terms of efficiency and resilience (Dolgui & Ivanov, 2023). In addition, the metaverse facilitates new forms of virtual collaboration and trust-building between supply chain partners, which are critical to improving supply chain resilience (Huang & Chen, 2023).

With the advent of digital technologies, research has explored the role of information systems in the supply chain. IS improve decision making and process efficiency through better data integration and processing. Research has focused on how IS can enhance supply chain performance through improved communication and transparency (Kakhki & Gargeya, 2019). DLT and smart contracts offer new opportunities to improve transparency, security and efficiency in supply chains. DLT makes it possible to store transactions securely and immutably, which is particularly beneficial in global supply chains. Smart contracts automate contract execution and improve compliance and speed of transactions (Saberli et al., 2019). Research shows that these technologies improve coordination within supply chains and help to reduce fraud and inefficiencies (Omar et al., 2022). The research in this thesis fits into this context by looking at supply chains as networks and investigating a future technology that not only

improves the performance of the entire supply chain network, but also involves all stakeholders to ensure greater traceability and accountability.

1.2.2 Positioning in information systems research

IS is a multidisciplinary field concerned with analysing the interaction of technology on organisational processes, structures and culture (Silva, 2019). Research on IS has existed since the 1960s, when it was commonly referred to as "management information systems" (Hirschheim & Klein, 2012). Since then, Information technology (IT) is increasingly becoming a part of all business environments (Silva, 2019) and information systems have rapidly evolved from an IT tool to an essential and strategic element of a successful organisation (Kadry, 2014). Nowadays, IS research addresses the overall use of those information technologies and systems in organisations (Silva, 2019). Besides considering technologies, IS research has incorporated various social theories to improve the understanding of phenomena related to information systems (Jones & Karsten, 2008). Over time, information systems research has continued addressing new topics and areas while retaining its core strength and identity, adopting information technology and using information services (Jeyaraj & Zadeh, 2019). Since the late 1990s, the focus has been managing widely distributed technologies and personnel (Hirschheim & Klein, 2012). More recent research topics include globalisation and intercultural studies, virtual teams, knowledge management, IT personnel, business intelligence, IS research productivity, design science and new disciplinary frameworks (Hirschheim & Klein, 2012). Due to the rapid advancement in information technology, the field of information systems research is expanding rapidly. New technologies such as artificial intelligence, distributed ledger technology, big data analytics, virtual and augmented reality, 5G networks, etc., lead to a constant need to identify and implement appropriate technologies that enable companies to remain in and compete in business (Taherdoost, 2022). The combination of future technologies provides new opportunities, including the development of the metaverse and other innovative applications (Rai & Vyas, 2023). These advancements enhance immersive experiences and enabling intelligent virtual agents (Huynh-The et al., 2023) and furthermore improve user interaction and content creation (Zhang, 2023).

The development of information systems in supply chains rapidly gained importance with the rise of the internet and was initially primarily aimed at optimising the information flow (Williamson et al., 2004). More recent developments are designed to improve the overall supply chain management and consider uncertainties and risks within supply chain relationships (Boiko et al., 2019). Today, information systems can not only improve supply chains, but also form the basis for digital or virtual supply chains by enabling seamless integration and real-time optimisation (Tan et al., 2000; Verdouw et al., 2016). Therefore, this research corresponds to advanced information systems research with a joint consideration of distributed technologies and human factors. It focuses on the core of information systems research, the implementation and use of information systems, but at the same time, takes into account new developments and the emerging research area of distributed ledger technology with smart contracts. With supply chain management, this thesis work and discusses an application context relevant to IS, which also includes research into elements of such by analysing smart contracts in virtual worlds.

1.2.3 Distributed ledger and smart contract technology

Distributed ledger technology is a concept encompassing various methods of securely storing and transmitting information through interconnected data blocks which are written in a network of distributed entities. While blockchain is a well-known and widely used example of DLT, multiple forms may differ in terms of their features, making DLT a more generalised term to describe this overarching technology. The shared key characteristics of DLT networks are integrity, immutability and transparency of the data and data security through distribution (Vo et al., 2021). Integrity means that DLTs have almost indestructible data, with the only theoretical vulnerability by quantum computers that could interfere with the code and decrypt it. Immutability means that once data has been written, it is difficult to edit, ensuring the permanency of records. The transparency in DLT networks is very high since users can track the path and content of data from one address to another and enable comprehensive tracking of the entire history of data content. The distributed nature of the network increases security as the information and data are distributed throughout the network. Access to the data and its updating is restricted to authorised persons with the identifiable code, which further guarantees the security of the data (Vo et al., 2021). DLT types differ mainly in how transactions are stored and verified, leading to

differences in scalability, flexibility, transaction speed, energy consumption and transaction costs (Chowdhury et al., 2019).

Smart contracts are digital agreements or automations written in the distributed ledger code. They are based on "if-then-that" logic and execute themselves without the need for third-party monitoring. This approach ensures that all parties involved are aware of the terms of the agreement, which are automatically enacted once the conditions are met (Vo et al., 2021). All parties set the conditions for executing events through smart contracts on the distributed ledger. Once the conditions match, the agreed contract terms are automatically executed. However, smart contracts are not necessarily associated with the traditional legal concept of a contract and can also be used for the simple execution of automation of processes. While the underlying distributed ledger technology mostly influences the characteristics of smart contracts, they introduce the additional feature of automation. Figure 1 illustrates how smart contracts integrated into distributed ledger work.

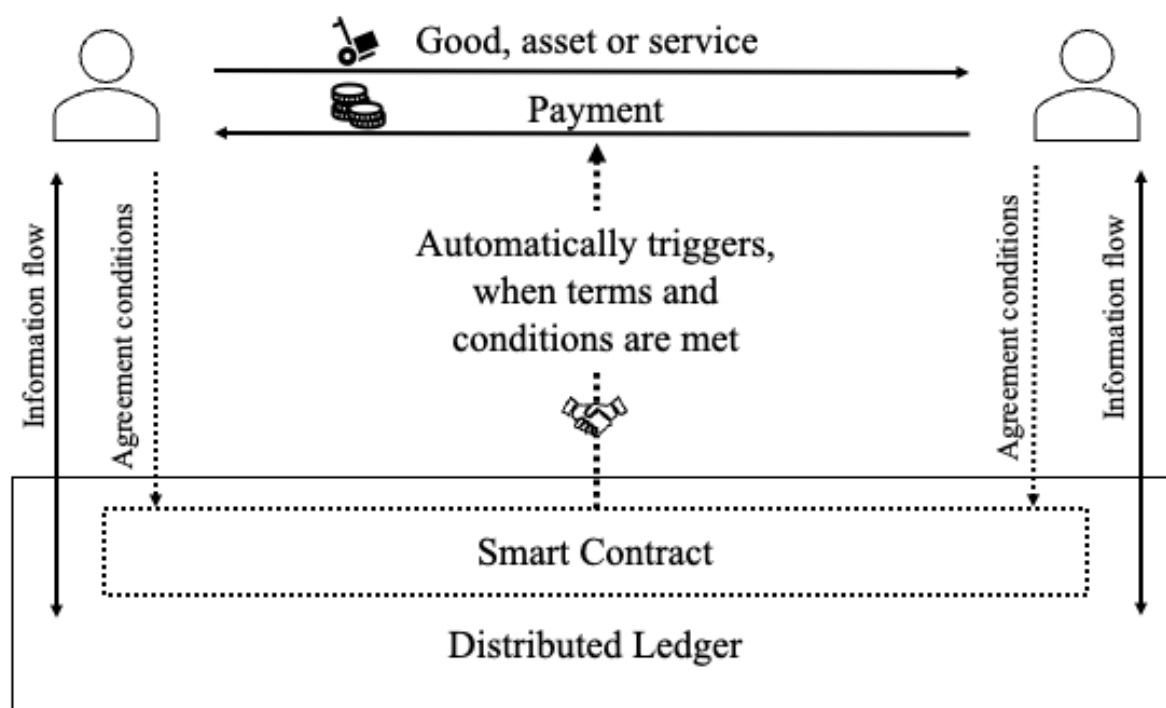


Figure 1: Functionality of Smart Contracts.

While information about processes or products could be stored directly in the distributed ledger, establishing connections between the distributed ledger and external databases is often more efficient. This would facilitate the streamlined transfer of information while enabling transparent tracking of all activities based on the data stored in the distributed ledger (Vo et al., 2021; Zhang et al., 2020).

1.2.4 Smart contracts in supply chains

In previous research, it was observed that only a limited number of studies have explored the application of smart contracts within a supplier-provider context. Nevertheless, there is a notable interest in this field (Martinez et al., 2019). A key advantage of implementing smart contracts in supply chains arises from the decentralised network structure of distributed ledgers. This decentralisation guarantees universal access to all information for all participants, eliminating the need for direct information exchange between individual actors (Korpela et al., 2017). The data stored on the distributed ledger or linked databases can encompass various types, such as transport details (sensor data, real-time location information), product specifications (price, quality, batch number), source information (manufacturing country, factory), or customer records (ownership certificates), among others (Vo et al., 2021).

Based on this, smart contracts can autonomously execute agreements that initiate the transfer of goods, services, assets, and payments (Vo et al., 2021). This marks a transformation in the conventional supply

chain dynamics, shifting the information exchange and contract establishment from a bilateral process between two parties to a decentralised network model (Wang et al., 2019).

As depicted in Figure 2, the integration of distributed ledger-based smart contracts into supply chains is visualised. Similar to the previous setup, the exchange of materials and finances transpires among individual participants in the chain. However, unlike the traditional approach, information dissemination now occurs decentralised through the distributed ledger or interconnected databases. By implementing smart contracts, which activate predefined actions based on stored data, the progression of material and financial transactions can be automated.

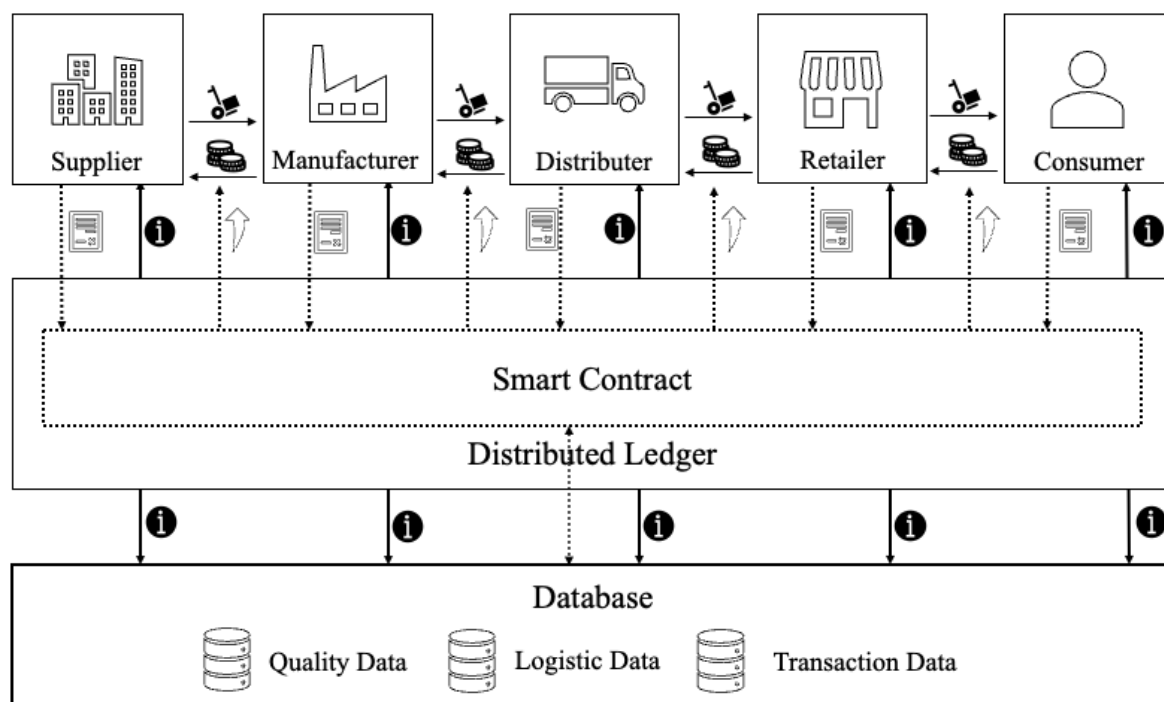


Figure 2: Distributed ledger-based smart contracts in a supply chain.

Adopting this approach opens the door to enhanced automation and the ability to circumvent intermediaries. The procedures gain a robust legal footing, becoming traceable, dependable, and secure through their technological foundation. Beyond improving efficiency, this method addresses issues in conventional supply chains, like data credibility and visibility into production (Casado-Vara et al., 2018). Smart contracts are also used to control extensive background processes and automation in supply chains, improve coordination and reduce costs through dynamic control (Bottoni et al., 2020; Dolgui et al., 2020). These tasks also take place primarily in fully digitalised, virtual supply chains based on distributed ledger technologies (Dolgui & Ivanov, 2023).

1.3 Research Design

1.3.1 Research Philosophy: Pragmatism

The research philosophy with which this work has been approached is pragmatism. Even often described as a practical philosophy (Simpson, 2018), pragmatism emphasises the close connection between theory and practice (Lavelle, 2007). The research philosophy states that theories and concepts should primarily serve as tools for solving practical problems and that theories should be evaluated primarily in terms of their usefulness and value for addressing real-world challenges (Legg & Hookway, 2008) and emphasises the practical application of ideas and the importance of experience for the development of knowledge (Morgan, 2014). The philosophy states that the truth of a concept or theory is determined by its practical applicability. As a general research philosophy, pragmatism means that research is directed towards practical applicability and that the research results should be applied in practice. It is widely

used in various fields of professional practice, such as technology, law, politics, medicine, social work, and education (Ormerod, 2021).

From an action-oriented perspective, pragmatism emphasises the importance of actions and their consequences (Morgan, 2014). Therefore, pragmatism encourages examining the impact of smart contracts on the behaviour and actions of the parties involved. It makes it possible to explore the practical impact of smart contracts and assess if they bring about positive changes in the supply chain.

Pragmatism also underscores the importance of context when evaluating ideas and theories (Morgan, 2014). The introduction of smart contracts in supply chains is a complex socio-technical phenomenon influenced by various factors, such as the specific industry, the actors involved and the cultural framework. The application context of supply chains allows for a contextual view of smart contracts and considers particular challenges and opportunities related to smart contracts.

Implementing smart contracts in supply chains requires an interdisciplinary approach, as both technical and social aspects must be considered (Shul'zhenko, 2020). Pragmatism allows to include different perspectives and thus obtain a more comprehensive view of the topic. It encourages collaboration and the exchange of knowledge and methods from other disciplines, allowing this combined view (Klein, 2022).

Pragmatism was chosen as the philosophy for this work because a practice-oriented view of the impact of smart contracts in supply chains is necessary to provide actual benefits for further research and later implementation. Pragmatism allows assessing the benefits and consequences of this technology on the actors involved and society as a whole. Moreover, the pragmatic approach allows for a flexible and contextual approach to the topic, which is especially important in a rapidly evolving field like smart contracts (Saunders et al., 2007).

Other research philosophies have been considered but found to be less suitable for investigating the socio-technical aspects of smart contracts in supply chain management. Positivism focuses on measurable facts and generalisations, but overlooks the complex interactions between technology and social systems and does not do justice to the nuanced nature of smart contracts. Critical realism explores the underlying structures and causal mechanisms, but is less suitable for assessing immediate, actionable impacts due to its emphasis on historical and complex relationships. Interpretivism offers insights into human experience but lacks the practical orientation required to develop technical solutions and evaluate their effectiveness in supply chains. Postmodernism highlights power dynamics and social constructs, but is too abstract and critical to formulate practical recommendations (Saunders et al., 2007). Pragmatism, on the other hand, bridges the gap between theory and practice and considers both technical and social perspectives. Its problem-solving and practical orientation make it the most appropriate philosophy for assessing the impact of smart contracts in supply chains and allows for a flexible and contextualised approach.

Knowingly or unknowingly, researchers will make several assumptions when they start their research (Burrell & Morgan, 2019). According to Burrell and Morgan (2019), there are three types of assumptions of a research philosophy. Ontological assumptions refer to beliefs about the nature of the reality that research confronts and how researchers can understand the existence of phenomena. Epistemological assumptions refer to understanding human knowledge, including what constitutes valid knowledge, its knowability and the methods by which researchers can acquire and communicate it. Axiological assumptions refer to recognising the researcher's values and potential impact on the research process, highlighting what is critical and valuable in the study (Burrell & Morgan, 2019). Table 1 below shows how these assumptions are represented in this work.

Table 1: Research assumptions

Assumptions	Representation in this work
Ontological (Nature of Reality)	In this research, the ontological assumption is that smart contracts and their impact on supply chains are a real phenomenon in the business environment. It is assumed that smart contracts exist as part of the supply chain ecosystem and can be studied as objective entities. The reality of smart contracts in

	supply chains is treated as an ordered and observable aspect of business operations.
Epistemological (Acceptable Knowledge)	From an epistemological perspective, the focus is on practical application and empirical knowledge. Theoretical knowledge is not excluded, however, and should above all help to better understand the fundamentals and develop hypotheses. In addition to own research of findings, previous research related to the implementation of smart contracts in supply chain management is also considered as acceptable knowledge.
Axiological (Role of values)	The axiological assumption in this research is an objectivity and neutrality of all contributing researchers, whether directly in this research or existing research works referred to. It is assumed that the influence of personal values and bias on the research process has been minimised and a detached and impartial analysis has been sought.

In this work, the application of pragmatism can be found in the selection of research methods. Pragmatism allows a flexible approach and the incorporation of a wide range of theories and practical insights into our work. This flexibility was particularly evident in the literature review, which considered different theoretical approaches to understand the role of smart contracts in supply chains. Furthermore, the pragmatic approach is reflected in the decision to use different research methods such as quantitative surveys and qualitative analyses. This approach allowed to analyse the research question from different perspectives and to obtain a holistic view on the topic. The results of these studies illustrate how the acquired findings can be applied in practice. A key focus of the work is to provide practical recommendations for decision-makers in supply chains. This emphasises the practical relevance of the research and illustrates how the developed models and concepts can be translated into practice.

1.3.2 Research Paradigm: Behavioural science

The IS discipline and research is dominated by the behavioural science paradigm on the one hand and the opposing design science paradigm on the other (Patas & Goeken, 2011). Behavioural science seeks to develop and verify theories that explain or predict human or organisational behaviour, while design science seeks to push the boundaries of human and organisational capabilities by creating new and innovative artefacts (Goldkuhl, 2017; Hevner et al., 2004). Behavioural science studies behaviour related to information technology use through empirical observation and testing of theories. The behavioural science paradigm is primarily a foundation for understanding human behaviour. Building on this, design science can provide a framework for developing innovative solutions (Gregor & Hevner, 2013). On the other hand, design science creates new and innovative artefacts through a process that includes problem identification and motivation, goals for a solution, design and development, evaluation and communication (Hevner et al., 2004; Peffers et al., 2020).

For this study, the behavioural science paradigm was chosen to understand the underlying drivers and behavioural aspects that influence the use of smart contracts in supply chain management. The behavioural science paradigm is particularly suitable for understanding human behaviour in the context of information technology (Hevner et al., 2004). Thus, it is consistent with the aim of this work, understanding the drivers and behavioural aspects that influence the use of smart contracts in supply chains. Furthermore, the behavioural science paradigm focuses on developing and verifying theories that explain or predict human or organisational behaviour (Hevner et al., 2004). It is critical to understand how supply chain actors respond to the adoption of smart contracts and how this technology affects their actions.

Although the design science paradigm is essential to develop innovative technologies (Hevner et al., 2004), it is not fitting well for this research. Smart contracts are a novel technology, and implementing artefacts such as concrete applications and solutions can be challenging. Therefore, the focus should first be understanding human behaviour and the implications of using smart contracts. Thus, concerning the current state of technology and knowledge, the behavioural science paradigm provides a more

appropriate methodological basis to explore and understand the complex aspects and challenges associated with adopting smart contracts in supply chain management.

The choice of the behavioural science as research paradigm is in line with the pragmatic philosophy by focusing on the study of human behaviour and psychological factors in different contexts. This approach allows scientific theories and models to be applied to their actual impact on human behaviour and decision-making. This paradigm values empirical research, data collection and the analysis of behavioural patterns to gain a deeper understanding of the impact of innovation and technology on human interaction and the organisation of companies. The integration of these two perspectives, pragmatism as a research philosophy and behavioural science as a research paradigm, enables practical insights based on an understanding of human behaviour and psychological aspects. The combination facilitates the development of realistic models and theoretical approaches that are not only theoretically grounded, but also practically applicable and useful to decision makers in various fields, including information systems and supply chain management.

1.3.3 Research Framework: Socio-technical systems theory

The behavioural science approach focuses on the analysis of individual and collective behaviour in organisations. It takes into account the psychological and social aspects that influence the behaviour of actors. The integration of the STS framework now brings an additional dimension by highlighting the interactions between social and technological elements in more complex systems.

The STS theory was used as a research framework and underlying theory of how systems represent themselves in the world. It was developed in the 1950s by Eric Trist, Ken Bamforth, and Fred Emery (Trist, 1981). They investigated performance problems associated with the introduction of new technology in the coal mining industry and noted that organisations need to take account of the people, social, and work changes related to their plans for technological changes in the workplace. They argued for a more holistic approach that combines the technical and social impacts of change, which they called the principle of co-evolution. In this way, they developed theories and methods for sociotechnical innovations in the workplace to benefit both the workforce and the management of the company (Stanton, 2022; Trist, 1981). An illustration of the theory is shown in Figure 3 below:

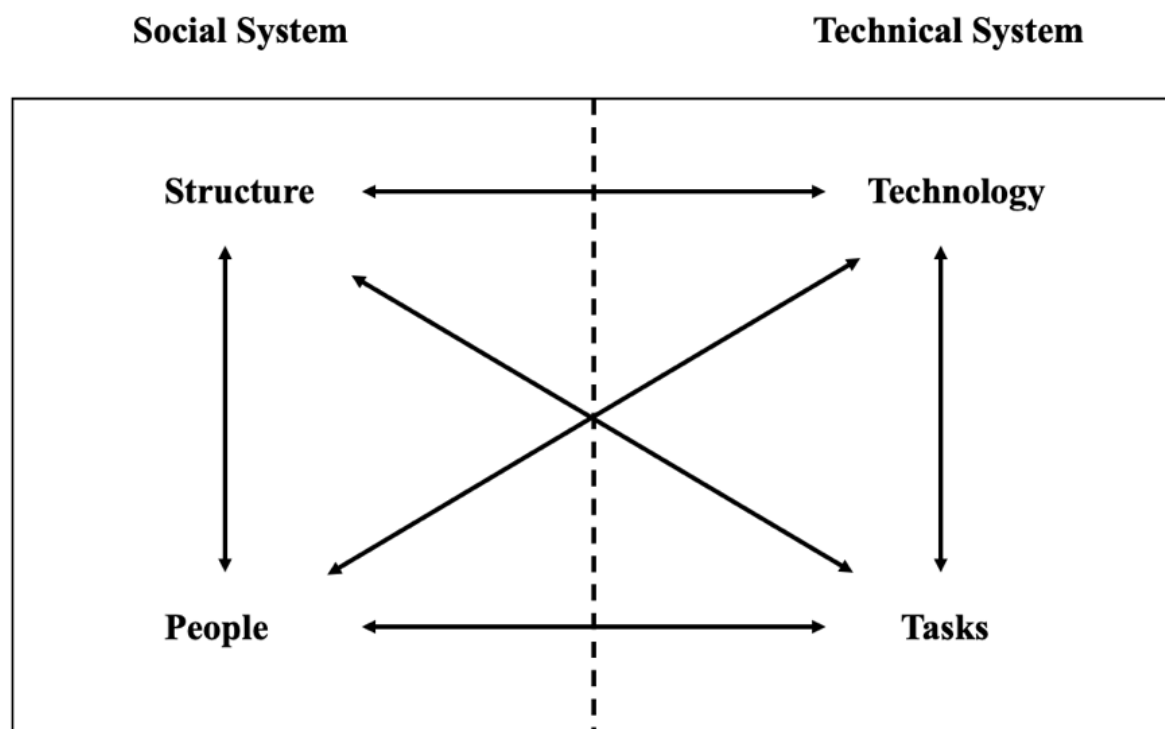


Figure 3: Socio-technical systems theory (Trist, 1981).

The traditional technical perspective focuses exclusively on the technical aspects of a system without considering the social context in which it functions. It assumes that technology can be designed and implemented independently of social factors, which is not always the case (Alter, 2015). The approach tends to view technology as a solution to problems rather than recognising that it can create new problems or exacerbate existing ones (Stanton, 2022). In contrast, the socio-technical systems theory is about the joint optimisation of technology and the social factors (Cooper & Foster, 1971). It emphasises the interdependence of social and technical systems in organisations. It recognises that technology and social systems are mutually related and that changes in one system impact the other (Alter, 2015).

The applicability is in management information systems and management science and operations research, where introducing a new technology must also consider the organisation and its members. The socio-technical approach helps to identify possible behavioural problems and failures that could arise when a technology is introduced (Bostrom & Heinen, 1977). Therefore, studying smart contracts in supply chains through a socio-technical perspective can help to bring together system conceptualisations, business realities and humanistic values in the development of information services (Alter, 2015).

Taking socio-technical systems theory into account when considering smart contracts in supply chains makes sense for several reasons: socio-technical systems theory enables a holistic view of smart contracts in supply chains. It considers the technical aspects of implementing smart contracts and the social impacts on the actors involved (Trist, 1981). Smart contracts can influence the interaction and cooperation between different parties in a supply chain (Philipp et al., 2019). Socio-technical systems theory helps to understand the impact on human interaction and the social dynamics that can affect acceptance, trust and collaboration. Introducing smart contracts into supply chains often requires changes to existing workflows and processes. Socio-technical systems theory provides a framework to analyse the impact of such changes on the actors involved and their adaptability. This enables targeted planning and implementation of changes to minimise resistance and ensure a smooth transition. Socio-technical systems theory can also help identify and assess potential risks and challenges associated with smart contracts in supply chains. Considering social and organisational aspects, it can identify potential vulnerabilities or issues that could impact the supply chain's security, privacy or performance. Overall, applying socio-technical systems theory contributes to the holistic view of smart contracts in supply chains and enables a more comprehensive analysis and optimisation of the system, considering both technical and social aspects.

While STS theory emphasizes joint optimization of technical and social systems for optimal performance and sustainability (Trist, 1981), alternatives could include the Technology-Organization-Environment (TOE) Framework, which examines technology adoption through technology, organization, and environment. However, TOE offers less insight into the social dynamics crucial for implementing smart contracts in supply chains (Tornatzky, 1990). The Diffusion of Innovations (DOI) Theory explores the spread of new ideas and technologies but focuses more on general dissemination processes than on specific social and technological interactions essential in supply chain management (Rogers, 1995). Network Theory analyses the structure and dynamics of actor networks but lacks emphasis on technological interactions and their impacts (Granovetter, 1973). Despite these alternatives, STS theory remains most suitable due to its holistic approach, as it incorporates both technical and social aspects that are crucial for understanding the multiple impacts of smart contracts in supply chains (Trist, 1981).

1.3.4 Research Process

The research process of this work aims to identify existing research gaps and close them through theoretical and empirical studies. Based on the research questions, three studies were conducted to gain a deeper understanding of the impact of distributed ledger-based smart contracts in supply chains.

The starting point of this work is to answer the first research question and analyse the implications of implementing distributed ledger-based smart contracts in supply chains, based on fundamental theories of supply chain management. A literature review was conducted to achieve the objectives, following the PRISMA 2020 guidelines (Paper title: "Understanding the role of distributed ledger-based smart

contracts in the supply chain: A literature review on theoretical implications and research agenda”). This review comprehensively covers the existing literature and identified research gaps.

To address these gaps, further empirical studies were conducted to gain deeper insights into the behavioural processes involved, described in the following. Therefore, the second study was based on a research gap identified in the literature review and aimed to answer the research question regarding the antecedents of the intention and the intention itself of supply chain employees to use smart contracts (Paper title: “Employees’ intention to use smart contracts in supply chains: The important role of performance expectancy”). A quantitative survey was conducted to assess the current willingness of employees in supply chains to adopt smart contracts. The UTAUT model was used to design the survey and gather data. The survey targeted supply chain employees to understand their attitudes towards using smart contracts.

Also based on the identified research gaps from the literature review, the third paper, a dual-study analysis, target the research question of a theoretical trust model towards smart contracts and uncovered various dimensions of trust regarding the use of smart contracts (Paper title: “Smart contracts as an enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis”). First, a theoretical model was developed to establish dimensions of trust concerning smart contract usage. A hypothetical survey validated the theoretical model, as smart contract usage was not yet widespread in supply chain management. In the second part of the analysis, the results regarding trust dimensions led to the development of a new theoretical framework that considered trust's impact on risk-taking behaviour. This theoretical model was subsequently put to the test through empirical validation. A detailed integrated framework was developed based on previous theoretical models to explore the concept of trust in smart contracts within supply chain management. An empirical study was also carried out to test the model in reality.

The fourth study, based on the research gaps identified in the literature review, aimed to answer the research question of how smart contracts can be designed in the metaverse from a transaction cost perspective (Paper title: “Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse”). A conceptual analysis was conducted to assess the feasibility and usability of smart contracts in virtual worlds, specifically Decentraland, Sandbox, and Roblox. By assessing transaction costs, the study gauged the feasibility and usability of smart contracts in virtual world transactions. The whole research process of this work is illustrated in Figure 4.

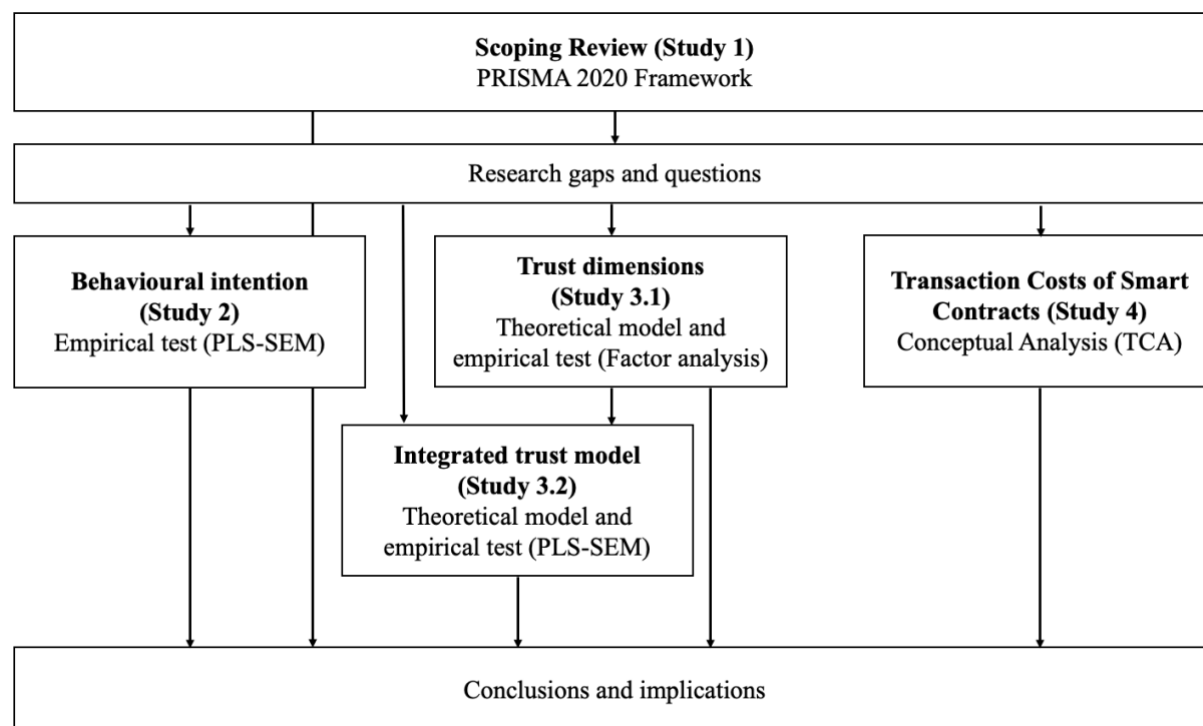


Figure 4: Research process.

This procedure allows to examine all four specific dimensions of the technical and social part according to the socio-technical systems theory: The social dimension, particularly in relation to the organisational structure, is reflected by exploring how the introduction of smart contracts may require changes to the organisational structure or the structure of interactions between different parties in the supply chain. The people dimension is an important focus of this work, particularly in examining the behavioural intentions of employees and the dimensions of trust in the context of smart contracts in supply chains. The technological dimension of technology is evident in the work by focusing on smart contracts as a technological innovation in supply chains. This involves considering how smart contracts are designed and should be implemented. The analysis and comparison of transaction costs within DLT and non-DLT based virtual worlds, further strengthen the understanding of the technical dimension. The task dimension of the technical part is reflected by considering how the introduction of smart contracts may impact specific processes within the supply chain and for which tasks types of smart contracts can be used to optimise processes.

The conducted research process integrates the research philosophy of pragmatism, behavioural science as research paradigm and STS theory as research framework. The research process reflects pragmatism, as we not only analyse existing theories and models, but also look for empirical evidence to support them and derive practical recommendations. The focus of this work is on the behaviour of individuals in organisations, with psychological and social factors playing a central role and thus taking into account the principles of the behavioural science research paradigm. However, also technical aspects and consequences of smart contract implementation are considered as well as the interactions between social and technological components. This is done in the context of analysing a future technology as part of an information system, whereby the interactions between social and technological components can also be taken into account in accordance with the STS research framework. This enables to comprehensively investigate behaviour, social interactions and technological aspects in supply chain management and information systems.

1.3.5 Research design and methods

To design specific studies, several frameworks can be used to determine research methods and techniques. The "research onion" (Saunders et al., 2007) illustrates the different aspects of research that need to be considered to develop a research design to provide a systematic approach to developing and conducting research (Saunders et al., 2019). It is widely applied as a guideline for research design (Mardiana, 2020) and has been successfully used in previous technology studies (Alturki, 2021).

Saunders et al. (2007) classified the research onion into three decision levels. The first level comprises the outer rings: research philosophy and research approach. The second level encompasses research design, which involves methodological choices, research strategy, and time horizon. Finally, the inner layers represent the specific techniques and procedures used for data collection and analysis (Saunders et al., 2019). The different layers and rings are shown below in Figure 5.

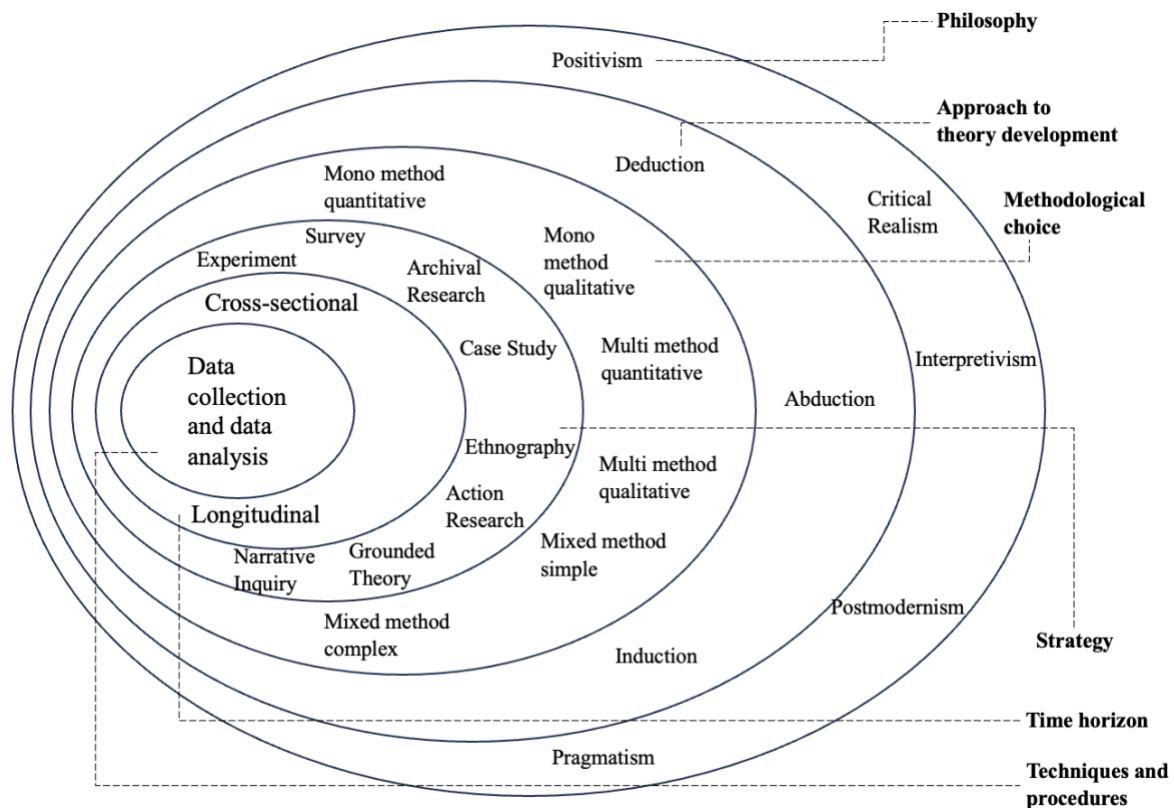


Figure 5: The "research onion" according to Saunders et al. (2007).

Also, for this work, the framework was applied for the different studies. Tables 2 to 5 show the respective choices of the various concepts and give explanation for the selections.

Table 2: Research design of "Understanding the role of distributed ledger based smart contracts in the supply chain: A literature review on theoretical implications and research agenda"

Layer	Choice	Explanation
Philosophy	Pragmatism	The aim is to identify real problems in the supply chain that arise from the integration of smart contracts. Pragmatism allows for a flexible combination of theoretical frameworks with practical insights.
Approach	Inductive	An inductive approach was chosen as the aim was to obtain a comprehensive overview of the existing literature on a topic without testing already established hypotheses. The inductive approach makes it possible to derive insights and patterns from the analysed literature, which helps to identify research gaps.
Method	Monomethod qualitative	This approach facilitates a deep exploration of theoretical findings, offering a nuanced understanding through qualitative analysis.
Strategy	Archival Research	Archival research is used to gain an overview of existing evidence and draw conclusions for future research needs.
Time horizon	Longitudinal	To identify developments in technology adoption as well as the potentially changing issues, the literature review was

		conducted at a single point in time but considered literature from several previous years.
Data collection	Structured qualitative	A structured qualitative approach is chosen to ensure a systematic and organized collection of relevant information from the literature. This method supports the scoping review's goal of summarizing theoretical knowledge and identifying research gaps.
Data analysis	PRISMA 2020 Framework	This well-established framework provides a structured and transparent approach to reviewing and synthesizing literature, ensuring rigor and reproducibility in the scoping review process. It helps maintain a systematic and comprehensive overview of the literature.

Table 3: Research design of “Employees’ intention to use smart contracts in supply chains: The important role of performance expectancy”

Layer	Choice	Explanation
Philosophy	Pragmatism	Pragmatism allows for a flexible approach here as well, focusing on solving real problems and applying technologies in practice.
Approach	Deductive	Empirical data is collected to test the UTAUT model in the application context of smart contracts in supply chains. The deductive approach makes it possible to derive hypotheses based on existing theories and then test them through the survey.
Method	Monomethod quantitative	The focus is on collecting numerical data to quantify and understand the relationship between different variables.
Strategy	Survey	The survey method is chosen to collect data directly from employees and understand their opinions, attitudes and intentions regarding the use of smart contracts in supply chains. This allows for an efficient collection of a large amount of data.
Time horizon	Cross-sectional	A cross-sectional approach is chosen as the study is conducted at a specific point in time to capture the employees' intention to use smart contracts. This facilitates data collection and analysis at a specific point in time.
Data collection	Structured quantitative questionnaire	A structured quantitative survey is chosen to collect clear and comparable data. A structured questionnaire allows for systematic data collection and is well suited to capture variables of a model.
Data analysis	PLS-SEM	PLS-SEM is particularly suitable for complex models with many latent variables and enables precise analysis of structural equation models in quantitative research.

Table 4: Research design of “Smart contracts as enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis”

Layer	Choice	Explanation
Philosophy	Pragmatism	Pragmatism allows for a flexible combination of theoretical established frameworks with practical recommendations.
Approach	Abductive, inductive and deductive	Trough an inductive approach, literature findings are collected to identify structures and to build a theoretical model as a conclusion. The abductive approach allows new explanations to be derived from the data collected, while the deductive approach tests the established model.
Method	Mixed-method simple	While the qualitative literature analysis serves to establish the model, the quantitative empirical testing of the model is the focus of the study.
Strategy	Survey	The survey method is chosen to collect data from supply chain employees. This allows for a broad amount of data to be collected and to understand employees' opinions regarding trust towards smart contracts.
Time horizon	Cross-sectional	A cross-sectional approach is chosen as the study is conducted at a specific point in time to capture the current state of trust in smart contracts. This is appropriate to determine how employees react to smart contracts in supply chain management.
Data collection	Structured quantitative questionnaire	A structured quantitative survey is chosen to collect clear and comparable data. This enables systematic data collection which is important to conduct the factor analysis, check the different dimensions of trust and supports the application of the PLS-SEM approach.
Data analysis	Confirmatory factor analysis and PLS-SEM	The confirmatory factor analysis should confirm the dimensions derived from the literature or enable a more realistic representation. PLS-SEM is chosen to analyse the complex relationship between trust, risk and behaviour. PLS-SEM enables a comprehensive analysis of structural equation models.

Table 5: Research design of “Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse”

Layer	Choice	Explanation
Philosophy	Pragmatism	Pragmatism allows also for this study a flexible combination of theoretical frameworks with practical insights to analyse the use of smart contracts in virtual worlds.
Approach	Inductive	An inductive approach was chosen to gain a comprehensive overview of the current state of smart contracts in virtual

		worlds without testing established hypotheses. The inductive approach allows for deriving insights and patterns from the analysis to identify research gaps and future research needs.
Method	Multi-method qualitative	This approach facilitates a deep exploration of the topic, offering a nuanced understanding through qualitative analysis of different virtual worlds.
Strategy	Case Study	Case studies of Decentraland, Sandbox, and Roblox are used to gain insights into the practical implementation and challenges of smart contracts in different settings.
Time horizon	Cross-sectional	A cross-sectional approach is chosen as the study is conducted at a specific point in time to capture the current state of smart contracts in the metaverse. This allows for a snapshot analysis of the existing landscape and challenges.
Data collection	Unstructured qualitative	An unstructured but theory driven qualitative approach is chosen to allow for flexibility and open-ended exploration of the topic. This method supports the identification of emerging themes and patterns in the use of smart contracts.
Data analysis	Transaction Cost Theory (TCT)	TCT is used as a theoretical framework to analyze the transaction costs associated with smart contracts in virtual worlds. This framework helps to identify the factors that influence the adoption and efficiency of smart contracts.

1.4 Research Results

1.4.1 Understanding the role of distributed ledger based smart contracts in the supply chain: A literature review on theoretical implications and research agenda¹

The first study is a scoping review investigating the impact of distributed ledger-based smart contracts in supply chains. It aims to fill a research gap, examining how smart contracts influence processes and operations in supply chain networks. Drawing from the foundational theoretical perspectives in supply chain management (principal-agent theory, transaction cost analysis, resource-based view, and network theory) outlined by Halldorsson et al. (2007), Ankenbrand et al. (2020) and Treiblmaier (2018), the study seeks to provide a comprehensive understanding of the topic and anticipate how smart contracts could shape future supply chain operations. The mentioned theories examine aspects of human behaviour in an organisational context, but with different emphases and perspectives. The review process was guided by the PRISMA 2020 statement, according to Page et al. (2021). We searched multidisciplinary and topic relevant databases Scopus, AIS eLibrary, IEEE Xplore, and ACM Digital Library. After a three-stage evaluation, only 29 of the previous 301 articles matched our expansive inclusion criteria, which we created based on recommendations from (Munn et al., 2018).

Findings from the principal-agent theory view revealed that smart contracts could address information asymmetries (Asante et al., 2021; Grosse et al., 2021; Madhwal et al., 2022), potentially enhancing financing for small and medium-sized enterprises (Asante et al., 2021). They also highlighted the role of smart contracts in reducing multiple problems related to asymmetric information distribution in supply chains, such as adverse selection, hold-up issues, and moral hazards (Beverungen et al., 2021;

¹ The article is currently under review at Journal of Service Management Research.

Xu et al., 2020). Additionally, smart contracts improve transparency, trust, and traceability in supply chains (Dwivedi et al., 2020; Liu et al., 2021).

For transaction cost analysis, findings suggested that smart contracts offer solutions to hidden information problems, potentially reducing ex-post transaction costs (Beverungen et al., 2021). The type of distributed ledger technology was noted to influence transaction costs (Halaburda et al., 2019; Jabbar & Dani, 2020), and once established, distributed ledger networks with smart contracts could facilitate the inclusion of new actors at relatively low costs (Korpela et al., 2017; Kumarathunga, 2020). Automation and decentralised data storage were fundamental mechanisms in reducing search, information, and negotiation costs (Raj et al., 2022; Schmidt & Wagner, 2019; Schmidt et al., 2019).

Previous articles that delved into the resource-based view indicated that smart contracts could contribute to emerging competitive capabilities (Martinez et al., 2019; Yin & Ran, 2021; Yuthas et al., 2021), improve operational-level capabilities (such as information sharing and coordination) (Nandi et al., 2020), and potentially lead to quality compliance (Schmidt et al., 2019), process improvement, flexibility, and cost reduction (Nandi et al., 2020). Smart contracts were also associated with positive effects on quality and the emergence of new business models in supply chains (Treiblmaier, 2018).

Regarding network theory, previous work highlighted the impact of smart contracts on supply chain networks. Smart contracts were found to eliminate redundant activities (Bingzhang & Zirianov, 2021; Treiblmaier & Špan, 2022), optimise routines, improve data capturing, enhance visibility (Compagnucci et al., 2022) and control in interactions with stakeholders (Dasaklis et al., 2019). Smart contracts were adopted to decentralise data, streamline inter-organizational relationships, and reduce dependence on third-party intermediaries (Lohmer et al., 2020; Treiblmaier, 2018). It was also suggested that smart contracts could increase anonymity within the supply chain network through automated communication between devices (Walia & Raghwa, 2022).

An additional outcome of this research is the development of a research agenda derived from the findings in the literature. Some of the research gaps identified related to specific problem solutions to increase trust and collaboration, the theoretical modelling of a trust model, or the existing intention to use smart contracts in supply chains.

1.4.2 Employees' intention to use smart contracts in supply chains: The important role of performance expectancy²

The second study of this work builds on the behavioural assumptions and research gaps identified in the previous literature review. This study utilises the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003) to investigate employees' intention to use and influencing factors towards distributed ledger-based smart contracts in supply chains. Focusing on effort expectation, performance expectation, social influence and favourable conditions, the study aims to provide concrete recommendations for increasing the intention to use and integrate smart contract technology into supply chains. Data was collected through a quantitative online survey of 125 German supply chain employees to gain new insights into adopting smart contracts in supply chains.

A PLS-SEM calculation revealed that among the key factors that mainly cause technology acceptance, according to UTAUT, a significant and strong positive correlation to using smart contracts in supply chains was only observed for performance expectancy. In contrast, neither effort expectation nor social influence showed any significant effects. The moderation variables from the UTAUT Model (Gender, Age, Experience with smart contracts, and Voluntariness of use) did not demonstrate any moderating effects on the key factors.

For control variables on an organisational level, it was observed that the type of industry exhibited a weak influence on behavioural intention, reaching a significance level of 0.1. The role of companies in the supply chain did not show a statistically significant influence. Shifting the focus to the individual level, the study found that various personal characteristics did not significantly impact behavioural

² The article is currently under review at Information Technology and Management.

intention. Specifically, attitude towards smart contracts, anxiety towards smart contracts, and personal openness did not demonstrate a substantial influence on behavioural intention.

However, the descriptive results show an overall positive attitude towards smart contracts. This is reflected in the high-performance expectations associated with smart contracts, a high perceived ease of use and a personal environment that is open to using smart contracts. Furthermore, there is a generally positive and increased intention to use smart contracts in supply chains.

1.4.3 Smart contracts as enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis³

The third study of this work also emerged from the research agenda set in the previous scoping review. This study aims to fill a critical research gap by developing and empirically testing a multidimensional model of trust in smart contracts in the context of supply chains. We follow a two-stage approach by conducting two quantitative surveys of employees of companies involved in supply chains in the US (n=193 for study 1, n=102 for study 2). In study 1, dimensions of trust specific to smart contracts were identified by conducting a confirmatory factor analysis. This provides the groundwork for study 2, in which the dimensions were integrated into a comprehensive trust model. We used a PLS-SEM analysis to empirically examine the role of trust towards smart contracts in supply chain management.

In study 1, a multidimensional trust model was established, based on the general trust dimension according to Hoff and Bashir (2014) and the trust layer of the distributed ledger according to (Lemieux et al., 2019). Following five distinct dimensions of trust were empirically identified: 1: Dispositional trust, 2: Situational social trust, 3: Situational data and situational technical trust (labelled as “Information-technology trust”), 4: Learned social and learned technical trust (named “Interaction-informed trust”), and learned data trust. The analysis revealed the varying contributions of each dimension to the overall trust construct, with information-technology trust being the most influential.

In study 2, the work contributes to the literature by providing an integrative model of trust towards smart contracts in supply chains. Drawing from established trust models, notably the trust model by Mayer et al. (1995) and the role of risk in human-automation trust according to (Stuck et al., 2021), we have adapted and extended existing models to account for the unique features of smart contracts, such as automation and distributed ledger technology. Our conceptualisation goes beyond the existing literature by introducing the five dimensions of trust towards smart contracts found in study 1. The resulting theoretical integrative model addresses the identified research gap and lays the groundwork for empirical investigation in study 2.

The empirical model testing revealed that trust towards smart contracts positively influenced risk-taking behaviour. However, only situational social and information-technology trust significantly impacted risk-taking behaviour among the specific trust dimensions. Perceived situational risk moderated the relationship between trust and risk-taking behaviour positively. Risk-taking propensity was found to increase risk-taking behaviour. The perceived relational risk did not significantly influence trust towards smart contracts. Control variables, age and gender, did not significantly impact risk-taking behaviour.

1.4.4 Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse⁴

The fourth study of this work also resulted from the research needs identified in the scoping review and applies Transaction Cost Theory (TCT) as conceptualised by North and North (1992) and Williamson (1981) to explore smart contracts' potential in virtual worlds. Smart contracts in virtual worlds can streamline supply chain transactions by automating and securing digital agreements, similar to their role in physical supply chains. This technology helps to manage the complex supply chains that form the basis of the virtual economy and facilitates the creation, distribution and exchange of digital goods and

³ The article is currently under review at Technological Forecasting & Social Change.

⁴ The article is published in the Proceedings of the 57th Hawaii International Conference on System Sciences.

services. In this study, Decentraland and Sandbox as virtual worlds with smart contract applications were compared with Roblox as a traditional virtual world without smart contracts. By evaluating the transaction costs, the study measures the feasibility and usability of smart contract-based transactions in virtual worlds. Findings indicate that smart contracts are still nascent and require enhancements from technical, organizational, and user standpoints.

The results show that the transaction costs are high, which represents a hurdle for non-technical users. Especially in the information and selection phase, a high degree of technical affinity is required to create the necessary crypto wallets. The difficulty of creating smart contracts is directly related to the risk of errors in the code. As the contract code is immutable, the cost of reviewing and testing the code is significantly higher and may even preclude the feasibility of complex smart contracts. It is clear that the costs and risks of creating smart contracts in virtual worlds are higher compared to traditional contracts.

In the negotiation phase, smart contracts can automate and accelerate processes; in general, negotiations take place similarly to traditional negotiations in virtual marketplaces. Due to the technical requirements of the distributed-ledger-technology (DLT) architecture, many transaction costs also arise in the decision-making phase, which cannot be reduced even if the processes are automated. The decision-making phase also includes process aspects, such as the maintenance of smart contracts, which are decided by majority vote of the participating nodes. Depending on the architecture, there are different consensus mechanisms that require different amounts of time and costs. For recurring processes in particular, this could lead to a rejection of the use of smart contracts, as no volume effects can be utilised here. This is a major disadvantage compared to non-DLT-based virtual worlds. In addition to blockchain technology, there are also other distributed technologies that can reduce or eliminate transaction costs at this point. However, these have not yet been implemented.

Post-contractual enforcement and monitoring involves storing the resulting transactions and the new status information in the blockchain and confirming them in accordance with the consensus protocol. The use of smart contracts reduces enforcement costs, as almost complete information on the "history" of contract fulfilment is available. However, there are also additional monitoring costs for checking the smart contract code. Another disadvantage of a smart contract is that it cannot be legally amended at a later date. The consensus mechanism is a central problem of transaction cost economics in traditional blockchains. It restricts the legally secure application and can therefore lead to high ex-post transaction costs.

1.5 Research Discussion

This work follows the current evolution of the field of information systems research towards its current multidisciplinary (Jeyaraj & Zadeh, 2019). This work combines the traditional focus on technology adoption with exploring new technologies. The research goes beyond technological considerations and incorporates social theories for a holistic understanding of information systems. With a specific application focus on supply chain management, the study makes a theoretical contribution. It has practical implications for industry practitioners addressing the complex intersection of technology and supply chain dynamics.

The research goal of the first study was to investigate the impact of distributed ledger-based smart contracts on supply chains according to basic supply chain theories and understand how the introduction of smart contracts will change the way supply chains operate. The scoping review underscores the multifaceted benefits of distributed ledger-based smart contracts in supply chains, addressing issues related to information asymmetry, transaction costs, competitive capabilities, and network dynamics. The limited number of 29 included articles can be attributed to the novelty of smart contract technology, the narrow focus on supply chain applications, and the inclusion of only four specific theories. The studies analysed looked at the various theories from different perspectives but were mainly consistent in their key conclusions. These four theories, which, according to previous literature, have been established as fundamental supply chain theories (Ankenbrand et al., 2020; Halldorsson et al., 2007; Treiblmaier, 2018), could also be applied to the smart contract context and have enabled a holistic approach here too. After the literature review, it can be concluded that smart contract technology represents an opportunity to analyse the primary research focuses of the theories and at least partially answer their key questions. By doing that, findings collectively emphasise the transformative potential

of smart contracts across various dimensions of supply chain management. In addition to emphasising the many benefits of smart contracts, shortcomings in current research were also highlighted. The established research agenda shows that despite the valuable insights already gained, there is a need for further research to close potential gaps in the understanding or implementation of smart contracts in supply chains.

The research goal of the second study was to determine the factors that influence employees' intention to use distributed ledger-based smart contracts in supply chains. The results of the empirical study of the UTAUT model in the smart contract context also led to results that need to be discussed individually. The importance of performance expectation as a determining factor for the intention to use smart contracts in supply chains could be explained as follows: Smart contracts offer easy-to-understand benefits such as increasing efficiency, reducing errors or saving time (Kumar et al., 2021; Raj et al., 2022). The simple perception of the benefits could be why performance expectancy is an influential reason for the intention to use. This also corresponds to the assumptions from previous literature (Alazab et al., 2021; Shi et al., 2022). Effort expectancy and social influence do not significantly influence intention to use, which contradicts previous findings (Queiroz & Pereira, 2019; Shi et al., 2022). However, this could be explained as follows: Employees' limited use and experience with this particular technology might need help appropriately evaluating the effort expectation. In contrast to technologies such as the Internet of Things (IoT) or big data, which have been analysed in previous studies (Queiroz & Pereira, 2019; Shi et al., 2022), smart contracts still need to be integrated into business processes. This could lead to a low social influence, as employees may need more contact or exchange about smart contracts.

The research goal of the third study was to investigate how a trust model for smart contracts can be realized taking into account the multidimensionality of the trust construct. In contrast to theoretical expectations, the results emphasised the blended multidimensionality of trust in smart contracts. This challenges the notion of a one-dimensional trust construct of many existing trust models (e.g. Pavlou (2003), Mayer et al. (1995) or Das and Teng (2001)) or existing distinct trust dimensions (Hoff & Bashir, 2014; Lemieux et al., 2019). The dimensions include dispositional, situational and learned aspects at different technology levels and highlight the complexity of trust in the context of smart contract-enabled environments. However, only situational social trust and information-technology trust showed a significant impact on risk-taking behaviour, both belonging to the situational trust layer, according to Hoff and Bashir (2014). This indicates that the situational context influences the intention to use smart contracts. It also suggests that, particularly in complex networks such as supply chain management, the situation determines whether new technologies, such as smart contracts, are utilised. In contrast, dispositional and learned trust levels may focus more on abstract or higher-level aspects of trust that may be less directly targeted at guiding individuals' behaviour in those situations. Furthermore, this again shows the situation and context-dependent significance of existing trust dimensions. Regarding the critical role of risk in building trust, theoretical assumptions made by Stuck et al. (2021) and existing empirical findings (Featherman & Fuller, 2003; Nicholson et al., 2005) could be confirmed.

The research goal of the fourth study was to investigate how smart contracts can be designed in the metaverse in order to optimize transaction costs. Smart contracts in DLT-based virtual worlds offer significant potential to improve efficiency, security and transparency while reducing costs for different types of processes and transactions (Halaburda et al., 2019). In our study, however, we found in a transaction cost analysis based on specific case studies that the various types of transaction costs are often higher compared to traditional automation processes. In addition to the direct costs of executing transactions, the development effort, technical barriers and time required are often higher compared to non-smart-contracts-based environments. To overcome these challenges, improvements should be made at different levels. From a technical perspective, there is a need for reducing smart contract execution costs using scalability solutions such as layer 2 protocols. Additionally, alternative consensus algorithms that offer better efficiency and scalability need to be implemented to address the limitations of traditional Proof-of-Work mechanisms. Interoperability and standardization should be addressed as well. Organizationally, it's important to explore specific use cases and optimize collaboration, governance, and ecosystem development. Building strategic partnerships can enhance the capabilities of virtual worlds, and regulatory and legal considerations are vital for ensuring the responsible and compliant use of smart contracts. From a user perspective, the role of intermediaries and user-specific contract

requirements needs to be considered more precisely. Simplifying the user interface and development frameworks can lower technical barriers, making smart contracts more accessible. Additionally, mitigating cryptocurrency volatility can enhance trust and reduce uncertainty.

In summary, the four studies emphasise the transformative potential of smart contracts in supply chain management. They emphasise the importance of both technological and social factors for successful implementation and integration. The results show how smart contracts can address and mitigate key issues such as information asymmetries, transaction costs, competitive advantage and network dynamics. Smart contracts provide a transparent and immutable record of transactions that is accessible to all parties, fostering trust, reducing disputes and enabling smoother transactions. Their automation capabilities streamline processes, reduce human error and lower transaction costs, especially in complex supply chains with many participants. Smart contracts improve the competitiveness of supply chains by enabling real-time data exchange and automating compliance and verification processes. This leads to better inventory management, faster turnaround times and a better ability to fulfil customer requirements. They also foster innovation through new business models and collaborative approaches based on the decentralised and secure nature of blockchain technology. In addition, smart contracts influence network dynamics by decentralising control and enabling peer-to-peer interactions. This creates more collaborative and resilient supply chain networks that are less dependent on centralised authorities and more responsive to market changes. In addition, the fourth study shows that despite the numerous advantages, the transaction costs of smart contracts are often higher than for traditional automation processes. Improvements in scalability, interoperability and usability are needed to overcome these challenges and realize the full potential of smart contracts.

The results are applicable to different types of supply chains, each with unique characteristics and challenges. In traditional supply chains, smart contracts can increase efficiency and transparency, but integration into existing systems and stakeholder acceptance are challenges. In digital supply chains, they improve automation and data integrity, although privacy and security issues remain. Complex supply chains benefit from improved coordination and trust, but struggle with interoperability and standardisation. Simpler supply chains benefit from error reduction and cost savings, but various high transaction costs and technical expertise can be a barrier. Global supply chains benefit from transparency and immutability, especially in cross-border transactions, but face challenges due to different legal frameworks and the complexity of transactions. Local supply chains can optimise processes and traceability, but the costs and effort can be too high. In regulated industries such as pharmaceuticals and food safety, traceability and compliance are of great value, but strict regulations and audits make implementation difficult. Less regulated industries focus on efficiency gains and cost reductions, but stakeholders need to be convinced and initial inertia needs to be overcome.

Some results could be transferred to adopting other technologies, although with certain limitations. In particular, the specific characteristics of decentralised ledger technology make it difficult to generalise the results. However, due to the automation characteristics of smart contracts, the results can serve as a reference for other automation technologies. Likewise, the generalisation of the results from smart contracts to other application scenarios depends on the particular application case. The theoretical perspectives explored in this work will likely have broader applicability beyond this specific context, as they are not exclusively limited to supply chain management's specific characteristics or challenges. A transfer of the results from this work is likely if the application case also refers to complex networks with different actors. Nevertheless, the use of case-specific characteristics and operational requirements must be considered, and the transferability of the results still needs to be improved.

1.6 Research implications

1.6.1 Theoretical implications

The research results of this thesis provide comprehensive insights into the theoretical implications of distributed ledger-based smart contracts in supply chain management. These findings enhance our understanding of human behaviour in information systems and emphasise the importance of context in technological advances by highlighting the close relationship between information systems and their social and organisational context.

More detailed, the scoping review underscores the multifaceted benefits of distributed ledger-based smart contracts in addressing various theoretical challenges in supply chain management. By providing a comprehensive understanding of how smart contracts influence information asymmetry, transaction costs, competitive capabilities, and network dynamics, the study highlights the transformative potential of smart contracts across different fundamental theoretical aspects of supply chain management. In addition, the identification of research gaps and the proposal for a research agenda represent important further theoretical contributions.

Moving to the domain of technology adoption, the second study contributes to the understanding of technology adoption by applying the UTAUT model to smart contracts in supply chains. This highlights the need for context-specific investigations and confirms the limitations of the general application of adoption models, especially considering the novelty of the technology.

The third study advances the theoretical understanding of trust in distributed ledger-based smart contracts by developing a multidimensional model. After empirical testing, five different dimensions of trust in smart contracts were identified, including dispositional trust, situational social trust, trust in information technology, experience-based trust and trust in learnt data. Furthermore, the study establishes an integrative model of trust towards smart contracts and enriches understanding the trust concept and its multiple factors. It explores the intricate interplay of trust dynamics and risk behaviour and expands the understanding of trust beyond interpersonal interactions in technologically mediated environments. Unlike previous models, the established model acknowledges the importance of a multidimensional understanding of trust while simultaneously considering trust-related constructs and taking into account the specific characteristics of a smart contracts, thus providing a comprehensive framework for the analysis of technology use.

The fourth study's theoretical implications offer a deeper understanding of the role of smart contracts in the metaverse through the lens of TCT, building on previous research (Halaburda et al., 2019). This analysis the groundwork for future studies on smart contracts in virtual environments. We present a detailed research agenda and offer a comprehensive framework for assessing the viability and impact of smart contracts. This encompasses potential benefits such as reduced transaction costs (Eickstädt et al., 2020), increased operational efficiency, and smoother integration between virtual and real-world settings.

Overall, the theoretical implications of this research are broad: This thesis provides a deeper theoretical understanding of how smart contracts can transform supply chain management by addressing key issues such as information asymmetry, transaction costs, competitive capabilities and network dynamics. It extends existing theories in the fields of information systems and supply chain management and provides a more nuanced understanding of technology adoption and trust dynamics specific to smart contracts. The research highlights the crucial role of context in the study of technological innovation and emphasises that the effectiveness and acceptance of smart contracts are closely linked to their social and organisational environment. The identification of research gaps and the proposal for a general and specific research agenda guide further studies that ensure continued exploration and refinement of the theoretical implications of smart contracts.

1.6.2 Practical implications

The results of our studies provide practical recommendations for supply chain managers, especially for those who want to introduce smart contracts in the foreseeable future. In general, a holistic approach is recommended when introducing information systems such as smart contracts. This means aligning the technology with social and organisational processes and understanding the specific circumstances of the business, including cultural and regulatory factors.

The scoping review highlights the transformative effect of smart contracts on supply chains and emphasises benefits such as increased transparency, reduced transaction costs, improved collaboration and trust-building between partners. However, successful implementation requires a holistic approach that includes process redesign, cultural change and collaboration among different actors. Therefore, supply chain managers are advised to assess the current state of their business, considering processes, data infrastructure and level of digitalisation, to determine readiness for adopting smart contracts. Based on the review, a clear smart contract strategy aligned with organisational objectives should be

formulated, specifying the implementation scope, target areas for improvement, and desired outcomes. Collaboration between key partners and actors is necessary. In addition, integrating smart contracts with emerging technologies like IoT and Artificial Intelligence (AI) is recommended to automate data inputs and enhance real-time decision-making, further optimising supply chain operations.

The study on the intention to use smart contracts highlights two critical findings for managers when introducing the technology into supply chains: Firstly, employees are positive towards using smart contracts, suggesting that the next step should be to run initial test programmes to validate and reinforce this attitude. By doing that, the focus on performance expectations is crucial. Secondly, personal characteristics do not influence employees' intention to use smart contracts; technology capability is the primary motivation. Therefore, management should focus on knowledge transfer for successful technology adoption. Leadership support, involving employees in decision-making, and delivering tailored training programmes are critical. To overcome hesitation, mentoring programmes and small pilot projects can help build confidence.

The third study highlights the practical implications for supply chain practitioners and decision-makers in enhancing trust and mitigating risk in smart contract-based networks. The identified trust dimensions provide actionable insights to improve collaboration and transaction security. The findings offer specific recommendations for supply chain managers, such as increasing technological literacy and strengthening user familiarity with smart contracts if there is a low level of trust learned on the technical layer. The study emphasises the link between trust and risk tolerance and suggests that transparent communication and a reliable track record are crucial for the successful integration of smart contracts. It also highlights the importance of situational social trust and trust in information technology in influencing risk-taking behaviour. It recommends tailored strategies to strengthen these dimensions for increased technology adoption.

The practical implications of the fourth study suggest that virtual worlds can leverage our findings to enhance their platforms and attract new customers. Our research agenda outlines practical steps for the development of smart contracts and blockchain technology. Service providers operating in the metaverse can use our analysis to transform their real-world products and services for virtual environments. Additionally, financial transaction providers can explore new service models based on our analysis, which have not been previously available (Masla et al., 2021).

Overall, this research provides practical guidance for the implementation of smart contracts in supply chains. Managers should take a holistic approach and ensure that technology is aligned with organisational and social processes. They should focus on developing a clear strategy that integrates smart contracts with existing systems and other future technologies to improve real-time decision making and operational efficiency. Additionally, fostering a culture of continuous learning and collaboration is vital. Emphasizing transparent communication, building a reliable track record, and supporting employees through tailored training and mentoring programs can significantly boost trust and technology adoption. Insights from the TCT analysis suggest that reducing transaction costs through smart contracts is needed to further enhance operational efficiency and streamline processes. By addressing these higher-level strategies, managers can effectively navigate the complexities of smart contract implementation and achieve sustainable improvements in supply chain operations.

1.7 Limitations

As with any study, this work has some limitations, which provide initial recommendations for future research. The first is the generalisation of the findings of specific studies within the review. Although generalisations provide a comprehensive understanding of particular situations, they may lead to specific aspects being overlooked or misinterpreted. Secondly, the limited sample size of the empirical studies is recognised as a limitation, and caution should be exercised when generalising those results. Despite the use of power analysis methods to determine a sufficient sample size, larger samples would ensure greater reliability of results. Third, the rapid development of smart contract technology is recognised as a factor that may affect the study results as the technology continues to mature. Examining the longitudinal dynamics of individual behaviour would provide further insight.

Another limitation is that the empirical studies focused on a particular application context, smart contracts in traditional or digital supply chain management. A more diverse sample in different contexts,

considering cultural, regulatory, technological and economic differences across regions and industries, is recommended to improve generalisability. Examining behaviour in other sectors, such as finance, healthcare, energy and manufacturing, would provide valuable insights and enable the development of industry-specific frameworks for smart contract-enabled environments. A further limitation is that the empirical research is based on hypothetical behaviour rather than actual behaviour. The reason for this is that the adoption of smart contracts in supply chains is still at an early stage. However, the study acknowledges the possibility of an intention-behaviour gap in both empirical studies and recommends future research to investigate the adoption and use of smart contracts in supply chains. An additional limitation from the TCA on virtual worlds include the restricted investigation of only three virtual worlds, two of which both used Ethereum as fundamental DLT and similar Smart Contract standards. This limited scope raises concerns about the generalizability of findings to other virtual worlds with different characteristics or blockchain technologies.

1.8 Future research

In addition to overcoming the limitations of this work, further research opportunities open up. These arise mainly from the research agenda outlined in the literature review. Future research relates to the need to address specific challenges in the implementation of smart contracts in supply chains. These include ensuring interoperability between different distributed ledger platforms and legacy systems as well as overcoming scalability issues due to high transaction volumes. The prevention of fraud in smart contract-enabled networks is also of great importance.

Future research areas include the practical implementation of monitoring smart contracts, the development of specific mechanisms to strengthen trust and continuous performance evaluation. Research should also be conducted into how smart contracts can optimise processes, reduce transaction costs and improve transparency, traceability and financial reliability in the supply chain. Creating targeted mechanisms to strengthen trust within smart contract networks is critical to fostering long-term collaboration between supply chain actors. Equally important is the development of methods for continuous performance evaluation to ensure that smart contracts continuously achieve their intended goals and thus strengthen the reliability of supply chain operations.

In addition, the empirical work of this thesis has resulted in concrete research recommendations. One important area is the investigation of organisational change processes in connection with the introduction of smart contracts. This includes exploring the challenges and opportunities of integrating smart contracts into existing supply chain systems. A comprehensive investigation of the barriers and benefits encountered when integrating smart contracts is needed and may require realignment of business processes and strategies to maximise the benefits.

Moreover, future research efforts should include a holistic assessment of contextual factors such as organisational culture and the regulatory environment. Understanding how these factors influence trust and risk perception in smart contract-enabled supply chains is critical. By recognising and breaking down these elements, researchers can develop a more nuanced understanding of the multiple interactions that influence the successful implementation and operation of smart contracts in different business environments.

Finally, future research should also take a closer look at different types of supply chains, especially digital and virtual forms. Future research should address the challenges of integration and scalability of smart contracts in both supply chains and blockchain-based virtual worlds, focussing on improving interoperability and reducing transaction costs.

1.9 References

- Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., Omar, M., & Ellahham, S. (2021). Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies. *IEEE Access*, 9, 44905-44927. <https://doi.org/10.1109/access.2021.3066503>
- Alazab, M., Alhyari, S., Awajan, A., & Abdallah, A. B. (2021). Blockchain technology in supply chain management: an empirical study of the factors affecting user adoption/acceptance. *Cluster Computing*, 24(1), 83-101. <https://doi.org/10.1007/s10586-020-03200-4>

- Alter, S. (2015). Sociotechnical Systems Through a Work System Lens: A Possible Path for Reconciling System Conceptualizations, Business Realities, and Humanist Values in IS Development. Conference on Advanced Information System Engineering, Stockholm.
- Alturki, R. (2021). Research Onion for Smart IoT-Enabled Mobile Applications. *Scientific Programming*, 2021, 4270998. <https://doi.org/10.1155/2021/4270998>
- Ankenbrand, K., Linß, I., & Sucky, E. (2020). Theorie(n) des Supply Chain Managements : Eine Literaturanalyse. 1-24. <https://fis.uni-bamberg.de/handle/uniba/45614>
- Asante, M. M., Epiphaniou, G., Maple, C., Al-Khateeb, H. M., Bottarelli, M., & Ghafoor, K. Z. (2021). Distributed Ledger Technologies in Supply Chain Security Management: A Comprehensive Survey. *IEEE Transactions on Engineering Management*, 70(2), 713 - 739. <https://doi.org/10.1109/TEM.2021.3053655>
- Azevedo, P., Gomes, J., & Romão, M. (2023). Supply chain traceability using blockchain. *Operations Management Research*, 16(3), 1359-1381. <https://doi.org/10.1007/s12063-023-00359-y>
- Bandhu, K. C., Litoriya, R., Lowanshi, P., Jindal, M., Chouhan, L., & Jain, S. (2023). Making drug supply chain secure traceable and efficient: a Blockchain and smart contract based implementation. *Multimedia Tools and Applications*, 82(15), 23541-23568. <https://doi.org/10.1007/s11042-022-14238-4>
- Beverungen, D., Overhage, S., Gorlick, A., Moerchel, P., & Schuermann, S. (2021). *Blockchains for pay-per-use Business Models: Insights from a Design Research Study* 54th Hawaii International Conference on System Sciences, Hawaii. <https://doi.org/10.24251/HICSS.2021.677>
- Bingzhang, L., & Zirianov, V. (2021). Blockchain in agricultural supply chain management. *E3S Web of Conferences*, 273(1), 1-10.
- Boiko, A., Shendryk, V., & Boiko, O. (2019). Information systems for supply chain management: uncertainties, risks and cyber security. *Procedia computer science*, 149, 65-70. <https://doi.org/10.1016/j.procs.2019.01.108>
- Bostrom, R. P., & Heinen, J. S. (1977). MIS problems and failures: A socio-technical perspective. Part I: The causes. *MIS quarterly*, 1(3), 17-32. <https://doi.org/10.2307/248710>
- Bottoni, P., Gessa, N., Massa, G., Pareschi, R., Selim, H., & Arcuri, E. (2020). Intelligent Smart Contracts for Innovative Supply Chain Management [Original Research]. *Frontiers in Blockchain*, 3. <https://doi.org/10.3389/fbloc.2020.535787>
- Burrell, G., & Morgan, G. (2019). *Sociological paradigms and organisational analysis: Elements of the sociology of corporate life*. Routledge. <https://doi.org/10.4324/9781315242804>
- Casado-Vara, R., Prieto, J., De la Prieta, F., & Corchado, J. M. (2018). How blockchain improves the supply chain: Case study alimentary supply chain. *Procedia computer science*, 134(1), 393-398. <https://doi.org/10.1016/j.procs.2018.07.193>
- Chen, I. J., & Paulraj, A. (2004). Understanding supply chain management: critical research and a theoretical framework. *International Journal of Production Research*, 42(1), 131-163. <https://doi.org/10.1080/00207540310001602865>
- Chen, W., Botchie, D., Braganza, A., & Han, H. (2022). A transaction cost perspective on blockchain governance in global value chains. *Strategic Change*, 31(1), 75-87. <https://doi.org/10.1002/jsc.2487>
- Chowdhury, M. J. M., Ferdous, M. S., Biswas, K., Chowdhury, N., Kayes, A., Alazab, M., & Watters, P. (2019). A comparative analysis of distributed ledger technology platforms. *IEEE Access*, 7(1), 167930-167943. <https://doi.org/10.1109/ACCESS.2019.2953729>
- Compagnucci, L., Lepore, D., Spigarelli, F., Frontoni, E., Baldi, M., & Di Berardino, L. (2022). Uncovering the potential of blockchain in the agri-food supply chain: An interdisciplinary

- case study. *Journal of Engineering and Technology Management*, 65, 101700.
<https://doi.org/10.1016/j.jengtecman.2022.101700>
- Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply Chain Management: More Than a New Name for Logistics. *The International Journal of Logistics Management*, 8(1), 1-14.
<https://doi.org/10.1108/09574099710805556>
- Cooper, R., & Foster, M. (1971). Sociotechnical systems. *American Psychologist*, 26(5), 467.
<https://doi.org/10.1037/h0031539>
- Das, T. K., & Teng, B.-S. (2001). Trust, control, and risk in strategic alliances: An integrated framework. *Organization studies*, 22(2), 251-283. <https://doi.org/10.1177/0170840601222004>
- Dasaklis, T. K., Casino, F., & Patsakis, C. (2019). Defining granularity levels for supply chain traceability based on IoT and blockchain. *Proceedings of the international conference on omni-layer intelligent systems*, 184-190.
- Dolgui, A., & Ivanov, D. (2023). Metaverse supply chain and operations management. *International Journal of Production Research*, 61(23), 8179-8191.
<https://doi.org/10.1080/00207543.2023.2240900>
- Dolgui, A., Ivanov, D., Potryasaev, S., Sokolov, B., Ivanova, M., & Werner, F. (2020). Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain. *International Journal of Production Research*, 58(7), 2184-2199.
<https://doi.org/10.1080/00207543.2019.1627439>
- Dwivedi, S. K., Amin, R., & Vollala, S. (2020). Blockchain based secured information sharing protocol in supply chain management system with key distribution mechanism. *Journal of Information Security and Applications*, 54, 102554. <https://doi.org/10.1016/j.jisa.2020.102554>
- Eickstädt, A., Horsch, A., & Seidel, E. (2020). Potentials and Limitations of Smart Contracts: A Primer from an Economic Point of View. *European Business Law Review*, 169-183.
<http://www.kluwerlawonline.com/api/Product/CitationPDFURL?file=Journals\EULR\EULR2020007.pdf>
- Featherman, M., & Fuller, M. A. (2003). Applying TAM to e-services adoption: the moderating role of perceived risk. *36th Annual Hawaii International Conference on System Sciences, 2003. Proceedings of the*, 1-11. <https://doi.org/10.1109/HICSS.2003.1174433>
- Fiore, M., Capodici, A., Rucci, P., Bianconi, A., Longo, G., Ricci, M., Sanmarchi, F., & Golinelli, D. (2023). Blockchain for the Healthcare Supply Chain: A Systematic Literature Review. *Applied Sciences*, 13(2).
- Goldkuhl, G. (2017). Separation or unity? Behavioral science vs. design science. 37th International Conference on Information Systems (ICIS),
- Granovetter, M. S. (1973). The Strength of Weak Ties. *American Journal of Sociology*, 78(6), 1360-1380. <http://www.jstor.org/stable/2776392>
- Gregor, S. D., & Hevner, A. R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. *MIS quarterly*, 37, 337-355. <https://doi.org/10.25300/MISQ/2013/37.2.01>
- Grida, M., & Mostafa, N. A. (2023). Are smart contracts too smart for Supply Chain 4.0? A blockchain framework to mitigate challenges. *Journal of Manufacturing Technology Management*, 34(4), 644-665. <https://doi.org/10.1108/JMTM-09-2021-0359>
- Grosse, N., Guerpinar, T., & Henke, M. (2021). Blockchain-Enabled Trust in Intercompany Networks Applying the Agency Theory. *Blockchain and Internet of Things Conference*, 3(1), 8-14.
- Halaburda, H., Levina, N., & Semi, M. (2019). *Understanding smart contracts as a new option in transaction cost economics* 40th International Conference on Information Systems, Munich, Germany,

- Halldorsson, A., Kotzab, H., Mikkola, J. H., & Skjøtt-Larsen, T. (2007). Complementary theories to supply chain management. *Supply Chain Management: An International Journal*, 20(6), 574-586. <https://doi.org/10.1108/SCM-06-2015-0228>
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS quarterly*, 28(1), 75-105. <https://doi.org/10.2307/25148625>
- Hirschheim, R., & Klein, H. K. (2012). A Glorious and Not-So-Short History of the Information Systems Field. *Journal of the Association of Information Systems*, 13, 188-235. <https://doi.org/10.17705/1jais.00294>
- Hoff, K. A., & Bashir, M. (2014). Trust in Automation: Integrating Empirical Evidence on Factors That Influence Trust. *Human Factors*, 57(3), 407-434. <https://doi.org/10.1177/0018720814547570>
- Huang, X., & Chen, P.-K. (2023). *A systematic literature review exploring the relationship between metaverse and supply chain resilience: the role of sensory feedback* Proceedings of the 2022 4th International Conference on E-Business and E-Commerce Engineering, Plymouth, United Kingdom. <https://doi.org/10.1145/3589860.3589872>
- Huynh-The, T., Pham, Q.-V., Pham, X.-Q., Nguyen, T. T., Han, Z., & Kim, D.-S. (2023). Artificial intelligence for the metaverse: A survey. *Engineering Applications of Artificial Intelligence*, 117, 105581. <https://doi.org/10.1016/j.engappai.2022.105581>
- Jabbar, A., & Dani, S. (2020). Investigating the link between transaction and computational costs in a blockchain environment. *International Journal of Production Research*, 58(11), 3423-3436. <https://doi.org/10.1080/00207543.2020.1754487>
- Jeyaraj, A., & Zadeh, A. (2019). Evolution of Information Systems Research: Insights from Topic Modeling. *Information & Management*, 57(1), 103207. <https://doi.org/10.1016/j.im.2019.103207>
- Jones, M. R., & Karsten, H. (2008). Giddens's Structuration Theory and Information Systems Research. *MIS quarterly*, 32(1), 127-157. <https://doi.org/10.2307/25148831>
- Kadry, S. (2014). On the Evolution of Information Systems. In F. Miranda (Ed.), *Systems Theory: Perspectives, Applications and Developments* (1 ed., pp. 197-208). Nova Publishers.
- Kajikawa, Y., Takeda, Y., Sakata, I., & Matsushima, K. (2010). Multiscale analysis of interfirm networks in regional clusters. *Technovation*, 30(3), 168-180. <https://doi.org/10.1016/j.technovation.2009.12.004>
- Kakhki, M., & Gargeya, V. (2019). Information systems for supply chain management: a systematic literature analysis. *International Journal of Production Research*, 57(15-16), 5318-5339. <https://doi.org/10.1080/00207543.2019.1570376>
- Kamath, R. (2018). Food traceability on blockchain: Walmart's pork and mango pilots with IBM. *The Journal of The British Blockchain Association*, 1(1), 1-12. [https://doi.org/10.31585/jbba-1-1-\(10\)2018](https://doi.org/10.31585/jbba-1-1-(10)2018)
- Klein, J. T. (2022). *Pragmatics for cross-disciplinary collaboration* (I. Camerlink, Ed.).
- Korpela, K., Hallikas, J., & Dahlberg, T. (2017). Digital supply chain transformation toward blockchain integration. *50th Hawaii international conference on system sciences*, 1-10.
- Kumar, A., Choudhary, S., Garza-Reyes, J. A., Kumar, V., Rehman Khan, S. A., & Mishra, N. (2021). Analysis of critical success factors for implementing Industry 4.0 integrated circular supply chain – moving towards sustainable operations. *Production Planning & Control*, 1-15. <https://doi.org/10.1080/09537287.2021.1980905>
- Kumar, N. M., & Chopra, S. S. (2022). Leveraging Blockchain and Smart Contract Technologies to Overcome Circular Economy Implementation Challenges. *Sustainability*, 15(15), 9492. <https://doi.org/10.3390/su14159492>

- Kumarathunga, M. (2020). Improving farmers' participation in agri supply chains with blockchain and smart contracts. *2020 Seventh International Conference on Software Defined Systems (SDS)*, 139-144.
- Lavelle, S. (2007). The philosophies of pragmatism and the relations between theory, practice and technology. *Philosophy in Engineering*, 197.
- Legg, C., & Hookway, C. (2008). Pragmatism.
- Lemieux, V., Hofman, D., Batista, D., & Joo, A. (2019). Blockchain Technology & Recordkeeping. <https://doi.org/10.13140/RG.2.2.28447.56488>
- Liu, L., Zhang, J. Z., He, W., & Li, W. (2021). Mitigating information asymmetry in inventory pledge financing through the Internet of things and blockchain. *Journal of Enterprise Information Management*, 34(5), 1429-1451. <https://doi.org/10.1108/JEIM-12-2020-0510>
- Lohmer, J., Bugert, N., & Lasch, R. (2020). Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study. *International journal of production economics*, 228, 107882. <https://doi.org/10.1016/j.ijpe.2020.107882>
- Madhwal, Y., Borbon-Galvez, Y., Etemadi, N., Yanovich, Y., & Creazza, A. (2022). Proof of Delivery Smart Contract for Performance Measurements. *IEEE Access*, 10, 69147-69159. <https://doi.org/10.1109/ACCESS.2022.3185634>
- Mardiana, S. (2020). Modifying Research Onion for Information Systems Research. *Solid State Technology*, 63(4), 1202-1210.
- Martinez, V., Zhao, M., Blujdea, C., Han, X., Neely, A., & Albores, P. (2019). Blockchain-driven customer order management. *International Journal of Operations & Production Management*, 39(6/7/8), 993-1022. <https://doi.org/10.1108/IJOPM-01-2019-0100>
- Masla, N., Vyas, V., Gautam, J., Shaw, R. N., & Ghosh, A. (2021). Reduction in Gas Cost for Blockchain Enabled Smart Contract. *2021 IEEE 4th International Conference on Computing, Power and Communication Technologies (GUCON)*, 1-6.
- Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An Integrative Model of Organizational Trust. *The Academy of Management Review*, 20(3), 709-734. <https://doi.org/10.2307/258792>
- Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business logistics*, 22(2), 1-25. <https://doi.org/10.1002/j.2158-1592.2001.tb00001.x>
- Morgan, D. L. (2014). Pragmatism as a Paradigm for Social Research. *Qualitative Inquiry*, 20(8), 1045 - 1053. <https://doi.org/10.1177/107780041351373>
- Munn, Z., Peters, M. D., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC medical research methodology*, 18(1), 1-7. <https://doi.org/10.1186/s12874-018-0611-x>
- Nandi, M. L., Nandi, S., Moya, H., & Kaynak, H. (2020). Blockchain technology-enabled supply chain systems and supply chain performance: a resource-based view. *Supply Chain Management: An International Journal*, 25(6), 841-862. <https://doi.org/10.1108/SCM-12-2019-0444>
- Naqvi, F. H., Ali, S., Haseeb, B., Khan, N., Qureshi, S., Sajid, T., & Aslam, M. I. (2023). Design and Implementation of Smart Contract in Supply Chain Management Using Blockchain and Internet of Things. *Engineering Proceedings*, 32(1).
- Nicholson, N., Soane, E., Fenton-O'Creevy, M., & Willman, P. (2005). Personality and domain-specific risk taking. *Journal of Risk Research*, 8(1), 157 - 176. <https://doi.org/10.1080/1366987032000123856>

- Nienaber, A.-M., Spundflasch, S., Soares, A., & Woodcock, A. (2020, 2020//). Employees' Vulnerability – The Challenge When Introducing New Technologies in Local Authorities. *HCI in Mobility, Transport, and Automotive Systems*, Cham. https://doi.org/10.1007/978-3-030-50537-0_22
- North, D. C., & North, D. C. (1992). *Transaction costs, institutions, and economic performance*. ICS Press San Francisco, CA.
- Omar, I. A., Jayaraman, R., Debe, M. S., Hasan, H. R., Salah, K., & Omar, M. (2022). Supply Chain Inventory Sharing Using Ethereum Blockchain and Smart Contracts. *IEEE Access*, 10, 2345-2356. <https://doi.org/10.1109/ACCESS.2021.3139829>
- Ormerod, R. J. (2021). Pragmatism in professional practice. *Systems Research and Behavioral Science*, 38(6), 797-816. <https://doi.org/10.1002/sres.2739>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., & Brennan, S. E. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery*, 88, 105906. <https://doi.org/10.1186/s13643-021-01626-4>
- Papathanasiou, A., Cole, R., & Murray, P. (2020). The (non-)application of blockchain technology in the Greek shipping industry. *European Management Journal*, 38(6), 927-938. <https://doi.org/10.1016/j.emj.2020.04.007>
- Patas, J., & Goeken, M. (2011). Paradigms and Information Systems as an applied discipline - A model-based representation, problems, and suggested solutions. *European Conference on Information Systems*,
- Pavlou, P. (2003). Consumer Acceptance of Electronic Commerce: Integrating Trust and Risk with the Technology Acceptance Model. *International Journal of Electronic Commerce*, 7(3), 101-134. <https://doi.org/10.1080/10864415.2003.11044275>
- Peffer, K., Tuunanen, T., Gengler, C. E., Rossi, M., Hui, W., Virtanen, V., & Bragge, J. (2020). *Design science research process: A model for producing and presenting information systems research* First International Conference on Design Science Research in Information Systems and Technology, <https://doi.org/10.48550/arXiv.2006.02763>
- Philipp, R., Prause, G. K., & Gerlitz, L. (2019). Blockchain and Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains. *Transport and Telecommunication Journal*, 20(4), 365 - 378. <https://doi.org/10.2478/tjt-2019-0030>
- Queiroz, M., & Pereira, S. (2019). Intention to adopt big data in supply chain management: A brazilian perspective. *Revista de Administração de Empresas*, 59, 389-401. <https://doi.org/10.1590/s0034-759020190605>
- Rai, A., & Vyas, S. (2023). *A Review on Big Data Utilization in Metaverse World* Proceedings of the 4th International Conference on Information Management & Machine Intelligence, Jaipur, India. <https://doi.org/10.1145/3590837.3590938>
- Raj, P. V. R. P., Jauhar, S. K., Ramkumar, M., & Pratap, S. (2022). Procurement, traceability and advance cash credit payment transactions in supply chain using blockchain smart contracts. *Computers & Industrial Engineering*, 167, 108038. <https://doi.org/10.1016/j.cie.2022.108038>
- Rogers, E. M. (1995). *Diffusion of innovations*. Free Press.
- Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7), 2117-2135. <https://doi.org/10.1080/00207543.2018.1533261>
- Saunders, M., Lewis, P., & Thornhill, A. (2007). *Research methods* (Vol. 6). Person.
- Saunders, M., Lewis, P., Thornhill, A., & Bristow, A. (2019). "Research Methods for Business Students" Chapter 4: Understanding research philosophy and approaches to theory development. In (pp. 128-171). Person.

- Schmidt, C. G., & Wagner, S. M. (2019). Blockchain and supply chain relations: A transaction cost theory perspective. *Journal of Purchasing and Supply Management*, 25(4), 100552. <https://doi.org/10.1016/j.pursup.2019.100552>
- Schmidt, R., Möhring, M., Keller, B., Fuchs, F., Kochsiek, A., & Völkel, F. (2019). *Empirical insights into the benefit from implementing smart contracts* 19th International Conference on Electronic Business (ICEB), Newcastle.
- Shi, Y., Siddik, A. B., Masukujjaman, M., Zheng, G., Hamayun, M., & Ibrahim, A. M. (2022). The Antecedents of Willingness to Adopt and Pay for the IoT in the Agricultural Industry: An Application of the UTAUT 2 Theory. *Sustainability*, 14(11), 6640. <https://doi.org/10.3390/su14116640>
- Shul'zhenko, T. G. (2020). Methodological Approach to the Reengineering of Logistics Business Processes in the Transport Chains with the Implementation of Smart Contracts. *Management science*, 10(2), 53-73. <https://doi.org/10.26794/2404-022X-2020-10-2-53-73>
- Silva, T. P. d. (2019). O impacto da Tecnologia da Informação na Gestão de Pequenas empresas. *Revista Formadores*, 12(6), 1-14.
- Simpson, B. (2018). Pragmatism: A philosophy of practice. *The SAGE handbook of qualitative business and management research methods*, 54-68.
- Stanton, N. A. (2022). Systems-thinking for safety: a short introduction to the theory and practice of systems-thinking. *Ergonomics*, 65, 327 - 327. <https://doi.org/10.1080/00140139.2021.1992965>
- Stuck, R. E., Holthausen, B. E., & Walker, B. N. (2021). Chapter 8 - The role of risk in human-robot trust. In C. S. Nam & J. B. Lyons (Eds.), *Trust in Human-Robot Interaction* (pp. 179-194). Academic Press. <https://doi.org/10.1016/B978-0-12-819472-0.00008-3>
- Sun, H., & Huang, Y. (2018). Distributed ledger technology and economic contract innovation. International Conference on Crowd Science and Engineering, Singapore. <https://doi.org/10.1145/3265689.3267929>.
- Sunyaev, A. (2020). Distributed Ledger Technology. In A. Sunyaev (Ed.), *Internet Computing: Principles of Distributed Systems and Emerging Internet-Based Technologies* (pp. 265-299). Springer International Publishing. https://doi.org/10.1007/978-3-030-34957-8_9
- Taherdoost, H. (2022). An Overview of Trends in Information Systems: Emerging Technologies that Transform the Information Technology Industry. *Cloud Computing and Data Science*, 4(1), 1-16. <https://doi.org/10.37256/ccds.4120231653>
- Tan, G. W., Shaw, M. J., & Fulkerson, B. (2000). Web-based Supply Chain Management. *Information Systems Frontiers*, 2(1), 41-55. <https://doi.org/10.1023/A:1010093803431>
- Thakker, U., Patel, R., Tanwar, S., Kumar, N., & Song, H. (2020). Blockchain for diamond industry: Opportunities and challenges. *IEEE Internet of Things Journal*, 8(11), 8747-8773. <https://doi.org/10.1109/JIOT.2020.3047550>
- Tornatzky, L. G. F. M. C. A. K. (1990). *The processes of technological innovation*. Lexington Books.
- Treiblmaier, H. (2018). The impact of the blockchain on the supply chain: a theory-based research framework and a call for action. *Supply Chain Management: An International Journal*, 23(6), 545-559. <https://doi.org/10.1108/SCM-01-2018-0029>
- Treiblmaier, H., & Špan, Ž. (2022). Will blockchain really impact your business model? Empirical evidence from Slovenian SMEs. *Economic and Business Review*, 24(2), 132-140. <https://doi.org/10.15458/2335-4216.1302>
- Trist, E. L. (1978). On socio-technical systems. *Sociotechnical systems: A sourcebook*, 43-57.
- Trist, E. L. (1981). *The evolution of socio-technical systems* (Vol. 2). Ontario Quality of Working Life Centre Toronto.

- Tsarsitalidis, S., Compagnucci, M. C., Kousiouris, G., & Dahi, A. (2021). Feeding Smart Contract Legal Requirements with Semantic and Event Detection Logic Structures from Modern Service Oriented Supply Chains. *SSRN Electronic Journal*, 1-13.
<https://doi.org/10.2139/ssrn.3876382>
- Tsvetkov, B., & Kostadinov, H. (2019). *DLT smart contract platforms for software lifecycle management* International Conference for Promoting the Application of Mathematics in Technical and Natural Sciences - AMiTaNS'19, <https://doi.org/10.1063/1.5130875>
- Vashistha, N., Hossain, M. M., Shahriar, M. R., Farahmandi, F., Rahman, F., & Tehranipoor, M. M. (2022). eChain: A Blockchain-Enabled Ecosystem for Electronic Device Authenticity Verification. *IEEE Transactions on Consumer Electronics*, 68(1), 23-37.
<https://doi.org/10.1109/TCE.2021.3139090>
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 27(3), 425-478.
<https://doi.org/10.2307/30036540>
- Verdouw, C. N., Wolfert, J., Beulens, A. J. M., & Rialland, A. (2016). Virtualization of food supply chains with the internet of things. *Journal of Food Engineering*, 176, 128-136.
<https://doi.org/10.1016/j.jfoodeng.2015.11.009>
- Vo, K. T., Nguyen-Thi, A. T., & Nguyen-Hoang, T. A. (2021). Building Sustainable Food Supply Chain Management System Based On Hyperledger Fabric Blockchain. *International Conference on Advanced Computing and Applications (ACOMP)*, 15(1), 9-16.
<https://doi.org/10.1109/ACOMP53746.2021.00008>
- Walia, K., & Raghwa, N. (2022). Social Networking in an Information-Centric System with Blockchain. *2022 3rd International Conference on Intelligent Engineering and Management (ICIEM)*, 175-182.
- Wang, S., Li, D., Zhang, Y., & Chen, J. (2019). Smart contract-based product traceability system in the supply chain scenario. *IEEE Access*, 7(1), 115122-115133.
<https://doi.org/10.1109/ACCESS.2019.2935873>
- Williamson, E. A., Harrison, D. K., & Jordan, M. (2004). Information systems development within supply chain management. *International Journal of Information Management*, 24(5), 375-385.
<https://doi.org/10.1016/j.ijinfomgt.2004.06.002>
- Williamson, O. E. (1981). The economics of organization: The transaction cost approach. *American journal of sociology*, 87(3), 548-577.
- Wu, Y., Li, J., Zhou, J., Luo, S., & Song, L. (2022). Evolution Process and Supply Chain Adaptation of Smart Contracts in Blockchain. *Journal of Mathematics*, 2022, 2839566.
<https://doi.org/10.1155/2022/2839566>
- Xu, L., Tu, P., & Tang, Q. (2020). Contract design for cloud logistics (cl) based on blockchain technology (BT). *Complexity*, 2020(4), 1-13. <https://doi.org/10.1155/2020/5305808>
- Yin, W., & Ran, W. (2021). Theoretical Exploration of Supply Chain Viability Utilizing Blockchain Technology. *Sustainability*, 13(15), 8231. <https://doi.org/10.3390/su13158231>
- Yuthas, K., Sarason, Y., & Aziz, A. (2021). Strategic value creation through enterprise blockchain. *The Journal of The British Blockchain Association*, 4(1), 1-18. [https://doi.org/10.31585/jbba-4-1-\(7\)2021](https://doi.org/10.31585/jbba-4-1-(7)2021)
- Zhang, X. (2023, 24-26 Feb. 2023). Blockchain Technology based Metaverse Development Application. 2023 IEEE 6th Information Technology,Networking,Electronic and Automation Control Conference (ITNEC), <https://doi.org/10.1109/ITNEC56291.2023.10082490>
- Zhang, Y., Yutaka, M., Sasabe, M., & Kasahara, S. (2020). Attribute-based access control for smart cities: A smart-contract-driven framework. *IEEE Internet of Things Journal*, 8(8), 6372-6384.
<https://doi.org/10.1109/IIOT.2020.3033434>

2 Understanding the role of distributed ledger based smart contracts in the supply chain: A literature review on theoretical implications and research agenda⁵

Wieland Müller and Michael Leyer

Abstract

The use of distributed ledger-based smart contracts in supply chain operations is relevant for automating processes, enhancing information availability, and ensuring transparency. However, despite technical advancements, a knowledge gap exists regarding the implications of smart contract integration. This scoping review aims to outline theoretical findings. Results highlight the potential for reducing intermediaries, enhancing trust, lowering transaction costs, and transforming supply chains into networks. This article contributes by summarizing theoretical knowledge, identifying research gaps, and proposing a research agenda. Furthermore, it offers practical recommendations, emphasizing the need for aligning company structures, establishing standards, and considering employee behaviour when implementing smart contracts.

Keywords: Smart Contracts, Supply Chain Innovation, Behavioural Supply Management, Supply Chain Theories, Research Agenda

⁵ The article is currently under review at Journal of Service Management Research.

2.1 Introduction

Supply chain management is confronted on the one hand with a growing demand for greater transparency and traceability of products and processes. On the other hand, the demand for individualised products and services is constantly increasing. Supply chains must adapt to these changes; due to their increasing complexity, the processes can no longer be managed using standard planning methods (Premm & Kirn, 2015). Also, trust must be established for traceability technologies to be accepted (Alahmadi & Lin, 2019).

Distributed ledger-based smart contracts present a solution that can meet all these requirements through the integration of the technology into the supply chain (Arumugam et al., 2018; Kim et al., 2018; Raj et al., 2022). The implementation of distributed ledger technology is already gaining popularity in supply chain management (Papathanasiou et al., 2020). For example, the chemical manufacturer BASF uses distributed ledgers to obtain and share information about the life cycle of products (Kouhizadeh et al., 2020).

While practical applications exist, only a few projects have started to use the potential of smart contracts. In addition to the still emerging technical development, there are other open questions regarding integrating smart contracts into supply chain processes and numerous opportunities to expand theory on traditional topics and explore new topics (Lumineau & Oliveira, 2020). Currently, little theoretical and practical literature specifically addresses the implementation of smart contracts (Sodhi & Tang, 2021). Moreover, studies focus primarily on the conceptual design of smart contracts rather than their actual impact on supply chain processes or just the higher-level distributed-ledger technology (Büttgen et al., 2021). Consequently, there is a need for further research to investigate the effects of smart contract use in supply chains.

Therefore, the research gap that we want to address in this paper concerns a clear overview of smart contracts' impact on supply chain networks' processes and operations. To provide a comprehensive understanding, we will examine the impact of smart contracts from the perspective of four critical supply chain theories. The existing supply chain operations can be assessed in a holistic view by using four different theories: The principal-agent theory (PAT), transaction cost analysis (TCA), the resource-based view (RBV), and network theory (NT) (Ankenbrand et al., 2020; Halldorsson et al., 2007). The combination of different theories enables a holistic approach to the study of the complex interactions within a supply chain.

By conducting a scoping review according to PRISMA 2020 guidelines, we want to answer the following research questions: *RQ1: What are the implications of using distributed ledger-based smart contracts in supply chains from the theoretical perspectives of principal-agent theory, transaction cost theory, resource-based view, and network theory?* This examination aims to present a comprehensive view and uncover the areas of the theories that still need to be considered. Furthermore, we also want to answer a second research question: *RQ2: How will adopting smart contracts change how supply chains operate?* This aims to predict future trends and give practical recommendations for managing supply chains. This paper seeks to set a research agenda for future research based on the results from both research questions. In addition to the theoretical results of the scoping review, this article also provides practical recommendations for supply chain organisations regarding smart contracts implementation.

The following section describes the technological fundamentals of smart contract technology and its application cases in the supply chain. It also explains the four selected supply chain theories in more detail. In section three, the methodology is presented, followed by an explanation of the strategy and the study selection. The results section then presents the existing literature. This is followed by a discussion, and future research directions are derived. This work concludes with theoretical and practical implications, limitations, and future research.

2.2 Fundamentals

2.2.1 Distributed ledger and smart contract technology

A distributed ledger is a technology for storing and transmitting information in encrypted form. In addition to the actual information, further data about the initialisation time is stored automatically (Vo et al., 2021). Blockchain is the best-known form of distributed ledger technology. It differs in its data structure from other distributed ledger architectures but also shares some similarities: Indestructibility, immutability, security, and transparency of data (Vo et al., 2021). Differences from distributed ledger technologies are mainly in how transactions are stored and validated, resulting in different scalability, flexibility, transaction speed, energy consumption, and transaction costs (Chowdhury et al., 2019).

Smart contracts are digital contracts written to the distributed ledger by an “if-this-then-that” code. They can be executed independently without the need for third-party management. It is ensured that all parties know the contract details and the terms are automatically enforced as soon as they are fulfilled (Vo et al., 2021). All actors define conditions for executing an event as a smart contract in the distributed ledger. As soon as the conditions match, the content specified in the smart contract is automatically executed. Direct contract discussions and intermediaries are no longer necessary. The characteristics of smart contracts are thus influenced to a large extent by the underlying distributed ledger. However, they also bring some more characteristics, especially the automation of processes.

Although information about processes or products can also be stored directly on the distributed ledgers, creating links between the distributed ledger and external databases makes more sense. This enables a more efficient performance of the information transfer, but all activities can still be transparently tracked via the data stored in the distributed ledger (Vo et al., 2021; Zhang et al., 2020).

2.2.2 Use of smart contracts in the supply chain

Including smart contracts in supply chain management would optimise production processes and expand them to include transparency and traceability. In addition to the production-related benefits, further data also ensures servitisation optimisation, which also occurs in manufacturing (Khan et al., 2022). Modern supply chains have become more complex, consisting of interconnected entities, and have evolved into a supplier network (Mari et al., 2015). Shorter paths and enable more efficient operations in supply networks (Hearnshaw & Wilson, 2013). Also, the connection between synchronicity, digital processes, and technologies through distributed ledgers is a promising research approach (Acero et al., 2022).

Only a few studies have conducted smart contracts in a supplier-provider context, but interest has substantially increased (Martinez et al., 2019). A key advantage of smart contract use in supply chains comes from the decentralised network form of distributed ledgers. Decentralisation ensures that all information is made available to all other actors and that no individual exchange of information takes place between individual actors. Data stored in the or linked to the distributed ledger network can be transport information (sensor data, real-time location data), product data (price, quality, batch number), origin data (country of manufacture, factory), or customer data (ownership certificate) and many others (Vo et al., 2021). Based on this information, smart contracts can automatically conclude contracts that trigger the transfer of goods, services, valuables, and payments. The traditional supply chain is changing because the exchange of information and contracting is shifting from two actors to a decentralised network (Wang et al., 2019).

The adoption leads to opportunities for increased automation and bypassing intermediaries. Due to the technical basis, the processes are legally secure, traceable, trustworthy, and safe. In addition to efficiency optimisation, problems of traditional supply chains, such as data reliability and production transparency, can be solved (Casado-Vara et al., 2018).

2.2.3 Theories of supply chain management

The focus on theory-driven perspectives is highly relevant as it provides a structured framework for analysing and interpreting the implications of smart contracts in supply chains, facilitating a

comprehensive understanding of the technology's impact on various critical aspects of supply chain management. According to Halldorsson et al. (2007), the existing supply chain operations can be assessed using four theories: The principal-agent theory, transaction cost analysis, resource-based view and the network theory. These four theories are the most crucial supply chain theories (Ankenbrand et al., 2020). They can be used complementary to describe the processes in a supply chain holistically and from different perspectives (Treiblmaier, 2018).

Principal-agent theory and transaction cost analysis are valuable theories for structuring supply chains. Still, they have limitations due to their assumptions about human behaviour and the static view of corporate boundaries (Halldorsson et al., 2007). The principal-agent theory focuses on the relationship between two actors, where both strive to maximise their advantage. Still, there is an asymmetrical distribution of information between the principal and the agent (Jensen & Meckling, 1976). The principal has incomplete information about the agent's behaviour and must rely on trust to some extent (Treiblmaier, 2018), leading to an imbalance of transaction power.

In supply chains, the relationships between participants can be seen as bonds that limit opportunistic behaviour and reduce default intentions due to common goals. However, the challenges of the principal-agent theory still arise. Negotiation and maintenance of agreements in supply chains continue to be based on information asymmetries and mutual trust (Liu et al., 2021). The principal-agent theory has been applied in various areas of supply chain management, such as procurement, manufacturing, and logistics. Many studies in supply chain management based on agency theory focus on general buyer-supplier (principal-agent) relationships, addressing conflicting goals, the uncertainty of outcomes, and evaluation of other actors' behaviour (Fayezi et al., 2012). However, a limitation remains as only some actions of the contractors can be observed.

Transaction cost analysis refers to the costs associated with conducting exchanges between companies or transferring resources within a company (Hobbs, 1996). These include information, communication, and coordination charges, such as search, initiation, agreement, handling, adjustment, and control costs. In supply chain management, transaction cost theory can be applied to the "make-or-buy" decision, contracting, and selection of the most cost-effective transaction types (Williamson, 2008). Outsourcing components is preferred when transaction costs are low or can be minimised through safeguards, while production should be done internally if transaction costs outweigh the benefits (Schwabe, 2013). Higher asset specificity increases the probability of transaction costs in contracting due to negotiation, planning, adherence, and monitoring of contracts (Schwabe, 2013). The prevention of opportunistic behaviour is crucial in supply chain management to execute complex transactions with less effort and lower transaction costs.

The resource-based view and network theory are complementary theories considering governance structures and inter-organizational relationships. The resource-based view focuses on individual supply chain actors' resources, capabilities, and competencies (Collis & Montgomery, 1995). It asserts that sustainable competitive advantage is achieved through valuable, rare, inimitable, and non-replaceable resources and capabilities, which must be absorbed and applied (Barney, 1991; Barney, 1994). Collaboration with upstream and downstream partners is essential for improving performance and survival in a competitive marketplace, benefiting the entire supply chain (Xu et al., 2014). Customers are an important external information source, especially when learning processes or innovation practices are the focus (Paiva et al., 2008). Integrating and coordinating processes like production, purchasing, sales, and logistics enhances business performance and provides competitive advantages (Vitorino Filho & Moori, 2020). Furthermore, Collaboration in supply chains allows resource sharing, creating a pool of resources that improves capabilities and competitive advantages for all players. Therefore, effective supply chain management should focus on resource sharing and cooperative collaboration to create competitive advantages.

Network theory is pivotal in understanding inter-organizational relationships and establishing trust through relational and exchange processes (Halldorsson et al., 2007). Often, within networks, intermediaries act as vital conduits for information dissemination (Treiblmaier, 2018). Network optimisation aims to enhance efficiency by shortening path lengths or establishing long-distance connections (Kajikawa et al., 2010). The applicability of network theory extends to supply chains, highlighting the significance of coordination mechanisms (Ankenbrand et al., 2020). In conventional

supply chains, relationships are primarily observed between two actors in direct downstream positions, necessitating the involvement of intermediaries to transmit information among actors further along the supply chain. Consequently, indirect relationships emerge among different actors within the supply chain (Treiblmaier, 2018). Table 6 compares the theories in terms of their characteristics and relates them to supply chain management Treiblmaier (2018).

Table 6: Comparison of supply chain theories (adopted from Treiblmaier (2018)).

Characteristics	PAT	TCA	RBV	NT
Problem orientation	Contract design, execution and control	Efficient governance structure	Internal competence development	Triadic networks relationships
Key question	What is the most efficient contract between suppliers and buyers?	How can transaction costs within the supply chain be reduced?	How can common resource advantages be exploited?	How can the supply chain network be evolved?
Primary focus of analysis	Control through contracts and incentives	Costs of intra- and interorganizational transactions	Competitive consequences of resource reallocation	Relationships in the network
Primary domain of interest	Risk and goal alignment	Optimization of transactions costs	Development of organizational resources and capabilities	Mutual adaptation of relations

2.3 Research Method

2.3.1 Search Strategy

A scoping review was conducted to present the implementation of smart contracts in supply chains. Scoping reviews are deliberately chosen to determine the full extent of a body of literature on a topic and to provide an overview of the available literature and studies (Munn et al., 2018). There are four main reasons for conducting a scoping study: (1) to examine the scope, range, and nature of existing research activity, (2) to determine the value of a full systematic review, (3) to summarise and distribute research findings, and (4) to identify research gaps in the existing literature (Arksey & O'Malley, 2005). Scoping reviews are not intended to provide a critically evaluated and synthesised answer to a specific question but rather to give an overview (Munn et al., 2018). This study examines the scope, range, and nature of existing research activity and summarises findings regarding the theoretical consideration of the distributed ledger-based smart contract implementation in supply chains. It also provides a basis for a research agenda by identifying research needs and summarising existing knowledge. The PRISMA 2020 Statement was chosen as a standard guideline for the review (Page et al. 2021).

2.3.2 Study Selection

In addition to the Scopus index, articles available on the more technology-based databases AIS eLibrary, IEEE Xplore and ACM Digital Library databases have been included in the search. Scopus, one of the two most extensive and multidisciplinary databases, was included in the search; the other databases specialise in information systems, computer science, and technology. The literature search was conducted in October 2022 and was limited to English-language journal articles and conference papers.

No time restriction was imposed. The following search string was used: ("smart contract" AND "supply chain" AND ("principal-agent theory" OR "transaction cost theory" OR "transaction cost analysis" OR "resource-based view" OR „network theory")). Combining these elements in the search string aims to retrieve relevant literature that discusses the use of smart contracts in supply chains while also considering different theoretical perspectives that can provide a deeper understanding of the topic. The general terms ensure that an enormous scope can be examined. The search string was applied to the title and abstract, and the later in-depth analysis also included the full text of the articles.

The studies were evaluated as "relevant" or "not relevant" in a three-stage process. First, based on the author and title, it was checked for duplications. Second, the title and abstract had to match two inclusion criteria: The article must relate to smart contracts (not just the use of distributed ledger in general), and it must be smart contracts based on distributed ledger technology. The third step was a deep analysis. Two further inclusion criteria were examined here: First, the results relate (at least among others) to the application in the area of supply chains, and second, the smart contract application was considered from a theoretical point of view using one of the four mentioned theories. Since a scoping review should use expansive inclusion criteria (Munn et al., 2018), no further inclusion criteria were determined. Finally, 29 articles could be included in the evaluation, some of which showed results for more than one theory considered. Given the small amount of research on the emerging field of smart contracts in supply chains, this area was further narrowed by considering only four individual theories. This resulted in a small number of eligible articles. However, focusing on articles with specific applications of the four theories mentioned ensures that the overall quality and reliability of the results are maintained. Figure 6 provides an overview of the selection process.

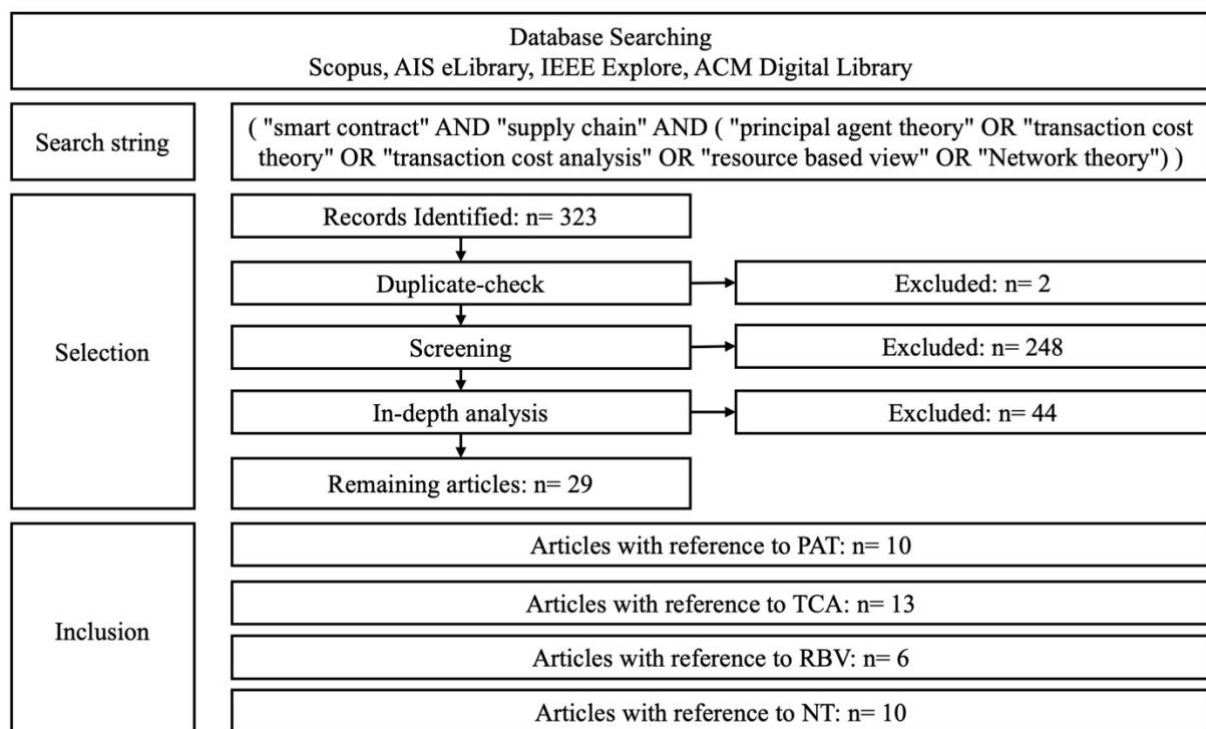


Figure 6: The selection process of articles adapted from Page et al. (2021).

The abstracts and full texts were reviewed independently by two reviewers. The Cohen kappa coefficient was used (McHugh, 2012) to capture differences within this independent process. The selection of relevant search results has a kappa value of 0.544, which according to McHugh (2012) corresponds to a moderate degree of agreement between the author and reviewer. We explain the small number of papers used mainly for three reasons: First, we deal with a novel technology on which little literature is available. Second, we also focus on a specific application, further narrowing the scope. Third, we only consider the four theories mentioned in our analysis. However, this substantial limitation is necessary to answer the research questions and derive concrete implications.

2.4 Results

The results of the scoping review are summarised in four tables below. The results of the scoping review are summarised in four tables below. They all relate to the specific topic of distributed ledger-based smart contracts in supply chains. Based on the literature search, nine articles that refer to the theoretical consideration of smart contracts in supply chains concerning the principal-agent theory could be found. The main findings are presented in the following Table 7.

Table 7: Results of the literature search regarding the principal agent theory.

Authors	Findings
Asante Boakye, Zhao, and Ahia (2022)	Smart contracts could reduce information asymmetries in the financial sector, improving financing for small and medium-sized enterprises
Beverungen et al. (2021).	The irreversible storage of transaction and contracts ensures high quality information. Irreversible and self-executing smart contracts providing little room for hidden information.
Chen et al. (2022)	A minor error in a smart contract can threaten the relationship between trading partners and disrupt trust in the entire supply chain if the smart contract rules are not coded correctly.
Dwivedi, Amin, and Vollala (2020)	The main problems identified in existing pharmaceutical supply chains were a lack of transparency, trust and traceability and can be overcome through distributed ledger technologies.
Grosse, Guerpinar, and Henke (2021)	Smart Contracts reduce multiple problems of asymmetric information distribution. Adverse selection due to hidden characteristics is prevented by increased credibility in the information and negotiation phase Hold-up due to hidden intentions can be decreased by the reduced number of intermediaries leading to a reduced source of mistrust. Moral hazard due to hidden information or actions is avoided by automatically executing predetermined activities without any party being able to influence them. Smart contracts can lead to increased trust among supply chain actors while eliminating information asymmetries.
Liu et al. (2021)	Smart contracts can help regulate accountability and claiming and promote negotiation efficiency between parties. The quality of information transmitted, the effectiveness of communication, and the volume and frequency of information exchange can be improved. A distributed ledger can facilitate credible information transformation that enables banks to extract knowledge from securities.
Madhwal et al. (2022)	Disintermediation in supply chains through smart contracts helps reduce information asymmetry Improving the monitoring of supply chain performance with distributed ledger-based smart contracts can increase operational reliability as there is less conflicting data

	between sending and receiving warehouses. This can contribute to a sense of fairness between partners, even when failed deliveries incur penalties.
Treiblmaier (2018)	Guarantees, embedded in smart contracts, provide guarantees for both parties that comprehensively solve the agency problem
van Groesen and Pauwels (2022)	Risks and trust issues between stakeholders in construction supply chains due to the pursuit of divergent goals and mutual dependencies can be reduced through smart contracts Smart contract-based asset tracking increases the efficiency of data collection, communication, and centralized storage
Xu, Tu, and Tang (2020)	In order to reduce information asymmetry and gain trust, certain mechanisms must be taken into account during implementation. These include the deposit of part of the amount the guarantee of the transactions, as well as automatic sanction functions and penalty payments.

Regarding the transaction cost analysis, thirteen articles with relevant content were identified. The main findings are presented in the following Table 8.

Table 8: Results of the literature search regarding the transaction cost analysis.

Authors	Findings
Beverungen et al. (2021)	Smart contracts offer little room for hidden information and thus can reduce ex-post transaction costs. How high the transaction costs turn out also depends on the type of distributed ledger technology on which the smart contracts are written. Once the distributed ledger network with smart contracts is established, new actors can be included in the smart contracts at comparatively low-cost.
Bingzhang and Zirianov (2021) and Zirianov (2021)	The delay and error rate of ownership documents could be reduced thanks to smart contracts, and transaction costs saved.
Chen et al. (2022)	Automating and decentralised data storage reduces search and information costs Smart contracts can significantly shorten the negotiation phase through automation and thus reduce negotiation costs. Smart contracts in distributed ledger enable the management of many short- or long-term contracts, allowing small businesses to operate as efficiently as larger companies.
Halaburda, Levina, and Semi (2019)	Costs for monitoring can be reduced by avoiding ambiguity about compliance with contract terms, avoiding costly disputes, and using software for monitoring. Smart contracts promise to prevent renegotiation by fixing terms in advance. It can be very costly to write a smart contract for all auteurs of a supply chain.
Jabbar and Dani (2020)	The excessive use of smart contracts can clog networks and lead to scaling problems.

Korpela, Hallikas, and Dahlberg (2017)	Distributed ledger technology provides security and flexibility at a lower cost than traditional transactions, as decentralization can simplify access to information and communication within the supply chain.
Kumarathunga (2020)	Supply chain actors can significantly reduce transaction costs if smart contracts are implemented. This allows many actors to join existing supply chains more simply.
Madhwal et al. (2022)	Smart contracts can decrease the number of delivery failures over time, reducing penalties and enforcement overall transaction costs. Smart contracts can increase operational reliability because there is less conflicting data between logistics service providers and receiving warehouses. The immutability of the data, and smart contracts can help reduce the cost of data verification and dispute resolution.
Raj et al. (2022)	By reducing paperwork and using software for product tracking, transaction costs are lowered through smart contracts.
Schmidt and Wagner (2019)	Automating and decentralised data storage reduces search and information costs Smart contracts reduce behavioural and environmental uncertainties through their specified terms, thus limiting opportunism and also thereby reducing transaction costs.
Schmidt et al. (2019)	Smart contracts can reduce transaction costs through disintermediation and automation.
Treiblmaier (2018)	The implementation of smart contracts simultaneously affects internal and external transaction costs
Treiblmaier and Špan (2022)	Smart contracts can increase transaction revenues in supply chains.

Only six papers addressed the use of smart contracts in supply chains from a resource-based view. The main findings are presented in the following Table 9.

Table 9: Results of the literature search regarding the resource-based view.

Authors	Findings
Martinez et al. (2019)	Potential emerging competitive capabilities of smart contracts include routines that identify and filter competitive opportunities based on consumer behaviour and knowledge of supply chain flexibility.
Nandi et al. (2020)	Current distributed ledger and smart contracts efforts in supply chains are aimed at improving capabilities at the operational level (information sharing and coordination) rather than the strategic level (integration and collaboration). The use of smart contracts can, lead to quality compliance and improvement, process improvement, flexibility, cost reduction and shortening of process time. Outcomes may vary by industry as they are unpredictable.
Schmidt et al. (2019)	The use of smart contracts has a significant positive effect on quality.

	Sharing smart contracts across supply chain actors enables work to be done consistently, resources to be used optimally and time and flexibility to be improved.
Treiblmaier (2018)	In addition to competitive advantages, new business models may also emerge, representing further competitive models. Existing companies could find innovative ways to integrate distributed ledger technology and smart contracts into their service portfolios. Thus, new supply chain participants could emerge that offer services required for distributed ledger and smart contracts technology
Yin and Ran (2021)	The more value smart contracts add to customers, the greater the potential competitive advantage of those supply chains.
Yuthas, Sarason, and Aziz (2021)	Through combined knowledge and experience with smart contracts, strategic competitive advantages can be achieved.

Ten of the articles were related to network theory. The main findings are presented in the following Table 10.

Table 10: Results of the literature search regarding the network theory.

Authors	Findings
Bingzhang and Zirianov (2021)	Some network activities are made redundant and eliminated through smart contract adoption. Actions can be executed automatically based on absolute or relative circumstances, replacing many communication paths and reviews.
Compagnucci et al. (2022)	Especially routines can be optimised by smart contracts. Smart contracts improve data capturing and change the way organisations interact with stakeholders. They improve visibility and control by simplifying data input and reducing the amount of information required. There is still a need for focal actors and interdisciplinary skills to initiate and support the network
Dasaklis et al. (2019)	Full decentralisation through smart ledger contracts would achieve end-to-end data transparency between entities, processes and actors in the supply chain.
Kajikawa et al. (2010)	Shortening the pathway by reducing intermediaries can increase efficiency in supply chain exchange processes.
Kumarathunga (2020)	Smart contracts can enable supply chain network participation through lower transaction costs.
Lohmer et al. (2020)	Unlike in traditional supply chains, the flow of information and networking no longer occurs only in the traditional upstream/downstream area but also at the horizontal and vertical levels and in the collaboration between companies in the supply chain. Smart contracts enable better collaboration through transparency, trust and reliability in exchanges between actors. The impact of smart contracts on the social capital of supply chain partners is mainly expressed through formal and informal trust building.

Petersen (2022)	The more effective the governance mechanisms enabled by applications with distributed ledger smart contract functionality, the lower the level of contractual governance used by distributed ledger participants will be.
Treiblmaier (2018)	Through decentralized data, the indirect relationship between two actors can be replaced by a direct one, and intermediaries can be bypassed Interorganizational relationships, will remain the same, but their overall importance and quality could change as they are no longer needed to ensure trust in supply chains.
Treiblmaier and Špan (2022)	Through smart contract automation, exchange processes are reduced or eliminated. Using smart contracts, organisations are less dependent on third parties to act as intermediaries
Walia and Raghwa (2022)	Automated communication between devices can increase anonymity within the supply chain network.

2.5 Discussion and Research Agenda

2.5.1 Considerations for theory and research

The principal-agent theory focuses on the relationship between two actors, the principal (buyer) and the agent (supplier), where information asymmetry exists. Smart contracts can reduce information asymmetries and improve the principal-agent relationship by providing a transparent and automated system for contract execution. The findings of this study showed that this can lead to enhanced trust, reduced opportunistic behaviour, and improved performance in supply chains. By automating the execution of predetermined activities, smart contracts provide transparency and reduce the chances of hidden information or intentions, leading to increased trust among supply chain actors. This can help address the adverse selection problem caused by hidden characteristics. They also can decrease hold-ups and moral hazard problems in the supply chain. With reduced intermediaries, there are fewer potential sources of mistrust, and automatic execution of activities eliminates the ability of any party to influence outcomes, reducing moral hazard concerns. Through disintermediation, smart contracts reduce information asymmetry by removing unnecessary intermediaries, leading to more direct interactions and less conflicting data. This can increase operational reliability and create a sense of fairness between partners. However, the specific implications of smart contracts in addressing information asymmetries and trust issues within supply chains from the perspective of principal-agent theory have yet to be extensively explored in the existing literature.

RQ: What should be considered when implementing smart contracts in supply chains to minimise information asymmetry and trust issues?

Transaction cost theory examines the costs of conducting exchanges between companies or transferring resources. Smart contracts can reduce supply chain transaction costs by automating and streamlining processes, eliminating intermediaries, and providing secure and transparent information exchange. Smart contracts offer little room for hidden information, which can reduce ex-post transaction costs. The transparent and traceable nature of smart contracts can reduce uncertainties and asymmetric information situations. Also, they enable the automation of processes and decentralised data storage. This leads to reduced search and information costs, as the relevant information is more easily accessible, and the need for manual search and reconciliation processes is eliminated. The use of smart contracts can lead to cost savings in areas such as negotiation, monitoring, and dispute resolution. However, the literature needs a comprehensive understanding of the specific areas within transaction cost theory that still need to be considered in the context of smart contracts in supply chains.

RQ: What should be considered when implementing smart contracts in supply chains to minimise overall transaction costs?

The resource-based view emphasises the importance of individual supply chain actors' resources, capabilities, and competencies in achieving competitive advantage. The results show that smart contracts in supply chain management can create new competitive capabilities for companies. Identifying and filtering competitive opportunities based on consumer behaviour and supply chain flexibility are capabilities based on companies' internal resources and knowledge. Resource-based-view emphasises that such unique capabilities enable companies to differentiate themselves from their competitors and gain long-term competitive advantage. Smart contracts enable better resource sharing, collaboration, and coordination among supply chain partners. They can enhance the efficiency and effectiveness of information sharing, production processes, and logistics operations. However, the literature needs to extensively explore the implications of smart contracts in terms of specific resource-based view concepts such as resource heterogeneity, resource immobility, and resource complementarity within supply chains.

RQ: What should be considered when implementing smart contracts to improve resource sharing among supply chain partners?

Network theory focuses on inter-organizational relationships and establishing trust through relational and exchange processes. Smart contracts have the potential to enhance collaboration, transparency, and trust among supply chain actors by providing a decentralised and automated system for information sharing and contract execution. They can enable direct relationships between actors, bypassing intermediaries and facilitating efficient exchanges. Smart contract adoption can lead to the elimination of redundant network activities. Automating actions based on predefined conditions allows communication paths and reviews to be streamlined or eliminated. This redundancy reduction can enhance the efficiency of the supply chain network by eliminating unnecessary steps and reducing delays in the exchange processes. Decentralisation through smart ledger contracts can replace indirect relationships with direct ones and bypass intermediaries. This enhances visibility and control over supply chain processes, leading to more efficient exchanges and reduced reliance on intermediaries. However, the literature needs a comprehensive understanding of the specific areas within network theory that still need to be considered about smart contracts in supply chains.

RQ: What should be considered when implementing smart contracts in supply chains to enhance direct collaboration between supply chain actors?

By combining four fundamental theories, a comprehensive framework can be developed to analyse the implications of smart contracts in supply chains. This integrated model would consider the interplay of information asymmetries, transaction costs, resource allocation, and inter-organizational trust. Such a model could show how smart contracts influence and shape supply chain relationships, resource utilisation, and overall performance. Furthermore, this combined theoretical approach could offer a holistic understanding of how adopting smart contracts in supply chains can lead to competitive advantages, enhanced collaboration, and improved trust among supply chain actors.

RQ: How should a comprehensive model be designed to combine principal-agent theory, transaction cost theory, resource-based view, and network theory to understand the impact of smart contracts in supply chains within a holistic model?

Despite smart contracts' potential benefits in enhancing trust among supply chain actors, the existing literature needs an in-depth analysis of trust within supply chains in the context of distributed ledger-based smart contracts. Investigating how trust towards smart contracts affects the usage of smart contracts and which factors influence risk-taking behavioural trust represents an essential research gap.

RQ: How should a conceptual model be designed to represent trust in distributed ledger-based smart contracts?

To create a model that represents different facets of trust, a more nuanced understanding of potential trust dimensions concerning the use of smart contracts in supply chains has yet to be explored.

RQ: How should a model be designed to represent the dimensions of trust in distributed ledger-based smart contracts?

2.5.2 Considerations for conception and implementation

The second research question aimed to answer how the adoption of smart contracts will change the way supply chains operate and give practical recommendations for managing them. The following sections address the applicability, impacts, and implications of the findings from different practical perspectives and derive deeper research questions.

The findings of the literature regarding the principal-agent theory show that implementing smart contracts in supply chains requires ongoing monitoring and evaluation to identify potential issues and optimise processes. This iterative approach will help identify areas for improvement and ensure that smart contracts align with the evolving needs of the supply chain ecosystem. Implementing smart contracts can help reduce trust issues among stakeholders in construction supply chains, as using smart contracts aligns interests and reduces the pursuit of divergent goals. However, it is essential to consider mechanisms like depositing part of the transaction amount, automatic sanctions, and penalty payments to enhance trust further and manage risks effectively. By leveraging distributed ledger technology, smart contracts can improve asset tracking, data collection, communication, and centralised storage, increasing operational efficiency. Organisations should establish mechanisms for continuously monitoring the performance of smart contracts, assessing their impact on supply chain operations, and gathering feedback from stakeholders.

RQ: How could smart contracts be integrated into monitoring systems to optimise the monitoring of processes?

Transaction cost theory can be applied to the implementation of smart contracts in supply chains to explain how this technology can reduce transaction costs and enable the desired improvements in transparency, traceability and financial reliability. The results of the transaction cost theory refer primarily to a possible cost reduction through process optimisation. Smart contracts can reduce the number of supply failures over time by better monitoring the supply chain and reducing data conflicts. This also reduces the cost of penalties and enforcement actions. Some studies indicate that the overuse of smart contracts can lead to network congestion and scalability issues. This is a point that supply chain managers need to consider when implementing smart contracts to ensure smooth operations.

RQ: How does the implementation of smart contracts in supply chains affect transaction costs and contribute to greater transparency, traceability and financial reliability?

Considering the results of the resource-based view from a managerial view, practitioners must be aware that (non-) use of smart contracts will affect the company's competitive position in the medium and long term. It is important to consider early on how one would like to expand one's capabilities to include distributed ledger and smart contracts in existing or new processes. The findings suggest combining smart contracts with other technologies could bring extra value and advantages. The results suggest that smart contracts can have a positive impact on quality. By sharing smart contracts, workflows in the supply chain can be carried out more consistently. This can help optimise resource use and achieve time and flexibility benefits. Companies should, therefore, strategically design their smart contract implementations to improve quality in the supply chain and ensure consistent processes. Future trends may see the combination of smart contracts with other technologies to gather valuable information and trigger smart contract executions. Organisations should explore this solution and invest in infrastructure to capture and utilise real-time data for improved decision-making and operational efficiency.

RQ: What technologies can smart contracts be combined with to enhance common benefits?

The findings from the management view on the network theory show that it is important that solutions are sought jointly within the networks. The results highlight the importance of interoperability between different systems and platforms when implementing smart contracts in supply chains. Smart contracts can optimise routine activities in the supply chain by automating processes and improving data capturing. This can lead to increased operational efficiency, reduced errors, and better utilisation of resources. Future trends may focus on developing standardised protocols and frameworks that facilitate

seamless integration and communication across various supply chain participants. Organisations should prioritise compatibility and interoperability considerations when selecting smart contract solutions and collaborate with industry partners to establish common standards.

RQ: What should common standards look like that make it possible for industry partners to work together with smart contracts more easily?

The research findings also offer valuable insights into the practical implementation and utilisation of smart contracts in real-world supply chain environments. A key discovery is that the successful integration of smart contracts relies on technical factors and organisational adjustments and changes. To effectively transition to smart contracts, it is crucial to establish clear definitions of contract terms and conditions, revamp existing processes, and provide adequate training to the involved employees. Hence, conducting a more in-depth investigation into the behaviour of intended usage concerning the adoption of smart contracts in supply chains is essential. Such a study would yield concrete implications for engaging employees and technology users in the implementation process and adequately preparing them for the changes ahead. By understanding the behavioural aspects, companies can facilitate a smoother and more successful adoption of smart contracts in their supply chain operations.

RQ: How do employees intend to use distributed ledger-based smart contracts in supply chains?

2.6 Conclusion

2.6.1 Theoretical implications

This paper presents theoretical findings on the specific use case of smart contracts in supply chains. According to the theories and previous studies, the results align with expectations. The previous section outlined the theoretical research topics that should be further explored. Now, we will look at how the four basic theories can be extended to provide more specific results in further research.

Transaction cost theory could be augmented to provide a detailed breakdown of how smart contracts influence each component, enabling a more granular analysis of potential cost savings. Principal-agent theory could be extended to include metrics for evaluating smart contract performance in supply chains. This would involve understanding how the adoption of smart contracts impacts principal-agent relationships and whether the desired outcomes, such as improved information transparency or reduced moral hazard, are achieved. The review highlights how smart contracts can enhance intangible resources like trust and collaboration. A resource-based view could help us understand how smart contracts contribute to building and leveraging these intangible resources to create competitive advantages. Network theory could incorporate how smart contracts impact governance structures and decision-making processes within supply chain networks. It would explore how the automation and transparency provided by smart contracts influence the power dynamics and coordination mechanisms among network participants.

2.6.2 Practical implications

The literature review's findings underscore the transformative potential of smart contracts in supply chains. By strategically implementing and leveraging smart contracts, supply chain managers can improve transparency, reduce transaction costs, enhance collaboration, and build trust among supply chain partners. Embracing smart contract technology is not just a technological shift; it requires a holistic approach involving process redesign, cultural change, and stakeholder collaboration to unlock this innovative solution's full benefits.

Supply chain managers should comprehensively assess their organisation's current processes, data infrastructure, and level of digitalisation. This evaluation will help determine the readiness and feasibility of adopting smart contracts. Managers must identify specific supply chain activities or processes where smart contracts can bring the most value and address existing challenges related to information asymmetry, transaction costs, and resource utilisation.

Based on the findings from the literature review, supply chain managers should formulate a clear smart contract strategy aligned with their organisational objectives. The strategy should define the scope of

smart contract implementation, target areas for improvement, and desired outcomes, such as enhanced transparency, reduced transaction costs, and increased collaboration.

Supply chain managers should collaborate with their key partners and stakeholders to fully leverage the potential of smart contracts. Interorganizational smart contracts can optimise processes, increase trust, and facilitate data sharing across the supply chain. Engaging partners in developing and implementing smart contracts fosters a collective commitment to their success.

Managers should explore integrating smart contracts with other emerging technologies, such as the Internet of Things (IoT) and artificial intelligence (AI). This integration can automate data inputs and trigger smart contract executions based on real-time information, further optimising supply chain operations.

2.6.3 Limitations and research

Our study comes with limitations as well. First, this scoping review generalises the results of specific studies, which may only sometimes be true in reality. Second, searching for smart contracts in supply chains may have excluded other studies of similar use cases. The inclusion and exclusion criteria used in the scoping review may introduce bias, as certain studies may be unintentionally omitted, leading to potential gaps in the literature coverage. Third, the studies examined represent theoretical considerations and case studies. Experience has yet to be gained in practice due to the technology's immaturity. The existing barriers to smart contract adoption have mostly yet to be considered. These include technological development, necessary standards, regulatory uncertainties, privacy laws, and frequent dependence on distributed ledger operators.

However, this is where future research can start. To overcome the limitations of the methodology of a scoping review, future studies can complement the findings from the scoping review and provide more nuanced and practical recommendations for supply chain managers seeking to implement smart contracts successfully. Conducting in-depth case studies of real-world supply chain implementations of smart contracts can provide valuable insights into their adoption's practical challenges and benefits. Future research could employ surveys and interviews to capture the perspectives of supply chain practitioners and stakeholders. Observational studies that directly observe supply chain processes before and after the implementation of smart contracts can provide empirical evidence of their impact.

The research agenda presented important topics for future research. They mainly relate to a detailed investigation of different aspects of the four supply chain theories. It is also important to investigate content that has yet to be considered but could play an important role, such as the influence and characteristics of trust or the intention to use. The initial aim here is to gather essential insights to fill research gaps and add new findings to the literature.

2.7 References

- Acero, B., Saenz, M. J., & Luzzini, D. (2022). Introducing synchromodality: One missing link between transportation and supply chain management. *Journal of supply chain management*, 58(1), 51-64. <https://doi.org/10.1111/jscm.12269>
- Alahmadi, A., & Lin, X. (2019). Towards secure and fair IIoT-enabled supply chain management via blockchain-based smart contracts. *ICC 2019-2019 IEEE International Conference on Communications (ICC)*, 1-7.
- Ankenbrand, K., Linß, I., & Sucky, E. (2020). Theorie(n) des Supply Chain Managements : Eine Literaturanalyse. 1-24. <https://fis.uni-bamberg.de/handle/uniba/45614>
- Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International journal of social research methodology*, 8(1), 19-32. <https://doi.org/10.1080/1364557032000119616>
- Arumugam, S. S., Umashankar, V., Narendra, N. C., Badrinath, R., Mujumdar, A. P., Holler, J., & Hernandez, A. (2018). IOT enabled smart logistics using smart contracts. *2018 8th International Conference on Logistics, Informatics and Service Sciences (LISS)*, 1-6.

- Asante Boakye, E., Zhao, H., & Ahia, B. N. K. (2022). Blockchain technology prospects in transforming Ghana's economy: a phenomenon-based approach. *Information Technology for Development*, 28(2), 1-30. <https://doi.org/10.1080/02681102.2022.2073580>
- Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99-120. <https://doi.org/10.1177/014920639101700108>
- Barney, J. B. (1994). Bringing managers back in: a resource-based analysis of the role of managers in creating and sustaining competitive advantages for firms. *Does management matter*, 1-36.
- Beverungen, D., Overhage, S., Gorlick, A., Moerchel, P., & Schuermann, S. (2021). Blockchains for pay-per-use Business Models: Insights from a Design Research Study 54th Hawaii International Conference on System Sciences, Hawaii. <https://doi.org/10.24251/HICSS.2021.677>
- Bingzhang, L., & Zirianov, V. (2021). Blockchain in agricultural supply chain management. *E3S Web of Conferences*, 273(1), 1-10.
- Büttgen, M., Dicenta, J., Spohrer, K., Venkatesh, V., Raman, R., Hoehle, H., De Keyser, A., Verbeeck, C., Zwienenberg, T. J., & Jørgensen, K. P. (2021). Blockchain in service management and service research—developing a research agenda and managerial implications. *Journal of Service Management Research*, 5(2), 71-102. <https://doi.org/10.15358/2511-8676-2021-2-71>
- Casado-Vara, R., Prieto, J., De la Prieta, F., & Corchado, J. M. (2018). How blockchain improves the supply chain: Case study alimentary supply chain. *Procedia computer science*, 134(1), 393-398. <https://doi.org/10.1016/j.procs.2018.07.193>
- Chen, W., Botchie, D., Braganza, A., & Han, H. (2022). A transaction cost perspective on blockchain governance in global value chains. *Strategic Change*, 31(1), 75-87. <https://doi.org/10.1002/jsc.2487>
- Chowdhury, M. J. M., Ferdous, M. S., Biswas, K., Chowdhury, N., Kayes, A., Alazab, M., & Watters, P. (2019). A comparative analysis of distributed ledger technology platforms. *IEEE Access*, 7(1), 167930-167943. <https://doi.org/10.1109/ACCESS.2019.2953729>
- Collis, D. J., & Montgomery, C. A. (1995). How do you create and sustain a profitable strategy? Competing on resources: strategy in the 1990s. *Harvard Business Review*, 73(4), 118-128.
- Compagnucci, L., Lepore, D., Spigarelli, F., Frontoni, E., Baldi, M., & Di Berardino, L. (2022). Uncovering the potential of blockchain in the agri-food supply chain: An interdisciplinary case study. *Journal of Engineering and Technology Management*, 65, 101700. <https://doi.org/10.1016/j.jengtecman.2022.101700>
- Dasaklis, T. K., Casino, F., & Patsakis, C. (2019). Defining granularity levels for supply chain traceability based on IoT and blockchain. *Proceedings of the international conference on omni-layer intelligent systems*, 184-190.
- Dwivedi, S. K., Amin, R., & Vollala, S. (2020). Blockchain based secured information sharing protocol in supply chain management system with key distribution mechanism. *Journal of Information Security and Applications*, 54, 102554. <https://doi.org/10.1016/j.jisa.2020.102554>
- Fayezi, S., O'Loughlin, A., & Zutshi, A. (2012). Agency theory and supply chain management: a structured literature review. *Supply Chain Management: An International Journal*, 17(5), 556-570. <https://doi.org/10.1108/13598541211258618>
- Grosse, N., Guerpinar, T., & Henke, M. (2021). Blockchain-Enabled Trust in Intercompany Networks Applying the Agency Theory. *Blockchain and Internet of Things Conference*, 3(1), 8-14.
- Halaburda, H., Levina, N., & Semi, M. (2019). Understanding smart contracts as a new option in transaction cost economics 40th International Conference on Information Systems, Munich, Germany,
- Halldorsson, A., Kotzab, H., Mikkola, J. H., & Skjøtt-Larsen, T. (2007). Complementary theories to supply chain management. *Supply Chain Management: An International Journal*, 20(6), 574-586. <https://doi.org/10.1108/SCM-06-2015-0228>

- Hearnshaw, E. J. S., & Wilson, M. M. J. (2013). A complex network approach to supply chain network theory. *International Journal of Operations & Production Management*, 33(4), 442-469. <https://doi.org/10.1108/01443571311307343>
- Hobbs, J. E. (1996). A transaction cost approach to supply chain management. *Supply Chain Management: An International Journal*, 1(2), 15-27. <https://doi.org/10.1108/13598549610155260>
- Jabbar, A., & Dani, S. (2020). Investigating the link between transaction and computational costs in a blockchain environment. *International Journal of Production Research*, 58(11), 3423-3436. <https://doi.org/10.1080/00207543.2020.1754487>
- Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of financial economics*, 3(4), 305-360. [https://doi.org/10.1016/0304-405X\(76\)90026-X](https://doi.org/10.1016/0304-405X(76)90026-X)
- Kajikawa, Y., Takeda, Y., Sakata, I., & Matsushima, K. (2010). Multiscale analysis of interfirm networks in regional clusters. *Technovation*, 30(3), 168-180. <https://doi.org/10.1016/j.technovation.2009.12.004>
- Khan, M. A., Stoll, O., West, S., & Wuest, T. (2022). Equipment upgrade service provision in the context of servitization: drivers, capabilities, and resources. *Production Planning & Control*, 1-19. <https://doi.org/10.1080/09537287.2022.2063199>
- Kim, M., Hilton, B., Burks, Z., & Reyes, J. (2018). Integrating blockchain, smart contract-tokens, and IoT to design a food traceability solution. 2018 IEEE 9th annual information technology, electronics and mobile communication conference (IEMCON), 335-340.
- Korpela, K., Hallikas, J., & Dahlberg, T. (2017). Digital supply chain transformation toward blockchain integration. 50th Hawaii international conference on system sciences, 1-10.
- Kouhizadeh, M., Zhu, Q., & Sarkis, J. (2020). Blockchain and the circular economy: potential tensions and critical reflections from practice. *Production Planning & Control*, 31(11-12), 950-966. <https://doi.org/10.1080/09537287.2019.1695925>
- Kumarathunga, M. (2020). Improving farmers' participation in agri supply chains with blockchain and smart contracts. 2020 Seventh International Conference on Software Defined Systems (SDS), 139-144.
- Liu, L., Zhang, J. Z., He, W., & Li, W. (2021). Mitigating information asymmetry in inventory pledge financing through the Internet of things and blockchain. *Journal of Enterprise Information Management*, 34(5), 1429-1451. <https://doi.org/10.1108/JEIM-12-2020-0510>
- Lohmer, J., Bugert, N., & Lasch, R. (2020). Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study. *International journal of production economics*, 228, 107882. <https://doi.org/10.1016/j.ijpe.2020.107882>
- Lumineau, F., & Oliveira, N. (2020). Reinvigorating the study of opportunism in supply chain management. *Journal of supply chain management*, 56(1), 73-87.
- Madhwal, Y., Borbon-Galvez, Y., Etemadi, N., Yanovich, Y., & Creazza, A. (2022). Proof of Delivery Smart Contract for Performance Measurements. *IEEE Access*, 10, 69147-69159. <https://doi.org/10.1109/ACCESS.2022.3185634>
- Mari, S. I., Lee, Y. H., & Memon, M. S. (2015). Complex network theory-based approach for designing resilient supply chain networks. *International Journal of Logistics Systems and Management*, 21(3), 365-384. <https://doi.org/10.1504/IJLSM.2015.069733>
- Martinez, V., Zhao, M., Blujdea, C., Han, X., Neely, A., & Albores, P. (2019). Blockchain-driven customer order management. *International Journal of Operations & Production Management*, 39(6/7/8), 993-1022. <https://doi.org/10.1108/IJOPM-01-2019-0100>
- McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Biochemia medica*, 22(3), 276-282. <https://doi.org/10.11613/BM.2012.031>

- Munn, Z., Peters, M. D., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC medical research methodology*, 18(1), 1-7. <https://doi.org/10.1186/s12874-018-0611-x>
- Nandi, M. L., Nandi, S., Moya, H., & Kaynak, H. (2020). Blockchain technology-enabled supply chain systems and supply chain performance: a resource-based view. *Supply Chain Management: An International Journal*, 25(6), 841-862. <https://doi.org/10.1108/SCM-12-2019-0444>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., & Brennan, S. E. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery*, 88, 105906. <https://doi.org/10.1186/s13643-021-01626-4>
- Paiva, E. L., Roth, A. V., & Fensterseifer, J. E. (2008). Organizational knowledge and the manufacturing strategy process: a resource-based view analysis. *Journal of Operations Management*, 26(1), 115-132. <https://doi.org/10.1016/j.jom.2007.05.003>
- Papathanasiou, A., Cole, R., & Murray, P. (2020). The (non-)application of blockchain technology in the Greek shipping industry. *European Management Journal*, 38(6), 927-938. <https://doi.org/10.1016/j.emj.2020.04.007>
- Petersen, D. (2022). Automating governance: Blockchain delivered governance for business networks. *Industrial Marketing Management*, 102, 177-189. <https://doi.org/10.1016/j.indmarman.2022.01.017>
- Premm, M., & Kirn, S. (2015). A multiagent systems perspective on Industry 4.0 supply networks. *German Conference on Multiagent System Technologies*, 101-118.
- Raj, P. V. R. P., Jauhar, S. K., Ramkumar, M., & Pratap, S. (2022). Procurement, traceability and advance cash credit payment transactions in supply chain using blockchain smart contracts. *Computers & Industrial Engineering*, 167, 108038. <https://doi.org/10.1016/j.cie.2022.108038>
- Schmidt, C. G., & Wagner, S. M. (2019). Blockchain and supply chain relations: A transaction cost theory perspective. *Journal of Purchasing and Supply Management*, 25(4), 100552. <https://doi.org/10.1016/j.pursup.2019.100552>
- Schmidt, R., Möhring, M., Keller, B., Fuchs, F., Kochsiek, A., & Völkel, F. (2019). Empirical insights into the benefit from implementing smart contracts 19th International Conference on Electronic Business (ICEB), Newcastle.
- Schwabe, T. (2013). Transaction cost economics in supply chain management [University of Twente].
- Sodhi, M. S., & Tang, C. S. (2021). Supply chain management for extreme conditions: research opportunities. *Journal of supply chain management*, 57(1), 7-16. <https://doi.org/10.1111/jscm.12255>
- Treiblmaier, H. (2018). The impact of the blockchain on the supply chain: a theory-based research framework and a call for action. *Supply Chain Management: An International Journal*, 23(6), 545-559. <https://doi.org/10.1108/SCM-01-2018-0029>
- Treiblmaier, H., & Špan, Ž. (2022). Will blockchain really impact your business model? Empirical evidence from Slovenian SMEs. *Economic and Business Review*, 24(2), 132-140. <https://doi.org/10.15458/2335-4216.1302>
- van Groesen, W., & Pauwels, P. (2022). Tracking prefabricated assets and compliance using quick response (QR) codes, blockchain and smart contract technology. *Automation in Construction*, 141, 104420.
- Vitorino Filho, V. A., & Moori, R. G. (2020). A RBV em contexto de gestão da cadeia de suprimentos. *Gestão & Produção*, 27. <https://doi.org/10.1590/0104-530X4731-20>
- Vo, K. T., Nguyen-Thi, A. T., & Nguyen-Hoang, T. A. (2021). Building Sustainable Food Supply Chain Management System Based On Hyperledger Fabric Blockchain. *International Conference on*

- Advanced Computing and Applications (ACOMP), 15(1), 9-16.
<https://doi.org/10.1109/ACOMP53746.2021.00008>
- Walia, K., & Raghwa, N. (2022). Social Networking in an Information-Centric System with Blockchain. 2022 3rd International Conference on Intelligent Engineering and Management (ICIEM), 175-182.
- Wang, S., Li, D., Zhang, Y., & Chen, J. (2019). Smart contract-based product traceability system in the supply chain scenario. IEEE Access, 7(1), 115122-115133.
<https://doi.org/10.1109/ACCESS.2019.2935873>
- Williamson, O. E. (2008). Outsourcing: Transaction cost economics and supply chain management. Journal of supply chain management, 44(2), 5-16. <https://doi.org/10.1111/j.1745-493X.2008.00051.x>
- Xu, D., Huo, B., & Sun, L. (2014). Relationships between intra-organizational resources, supply chain integration and business performance: an extended resource-based view. Industrial Management & Data Systems, 114(8), 1186-1206. <https://doi.org/10.1108/IMDS-05-2014-0156>
- Xu, L., Tu, P., & Tang, Q. (2020). Contract design for cloud logistics (cl) based on blockchain technology (BT). Complexity, 2020(4), 1-13. <https://doi.org/10.1155/2020/5305808>
- Yin, W., & Ran, W. (2021). Theoretical Exploration of Supply Chain Viability Utilizing Blockchain Technology. Sustainability, 13(15), 8231. <https://doi.org/10.3390/su13158231>
- Yuthas, K., Sarason, Y., & Aziz, A. (2021). Strategic value creation through enterprise blockchain. The Journal of The British Blockchain Association, 4(1), 1-18. [https://doi.org/10.31585/jbba-4-1-\(7\)2021](https://doi.org/10.31585/jbba-4-1-(7)2021)
- Zhang, Y., Yutaka, M., Sasabe, M., & Kasahara, S. (2020). Attribute-based access control for smart cities: A smart-contract-driven framework. IEEE Internet of Things Journal, 8(8), 6372-6384. <https://doi.org/10.1109/JIOT.2020.3033434>

3 Employees' intention to use smart contracts in supply chains: The important role of performance expectancy⁶

Wieland Müller

Abstract

Distributed ledger-based smart contracts enhance supply chain transparency, traceability, and efficiency. However, the success of this technology hinges on employee intention to use it. We used a quantitative questionnaire, based on the UTAUT model to investigate the antecedents of behavioural intention further and analysed them using PLS-SEM. Using a quantitative questionnaire based on the UTAUT model, we examined the determinants of behavioural intention using PLS-SEM. Results indicate that performance expectancy positively influences behavioural intention, while industry type has a weak impact. Effort expectancy, social influence, attitude, anxiety, personal openness, gender, and experience do not affect behavioural intention. This study contributes theoretically by applying UTAUT to a new use case and discussing its applicability to modern technologies. Practically, managers should foster willingness to use smart contracts and conduct prototype testing until technology readiness is achieved for adoption. This study is the first to examine the intention to use smart contracts in supply chains and can thus provide specific operational advice.

Keywords: smart contracts, supply chain, distributed ledger, performance expectancy, behavioural intention

⁶ The article is currently under review at Information Technology and Management.

3.1 Introduction

Smart contracts are a future technology with a huge potential to transform traditional business processes. They can be used in various industries, including, e.g. financial services, retail and real estate. In particular, smart contracts provide promising optimisation possibilities for supply chain management (Agrawal et al., 2022). Problems in traditional supply chain networks include trust issues due to the involvement of multiple companies, sometimes across national borders, error sources due to manual processes and human interactions, and increased time required due to manual processes (Chen et al., 2014). Other problems are lack of transparency regarding location and supply process and lack of traceability of goods, services and their components (Kayikci et al., 2022). In addition, future supply chain regulations will also require legally backed, traceable and transparent supply chain processes to promote a fair and more sustainable global economy (Dietrich et al., 2022). Smart contracts can help improve both the efficiency and transparency of supply chain processes and increase trust between the parties involved (Casado-Vara et al., 2018; Grosse et al., 2021). While smart contracts primarily operate as a backend technology, their implementation can significantly impact supply chain processes (Agrawal et al., 2022), which in turn affects employee perception and has a causal impact on key organizational outcomes (Harter et al., 2010). Several factors influence the adoption success when industry 4.0 technologies like smart contracts are introduced in organisations. Those include technology readiness (Dora et al., 2022), management form and leadership (Pozzi et al., 2021) and existing knowledge about Industry 4.0 (Kumar et al., 2021). The success of technology adoption is influenced at an organisational, intra-organisational and individual level (Scott, 2010). Also, in the field of supply chain management, the influence of individual factors on technological success is confirmed alongside organisational factors (Russell & Hoag, 2004). One individual success factor of an information system is the intention of employees to use a technology (Fan & Fang, 2006; Taherdoost, 2019). Various models and theories explain possible antecedents for usage intention. Those include attitude toward use, perceived usefulness (Technology Acceptance Model (TAM) by Davis (1989)), intrinsic and extrinsic motivation (Davis et al., 1992) and performance expectancy, effort expectancy, social influence and facilitating conditions (UTAUT by Venkatesh et al. (2003)) as antecedents for usage intention.

Research to date has been able to apply and confirm the various technology acceptance models to blockchain in general (Ferri et al., 2021; Kabir & Islam, 2021; Lee et al., 2019; Pieters et al., 2021). Also, regarding general technology adoption in supply chains, the assumptions of those theoretical considerations could be confirmed to a large extent (Alazab et al., 2021; Park, 2020).

However, few studies have examined smart contracts' intention to use them. One of the few findings shows that employees are divided on whether smart contracts should be introduced in organisations (Badi et al., 2021). A further study identified perceived financial costs, presence of facilitating, personal readiness, trust in smart contracts, perceived usefulness and perceived ease as factors for general smart contract usage intention (Chaveesuk et al., 2020). Studies that refer to the specific application case of smart contracts usage intention in supply chains do not exist currently. Hence, we address this research gap based on smart contracts' opportunities and the lack of scientific research.

Therefore, this article aims to provide knowledge of usage intention and its drivers for smart contracts in supply chains. Based on this, we want to give specific advice on raising usage intention and successfully integrating smart contract technology in supply chains. In order to investigate the acceptance and use of smart contracts in supply chain management, we formulate two central research questions: RQ1: To what extent are employees willing to use distributed ledger-based smart contracts in supply chains? RQ2: What factors influence the intention to use distributed ledger-based smart contracts in supply chains?

To answer the research questions, we use the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003). The UTAUT states that effort expectancy, performance expectancy, social influence, and facilitating conditions determine individuals' behavioural intentions regarding using a technology (Venkatesh et al., 2003). We identify relevant reasons for behavioural intention using a theory-based structural equation model. To the best of our knowledge, we are the first to apply UTAUT on the specific field of usage intention of smart contracts in supply chains. We conducted a quantitative online survey, which included adopted questions from the original UTAUT

questionnaire. The survey was conducted in Germany and allowed employees from companies involved in a supply chain to represent their behavioural intentions.

Our study makes a valuable contribution to the existing literature by analysing the role of individual usage intentions, in particular performance expectations, in the adoption of smart contracts in supply chains. By understanding employees' expectations and intentions towards the use of this technology, organizations can develop effective strategies to facilitate its adoption and maximize its potential to improve supply chain efficiency, transparency, and trust. This fills a critical gap in understanding the factors influencing technology adoption in a sector characterised by complex logistical and operational challenges. By extending this knowledge, our research offers important insights that can inform future theoretical frameworks and practical strategies in supply chain management.

The paper is organised as follows: The second section presents characteristics of distributed ledger and smart contract technology. Furthermore, previous research results are presented regarding the usage intention of distributed ledger technology and smart contracts. Next, the research model and hypotheses are stated. Section three presents the quantitative survey as the study method, analyses the sample, and presents statistical tests. Section four gives the descriptive results and answers to the hypotheses associated with the study model, followed by a critical discussion in section five. In the conclusion, we draw the theoretical and practical implications of the study as well as its limitations and directions for future research.

3.2 Theoretical Background

3.2.1 Distributed ledger based smart contracts

There are several types of distributed ledger technology. Most of the literature refers to blockchain technology, which is often incorrectly used as a synonym for distributed ledger (El Ioini & Pahl, 2018). Blockchain is a technology for storing and transmitting in encrypted form. In addition to the actual stored data, each data block contains information about the initialisation time and other information about the transaction process (Vo et al., 2021). The key differences between blockchain and other types of distributed ledgers are in how transactions are stored and validated. This leads to differences privacy and more performance-related outcomes like scalability, flexibility, transaction speed, energy consumption, and transaction costs (Chowdhury et al., 2019). Despite different architectural structures, the various types have some fundamental common characteristics: The immutability, traceability and transparency of cryptographically secured data, shared on distributed entities (El Ioini & Pahl, 2018).

Smart contracts are digital contracts that can be written by an "if-this-then-that" code in the distributed ledger structure (Vo et al., 2021). They refer to conditions previously defined jointly by the network actors and are automatically executed as soon as these contract conditions are met. Once they have been determined, there is no need for further management of the contracts. Performance-related improvements through smart contract include automated processes and elimination of the need for intermediaries. Once defined; direct contract discussions are no longer necessary. Due to distributed ledger technology forming the underlying technology of smart contracts, contracts are legally secure, transparent, and traceable (Vo et al., 2021; Wang et al., 2019).

3.2.2 Smart contracts in supply chain networks

Supply chains are companies collaborating to deliver a product or service to the end customer, connecting flows from raw material supply to final distribution (Ellram, 1991). In addition to the material flow, there are additional financial and information flows within the network. In traditional supply chains, these three flows exist between two subsequent actors, following the chain (Pfohl & Gomm, 2009).

Especially the flow of information is becoming increasingly important in modern supply chains. In addition to fundamental information, there is a growing demand for greater transparency, traceability and data availability of products and processes in supply chains (Bäckstrand & Fredriksson, 2022). Digitisation of previously analogue supply chain processes and the growing personalisation of products

and services also increases the complexity of planning processes and, thus the quantity of information (Premm & Kirn, 2015).

If the information has to be exchanged with actors who do not follow directly in the chain, the intermediaries make the information transfer inefficient and more open to errors. The use of decentralised distributed ledgers allows information to be exchanged directly between different actors, even if they do not subsequently participate in the chain. Data relevant to supply chains can be, transportation information (sensor data, real-time location data), product data (price, quality, batch number), origin data (country of manufacture, factory), or customer data (proof of ownership) (Vo et al., 2021). Based on this input data, smart contracts can automatically execute contracts that initiate the transfer of goods, services, valuables, payments or other previously determined actions (Wang et al., 2019) and control the three main flows of material, information and finance automatically. In addition to automation, other problems of traditional supply chains related to data reliability and production transparency can be solved (Casado-Vara et al., 2018).

Trough the improvement of transparency and efficiency, smart contracts can thus promote environmental and social sustainability. They enable better tracking of goods and their environmental footprint and enable companies to comply with sustainability standards more effectively (Groschopf et al., 2021). Smart contracts can not only reduce emissions through process optimisation, but also automatically calculate, verify and report emissions to ensure accuracy and accountability (Arinze et al., 2024). Also, streamlining processes and reducing costs can enable sustainable business practices and promote economic development (Dal Mas et al., 2020).

3.2.3 State of the art of smart contracts in supply chains

The current state of the art in smart contracts in supply chains is rapidly evolving and holds great potential for improving transparency, efficiency, and trust in supply chain operations. Various application cases and their benefits can already be seen: Smart contracts can track and trace products throughout the supply chain, ensuring transparency and authenticity (Kumar & Chopra, 2022). Another possible application is crowdfunding as part of a financial supply chain (Ayu Sanjaya & Akhyar, 2022). They can automate inventory management processes, such as reordering and restocking, based on predefined conditions (Ahmad et al., 2021). Smart contract automation can decrease document and database errors (Bingzhang & Zirianov, 2021; Chen et al., 2022) and further reduce transaction costs by reducing paperwork in supply chains (Raj et al., 2022). Less conflicting data between sending and receiving warehouses when data is automatically, and decentral overlaid can achieve higher operational reliability (Madhwal et al., 2022). Shortening the path through decentralisation also leads to increased efficiency in supply chain exchanges (Kajikawa et al., 2010). Automatic penalty features, such as automated penalty fee collection for non-compliance with agreements, can ensure the implementation of the agreements (Xu et al., 2020). Long-term contracts can sustainably reduce transaction costs (Kumarathunga, 2020). Also, smart contracts allow transparent traceability of transactions in supply chains and thus increase the trust of the actors involved (Wang et al., 2019). Another advantage is the real-time availability of smart contracts (Vo et al., 2021), which can also make processes more efficient. Previous recent studies focused mainly on the development of frameworks for stakeholder interaction through a procurement and distribution entity supported by blockchain technology (Agrawal et al., 2022), described the potential for innovation (Natanelov et al., 2022), or its merits (Schwarze & Sushchenko, 2022).

Nevertheless, smart contracts have their limitations especially with regard to legal and regulatory challenges. Traditional legal frameworks and regulations may not fully accommodate or recognise the validity and enforceability of smart contracts. This can create uncertainty and potential legal disputes when it comes to contract interpretation, liability, and dispute resolution (Alnodel et al., 2020).

3.2.4 Distributed ledger and smart contract usage intention

Although it is primarily a back-end technology and employees often do not interact directly with smart contracts in back-end networks, its implementation can have an impact on employees' work experience by influencing organizational processes (Harter et al., 2010), making their usage intention towards this technology of great importance for organizational leadership and technology adoption planning. A

previous study of the intention to use smart contracts in the public sector finds that the perceived valuation of smart contracts has a significant and positive influence on the intention to use smart contracts. However, the user's resistance to change and the perceived smart contracts switching costs have no influence (van Geldere, 2023). A more general and combined survey of students and employees found neutral to negative attitudes toward distributed ledger adoption and usage intention. For perceived ease of use and trust, no positive influence on intention to use was found (Lee et al., 2019). Other results showed the perceived operational usefulness of distributed ledger use in general (Lee et al., 2019). Ferri et al. (2021) found that auditors' intention to use distributed ledger is primarily determined by performance expectations and social influence. While IT systems are often introduced on a mandatory basis (Xue et al., 2011), management and leadership still play a crucial role in promoting the adoption and acceptance of innovative technologies (Van Dun & Kumar, 2021). An influence of effort expectancy (the perception of how easy or difficult it is to use a particular technology or application) could not be confirmed (Pieters et al., 2021). In the context of Bangladeshi banking companies, social influence was found to have no impact on usage intention though it was determined by trust in the technology, ease of use, and perceived usefulness (Kabir & Islam, 2021).

From the studies presented, it can be seen that although there are several studies on the intention to use a distributed ledger, some contradict each other in their results. This may be because different groups of people were surveyed. To identify concrete implications for supply chain management, it is also necessary to address this specific field in the survey. With a focus on general blockchain use in logistics and supply chains, a significant effect of performance expectancy, effort expectancy, social influence and facilitating conditions on the intention to adopt blockchain was found (Park, 2020). Another cross-sectoral survey found that the following constructs positively influence employees' willingness to adopt distributed ledger in supply chains: performance expectations, efforts expectations, facilitation of conditions, distributed ledger efficiency, user satisfaction and task technology fit. The social influence construct was perceived as a non-significant (Alazab et al., 2021). It was also found that behavioural intentions are positively and significantly influenced by performance expectancy, effort expectancy, hedonic motivation, price value, and trust (Sheel & Nath, 2020).

Even though interest in smart contract technology has increased in recent years, only a few studies still refer to the actual intention to use the technology. A survey of the UK construction sector found that 25% of employees believe their company intends to use smart contracts actively. 32% disagreed with the statement, and 43% neither agreed nor disagreed (Badi et al., 2021). It is assumed that the perceived financial costs, presence of facilitating, personal readiness, trust in smart contracts, perceived usefulness and the perceived ease of use directly influence the use of distributed ledger based smart contracts mechanism (Chaveesuk et al., 2020). Also, it was found that initial trust is moderate to strong, and performance expectancy strongly affects behavioural intention. No significant effect could be confirmed for task technology fit (Lombard, 2017).

3.2.5 Research model

For this study, we chose the Unified Theory of Acceptance and Use of Technology (UTAUT) by (Venkatesh et al. 2003). UTAUT is built upon an extensive theoretical foundation, combining and integrating several well-established technology acceptance and adoption theories. It draws upon the Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB), Social Cognitive Theory (SCT), and other influential models. This comprehensive theoretical base ensures that UTAUT captures various factors that influence individuals' intention to use technology. Using UTAUT, we can analyse the specific organisational factors influencing the intention to adopt and use smart contracts within the supply chain context. Smart contracts are a unique technology with distinct characteristics, such as automation, transparency, and decentralised control. The UTAUT framework allows for examining how these specific characteristics influence users' intention to adopt smart contracts.

Regarding distributed ledger usage intention, next to UTAUT, UTAUT2 and TAM3 are very commonly used model in the literature. UTAUT2 refers to the consumer market (Venkatesh et al., 2003), so it is unsuitable for our research purposes. While UTAUT2 includes additional constructs such as hedonic motivation and price value, it is not specifically designed for studying technology adoption in an organisational context. While the different TAM Models extensively explores individual motivations

and cognitive behaviours in relation to technology adoption, they often fail to consider the organisational factors that can significantly influence the adoption and use of technology in organisations (Bouwman & Wijngaert, 2009). Given the focus on smart contract adoption in supply chains within organisations, it is important to use a theory that specifically addresses the organisational context and factors influencing adoption. The original UTAUT model has been successfully applied in various organisational contexts and can be used effectively to predict usage intentions in organisational contexts (Chatterjee et al., 2023).

The current state of the art in smart contracts within supply chains is undergoing rapid advancements, offering immense potential for transformative changes across multiple industries. Examining the intent to use smart contracts can provide valuable insights into the factors influencing individuals or organisations to adopt or reject this innovation (Venkatesh et al., 2012). The research model can be seen in Figure 7.

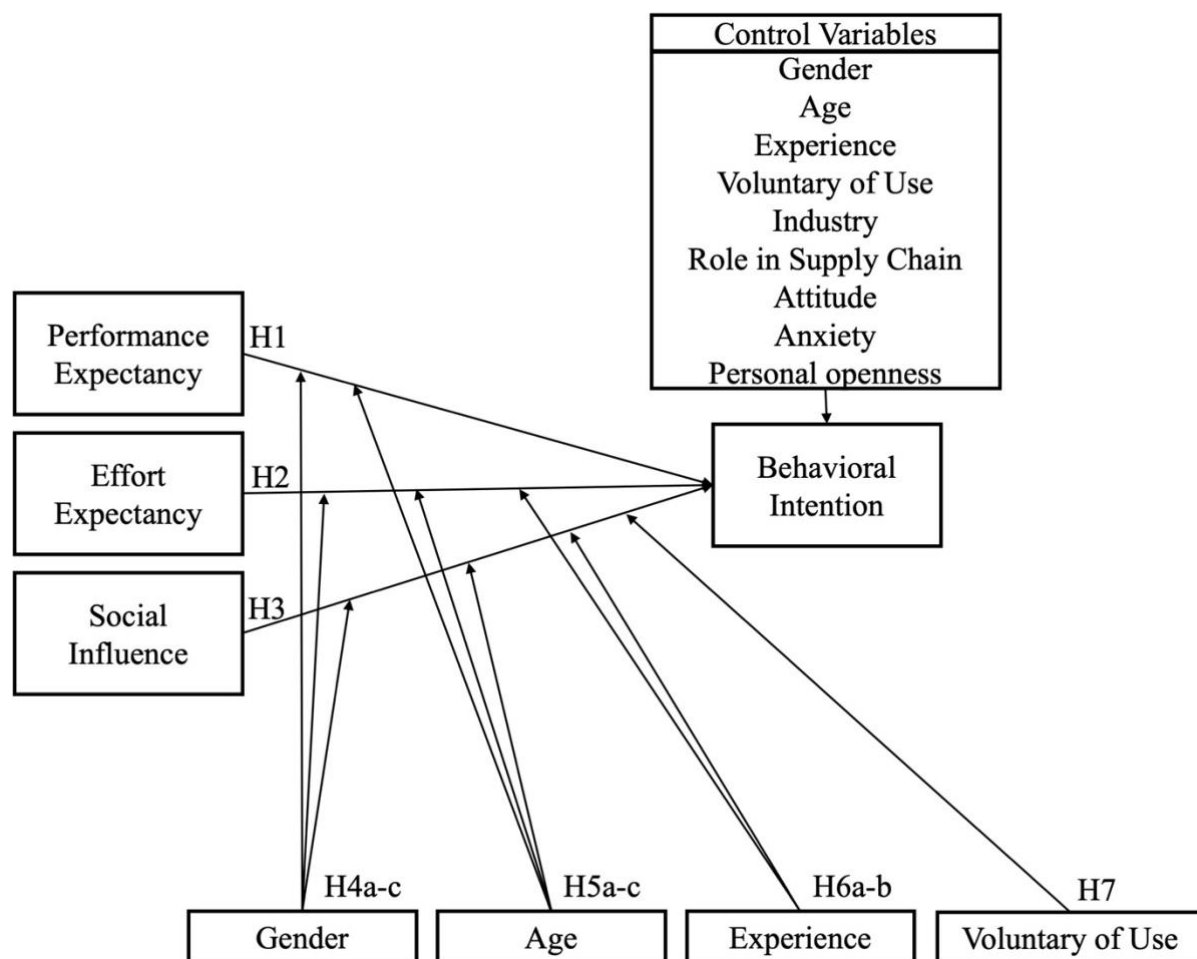


Figure 7: Research model adapted from Venkatesh et al. (2003) and hypotheses.

3.2.6 Hypothesis development

The hypotheses presented in the Figure 7 will now be derived based on the results of previous literature. Performance expectancy presents the extent to which a person believes that using the system will help them to improve their job performance (Venkatesh et al., 2003). For example, smart contracts applications on distributed ledger networks are seen as a way to simplify business processes (Sánchez-Gómez et al., 2019). Their use can optimise processes (Nelaturu et al., 2021), automatically perform tasks within the supply chain (Prause, 2019) and can therefore be seen as a technology to improve job performance. For other technologies like IoT or distributed ledger, a positive correlation between performance expectations and usage intention in supply chains has already been confirmed (Alazab et al., 2021; Ferri et al., 2021; Shi et al., 2022), but no studies have yet been conducted on smart contracts.

Therefore, we think that this assumption also applies to smart contracts, and users with a high-performance expectancy regarding smart contracts are more likely to use them in supply chains.

H1: Performance expectancy has a positive effect on behavioural intention.

Effort expectancy presents the degree of ease which is related to the use of the system (Venkatesh et al., 2003). While the effort to implement smart contracts for the first time is quite high, the subsequent use will significantly reduce (Hamledari & Fischer, 2021). Nguyen et al. (2023) found, that effort expectancy of blockchain technology in general positively influences the behavioural intention to use blockchain in logistics. Similar results from the field of crypto technologies were found by Li et al. (2023). In a study, they were able to show that effort expectancy significantly affects intentions to use cryptocurrency. About other new technologies like IoT or Big Data, a positive correlation was found between effort expectation and intention to use them in supply chains (Queiroz & Pereira, 2019; Shi et al., 2022). Therefore, we hypothesise that, also about smart contracts, employees with high effort expectancy will be more willing to use them for activities within the supply chain and are more likely to use them in supply chains.

H2: Effort expectancy has a positive effect on behavioural intention.

According to Groschopf et al. (2021), there are different social interactions during smart contract implementation that need to be considered. Conversely, social expectations can also influence behavioural intention. Social influence presents the extent to which an individual perceives that others believe they should use the new system (Venkatesh et al., 2003). Interactions between employees, their colleagues, other supply chain actors and external people can influence the behavioural intention (Wamba & Queiroz, 2019). These influence the intent to use technologies in supply chains in general (Russell & Hoag, 2004). While little previous research has tested these assumptions for smart contracts, it has been tested for other technological fields. With regard to the sharing of technological data, the impact of social influence on behavioural intention has been positively confirmed (Adams & Lennard, 2019). We argue that this general statement can be applied to the specific technology of distributed ledger based smart contracts. We assume that social influence also positively impacts usage intention towards smart contracts in supply chains.

H3: Social influence has a positive effect on behavioural intention.

In addition to the direct effects, we also suspect moderation effects of gender, age, experience with smart contracts, and voluntariness of use. According to the original UTAUT model (Venkatesh et al., 2003), those variables have been shown to affect various independent variables.

Based on the findings from the mentioned studies, it can be observed that gender, age, and experience play important moderating roles in influencing consumer intentions in various contexts. These factors could have similar effects on the intention to use smart contracts in supply chain management. Considering the research by Merhi et al. (2021) and Magsamen-Conrad et al. (2015) we can hypothesise that gender may moderate the intention to use smart contracts in supply chain management. Drawing from the study conducted by Phichitchaisopa and Naenna (2013) on healthcare technology adoption, age could moderate the intention to use smart contracts in the supply chain. Younger individuals might be more familiar and comfortable with new digital technologies, leading to a higher intention to adopt smart contracts than older individuals. The research by Celik (2016) and Puriwat and Tripopsakul (2021) suggests that experience might play a role in moderating intentions related to technology adoption. Similarly, we can hypothesise that individuals with prior experience using blockchain technology or other digital solutions in supply chain management may exhibit a stronger intention to use smart contracts than those without such experience. When users feel they have control over whether or not to use technology, they may be more likely to adopt it (Cranor & Wright, 2000). Also, voluntary nature of technology can influence users' intention to use a technology (Schultz, 2020). When individuals perceive the adoption of smart contracts as a voluntary choice, they will likely approach it differently. This perception can positively influence their intention to use smart contracts in the supply chain. Based on these previous findings and the assumptions of the UTAUT by Venkatesh et al. (2003), we derived the following further hypotheses:

H4: Gender influences the relationship between (a) performance expectancy, (b) effort expectancy and (c) social influence and intention to use smart contracts technology in supply chains.

H5: Age influences the relationship between (a) performance expectancy, (b) effort expectancy and (c) social influence and intention to use smart contracts technology in supply chains.

H6: Experience influences the relationship between (a) effort expectancy and (b) social influence and intention to use smart contracts technology in supply chains.

H7: Voluntary of use influences the relationship between social influence and intention to use smart contracts technology in supply chains

As a control variable at the organisational level, we included the industry and the company's role within the supply chain as potential variables influencing the behavioural intention. On individual level, we included personal openness, anxiety, and attitude toward smart contracts as control variables in the research model. We tested control variables at organisational and individual level, as both levels can have an influence on organizational technology success in supply chains (Russell & Hoag, 2004). A representation of the hypotheses in the research model can be seen in Figure 7.

3.3 Research Method

3.3.1 Questionnaire

The questionnaire (which can be in full the data repository) included questions about the independent variables, the moderating variables, the dependent variable, the control variables, and demographic data. After an attention check, filter questions were used to ensure that participants were individuals working in companies in a supply chain with at least 50 employees and had no managerial responsibility. This ensures that employees are exposed to a sufficient number and complexity of colleagues/processes to report on work processes and their individual behaviour (Leyer & Oberländer, 2022). This was followed by questions to explain the research model and answer hypotheses; the expression of the items was determined in seven-point Likert scales. We adopted the items from the original Unified Theory of Acceptance and Use of Technology to collect data. In the adaptation, we closely followed the original framework and idea of (Venkatesh et al., 2003).

First, respondents were asked to indicate their performance expectations toward smart contracts in supply chains. The following questions refer to effort expectancy and a possible social influence. Then, to finalise the research model, the dependent variable behavioural intention and possible moderator variables gender, age, experience and voluntariness of use were asked. The items were taken from the original UTAUT questionnaire of Venkatesh et al. (2003) and adapted to Smart Contracts into Supply Chains. In addition, the industry and the company's role within the supply chain were asked as control variables.

3.3.2 Sample

The questionnaire was administered to participants via the online platform Clickworker to supply chain employees in Germany. This region is suitable for our study because in industrialised countries like Germany, supply chains often already use Industry 4.0 technologies and employees are aware of the effort and benefits (da Silva et al., 2019). After two months, the items of the dependent variable (behavioural intention) were repeatedly sent to the same respondents. Anonymous identification numbers ensured that responses from the first and second questionnaires could be linked. The questionnaire was answered completely by 147 persons in the first survey round. In the second round, a saturation of the renewed responses sets in early. Therefore, after 125 completed questionnaires for round one and two, the survey was ended. Using data from the second survey avoids the usual method bias due to independent questioning of the independent and dependent variables. The required sample size was determined a priori using the inverse square root method by Kock and Hadaya (2018). A priori analyses are an efficient method for checking statistical power before a study is actually conducted (Faul et al., 2007). G*Power 3.1.9.6 was used as the statistical power analysis program for the calculation. According to Cohen (1992), a rather small effect size of 0.05 was chosen as the input variable. The α

error probability was set to 0.05, and the number of predictors corresponding to the adopted UTAUT 1 model (Venkatesh et al., 2003) to 3. Power was set to 0.8, as recommended by Kock and Hadaya (2018) for studies in the field of information systems. After calculation, a required sample size of 125 was given to reach a statistical power of 0.8, which is appropriate in behavioural research, according to Cohen (1977). Table 11 below shows the demographics of the participants and their role in the supply chain.

Table 11: Demographic data and role of companies in the supply chain.

Demographic data	Men	70.4%
	Women	29.6%
	Other	0.0%
	Average Age	36.7 years
Role of companies in the supply chain	Manufacturing and production	41%
	Transportation and distribution	19%
	Trade and distribution	19%
	Suppliers (of materials and raw materials)	18%
	Other	2%

The most strongly represented industry was plant/mechanical engineering, with 18%, followed by automotive manufacturers/ automotive suppliers with 12% and transportation/ logistics with 10%. The other industries represented are 8% electronics, 8% trade, and 8% IT/telecommunications. 7% consumer goods manufacturing, 4% public-sector institutions and 4% banking/ insurance/ financial services. Chemicals and health care/ social services each accounted for 3%. Energy supply, fabricated metals and pharmaceuticals are represented by 2% each. Other industries accounted for 3%. The relative amounts of the different types of industry and detailed demographic data can also be found in the data repository.

3.3.3 Statistical tests

To analyse our research model, we used the partial least squares (PLS) method. We chose PLS-SEM (structural equation modelling) because it can work efficiently with a wide range of sample sizes and increased model complexity while making few restrictive assumptions about the data (Hair et al., 2011). We performed bootstrapping with a significance level of 0.05, and the recommended number of 5,000 samples (Hair Jr et al., 2021; Henseler et al., 2009a), implemented with SmartPLS 4.0.8.9. Before the analysis, we conducted statistical tests to assess the quality of the measurement model and the overall quality of the structural model. We followed the proposed procedure for PLS model evaluation according to Henseler et al. (2009b). While all detailed statistical tests, the specific settings used, the data set and results can also be found in the data repository, the most relevant results will be presented following.

All of the used variables of the model are reflective variables, so we first assessed the reliability and validity of performance expectancy, effort expectancy, social influence and behavioural intention. All used constructs have a composite reliability (rc) above the required value of 0.8 for advanced stages of research, which confirms the reliability of internal consistency (Henseler et al., 2009a).

Since the Items PE4, PO3 and SI3 indicators showed insufficient outer loadings under 0.6, they were removed from the model (Henseler et al., 2009a). Each construct still consists of at least three other indicators and was therefore included for further testing and analysis. All other indicators meet the indicator reliability criterion, which is confirmed by sufficient outer loadings over 0.8 according to Henseler et al. (2009a).

Furthermore, discriminant validity is confirmed by exclusive values below 1 for the heterotrait-monotrait (HTMT) criterion. Convergent validity was assessed by the average variance extracted (AVE), for which all values are above 0.7, also indicating the very high quality of the model (Henseler et al., 2009a). Second, we evaluated the quality of the structural model. The coefficient of determination (R²) of the endogenous latent variable serves as the essential criterion for assessing the structural mode (Henseler et al., 2009a). With an R² of 0.473, our model can be described as moderate according to Hair Jr et al. (2021). The Standardised root mean square residual (SRMR) represents a value of 0.054 and is therefore considered a good model fit (Hair et al., 2014).

To minimise common bias in advance, we followed the procedure of Kortmann (2015) in terms of anonymity, confidentiality, placement of variables, and use of different scale types. Also, we followed the recommendation according to Podsakoff et al. (2003) and measured the independent and depended variables with weeks in between. In addition, a post-hoc test was conducted for our data to assess bias due to the common method. Harman's one-factor test shows that the total variance of the main factor is only 34.71%. Thus, we conclude that the bias due to the common method is either non-existent or negligible.

3.4 Results

3.4.1 Descriptive results

Descriptive statistics of all variables in the structural equation model are compiled in Table 12.

Table 12: Descriptive statistics and correlations among variables

	M	SD	Inter-construct correlations											
			EE	SI	B I	G	A	E	V	I	R	At	An	PO
PE	5.44	1.15	.45***	.20*	.52***	.25**	-.01	-.08	.56***	-.01	-.05	.69***	-.43***	.59***
EE	4.89	1.17		.163	.37***	.23**	-.04	-.16	-.37***	-.03	-.04	.52***	-.40***	.57***
SI	4.36	1.25			.03	-.02	-.04	-.01	-.18	-.17	-.05	.29**	-.09	.24**
BI	5.00	1.21				.14	-.14	-.19	-.38***	-.14	-.08	.49***	-.31***	.48***
G	1.3	0.46					-.19*	-.03	-.13	-.03	.06	.13	-.20*	.12
A	36.78	9.13						.06	.09	.12	.08	.02	-.02	-.04
E	1.86	0.35							.02	.00	.04	-.12	.02	-.23*
V	1.25	0.43								.16	.24**	-.58***	-.46***	-.62***
I	6.81	4.57									.28**	-.09	.12	-.04
R	2.49	1.14										-.07	.11	-.13
At	5.11	1.19											-.52***	.79***
An	3.43	1.44												-.48***
PO	4.89	1.25												

Notes: N=125, M=Mean, SD=Standard Deviation, PE=Performance expectancy, EE=Effort expectancy, SI=Social influence, BI=Behavioural intention, G=Gender, A=Age; E=Experience, V=Voluntary of Use, I=I

3.4.2 Test of hypotheses

In the following Table 13, the results from testing the hypotheses are presented:

Table 13: Tests of Hypotheses

Number	Hypothesis	Result	Statistical data
1	Performance expectancy has a positive influence on behavioural intention.	Supported	$\beta = .406, p = .002$
2	Effort expectancy has a positive effect on behavioural intention	Not supported.	$\beta = .108, p = .366$
3	There is a positive effect of social influence on behavioural intention.	Not supported.	$\beta = -.033, p = .462$
4	Gender influences the relationship between (a) performance expectancy, (b) effort expectancy and (c) social influence and intention to use smart contracts technology in supply chains.	All: Not supported.	a: $\beta = -.117, p = .284$; b: $\beta = .069, p = .488$; c: $\beta = -.052, p = .623$
5	Age influences the relationship between (a) performance expectancy, (b) effort expectancy	All: Not supported.	a: $\beta = 1.39, p = .203$; b: $\beta = .083, p = .478$; c: $\beta = -.048, p = .694$

	and (c) social influence and intention to use smart contracts technology in supply chains.		
6	Experience influences the relationship between (a) effort expectancy and (b) social influence and intention to use smart contracts technology in supply chains positively	All: Not supported.	a: $\beta = -.043$, $p = 0.447$; b: $\beta = .055$, $p = .436$
7	Voluntary of use influences the relationship between social influence and intention to use smart contracts technology in supply chains.	Not supported.	$\beta = -.531$, $p = .153$

For the direct influence of the control and moderation variables, the following results were found: The type of industry has a weak influence on the behavioural intention at a significance level of 0.1 ($\beta = -.166$, $p = .060$). An influence of the companies' role in the supply chain is not supported ($\beta = .039$, $p = .659$). An influence of the different personal characteristics on the behavioural intention could not be supported (Attitude towards smart contracts: $\beta = .087$, $p = .269$; Anxiety towards smart contracts: $\beta = .087$, $p = .403$; Personal openness: $\beta = .158$, $p = .147$). Furthermore, no direct influence of the moderation variables could be confirmed (Gender: $\beta = -.009$, $p = .901$; Age: $\beta = -.086$, $p = .398$; Experience with smart contracts: $\beta = -.082$, $p = .408$; Voluntariness of use: $\beta = .030$, $p = .462$). Figure 8 shows the results of hypothesis and control variables testing in the research model:

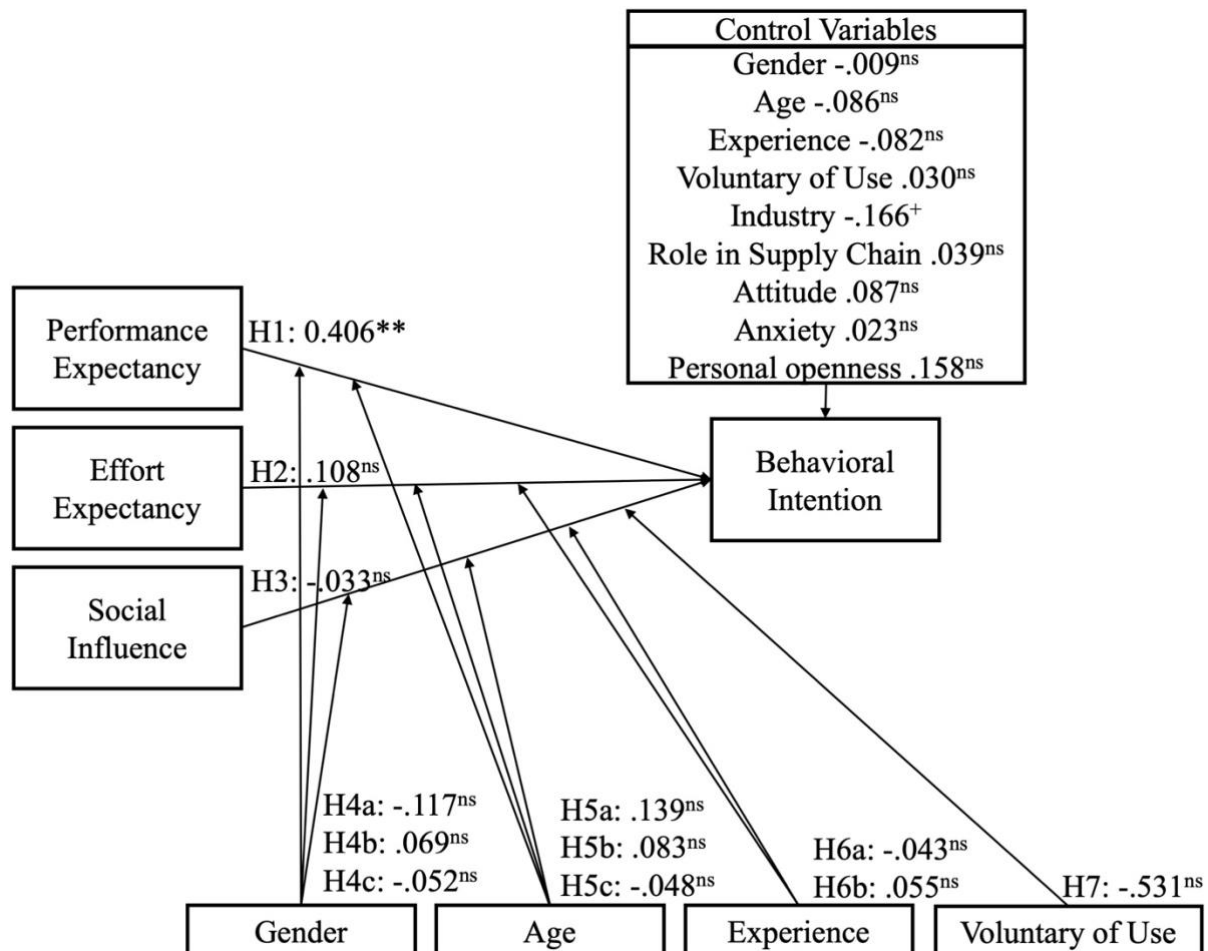


Figure 8: Research model adapted from Venkatesh et al. (2003) and results (Notes: $+ p < .1$; $* p < .05$; $** p < .01$; $*** p < .001$).

3.5 Discussion

The research questions of this study were to examine the intent of employees to use distributed ledger based smart contracts in supply chains (RQ1) and the factors which influence the intention to use (RQ2). Our findings show that employees' perception of smart contracts depends not only on their direct interaction with the technology, but also on their understanding of how this technology can affect their daily tasks, workflows and the entire supply chain. Based on the results, we can derive answers to both research questions. With a median of 5.00 (on a 7-point Likert scale with 1=Maximum disapproval and 7= Maximum approval) and a standard deviation of 1.21, we can assume that there is a high willingness of employees to use smart contracts in supply chains. Also, attitudes ($M=5.11$, $SD=1.19$) and personal openness ($M=4.89$, $SD=1.25$) toward smart contracts are also high and clearly higher than the existing anxiety regarding the technology ($M=3.43$, $SD=1.44$). The personal openness and positive attitude towards smart contracts, together with the low level of anxiety, provide a clear picture of the general perception and willingness to use of employees towards smart contracts in supply chains.

Regarding RQ2, performance expectancy was identified as the only significant influence variable of behavioural intention. This highlights the critical role that leaders and a positive corporate culture play in driving adoption of new technologies such as smart contracts, even if they are not directly used by employees. Clear communication of the benefits, training and creating an atmosphere that welcomes technological innovation are crucial. This is in line with findings from Ferri et al. (2021), who found that auditors' intention to use distributed ledger is primarily determined by performance expectations and social influence. Our findings therefore suggest that training and transparent communication about the benefits and functionality of smart contracts can help to improve employee acceptance and understanding, even if they do not interact directly with the technology. This can help to overcome concerns and encourage employees to support the adoption of new technologies. Furthermore, the type of industry in which the employee works has a slight further influence at a lower significance level. The existing influence of the performance expectancy corresponds to the expectations and the model according to (Venkatesh et al., 2003). Thus, the findings from other literature that the use of modern technologies that improve job performance correlates with high intent to use (Alazab et al., 2021; Shi et al., 2022) can also be applied to smart contracts in supply chains. Since usage intention has an influence on the successful implementation of new technologies (Taherdoost, 2019), the role of performance expectation for adoption is further strengthened by the results of this work.

Surprisingly, and contrary to the model assumptions according to Venkatesh et al. (2003), a significant influence of effort expectancy and social influence could not be confirmed. These results contrast with previous studies focused on similar modern technologies. One possible reason for this discrepancy is the novelty of smart contract technology. Unlike technologies such as IoT and Big Data (Queiroz & Pereira, 2019; Shi et al., 2022), which have established applications in supply chain processes, smart contracts are still emerging and have not yet been widely implemented in practice. While the benefits and performance capabilities of smart contracts are frequently studied (Bingzhang & Zirianov, 2021; Chen et al., 2022; Raj et al., 2022; Vo et al., 2021) there is only a little research on the effort involved in using smart contracts. This could lead to uncertainty with regard to the effort expectancy and employees may not be able to anticipate the effort and its impact.

In a similar way, it can also be explained why no influence of social influence on behavioural intention could be confirmed. While social influence has often been found to have a significant impact on the use of technologies in supply chains in previous literature (Russell & Hoag, 2004), these studies have also examined technologies that are already integrated into processes in various forms and do not exhibit the novelty of distributed ledger based smart contracts. The very few existing use cases of smart contracts may lead to a low relevance of smart contracts in professional and private environments and, therefore, to a minor influence on the employee. Another explanation is that the current low importance of technology from the employee's perspective leads to a low extent of social influence, as is the case with other tasks of lower importance (Baron et al., 1996).

Contrary to expectations, none of the presumed moderation hypotheses (H4 – H7) from the model according to (Venkatesh et al., 2003) could be confirmed. The absence of significant moderation effects in the study suggests that gender, age, experience, and voluntariness of use do not have a significant

influence on the relationship between the independent variables (performance expectancy, effort expectancy, social influence) and the behavioural intention to use smart contracts in supply chains. This could be attributed to insufficient variability, irrelevance of the moderating variables, complex interactions, or limited sample size.

Previous studies, which referred to the intention to use technologies in another context, confirmed at least one of the stated hypotheses (Celik, 2016; Magsamen-Conrad et al., 2015; Phichitchaisopa & Naenna, 2013; Puriwat & Tripopsakul, 2021). While previous studies have often found mixed-gender differences in moderation of technology adoption (Goswami & Dutta, 2015), gender does not play a role in our case. Similarly, age did not moderate between performance expectancy, effort expectancy, social influence, and behavioural intention. The assumption of a moderator effect concerning the experience with smart contracts on the intention to use it could not be confirmed either. Also, whether using smart contracts would be voluntary could not be determined as a moderating effect for social influence and intention to use. Although the results do not correspond to their findings in other studies, they do not contradict them. Smart contract technology is a relatively new and unfamiliar, which may have made it difficult for participants to form strong opinions about it. This assumption also corresponds to the conclusions of Lee et al. (2019). As a result, individual differences based on gender, age, experience, or voluntariness of use may not have played as significant a role in shaping participants' intentions to use smart contracts as they might have with more established technologies.

It is worth mentioning that the type of industry slightly influences behavioural intention at a significance level of 0.1. Since the number of employees per industry in our sample is not balanced and representative, we could not investigate this in detail. However, for the other control variables, no direct influence on behavioural intention was found. The fact that gender, age, experience, and voluntary of use have no direct influence is also consistent with the missing moderator effects. The results suggest that these variables play a subordinate role at the current time.

We suspect that the novelty of smart contracts and the unfamiliarity of the employees towards the technology could play a substantial role in those results. With an average value of 1.86 (SD= 0.35) on a 7-point Likert scale, the participant's experience with the technology is very low. The limited knowledge and experience with the technology may result in decisions being made more randomly rather than about personal characteristics. It also strengthens the role of performance expectancy, the only significant influence. Nevertheless, even without significant influence on the intention to use, a positive attitude, personal openness, and lower anxiety should be seen as positive indicators of willingness to use. However, according to our results, they do not play a role in influencing the intention to use.

3.6 Conclusion

3.6.1 Theoretical contribution

Contributing to the topic of distributed ledger based smart contracts and antecedents of individual technology adoption behaviour, our study entails three major theoretical contributions: First, the study addresses a research gap by focusing on the adoption of smart contracts in supply chains from a sociotechnical perspective. While there is a growing interest in smart contracts and their potential applications, there is a lack of research specifically examining their adoption within supply chain management. By investigating the factors influencing the intention to use smart contracts in supply chains, the study provides valuable insights into this emerging area of research. Thus, the results contribute to further exploring the research fields for information systems research and operational systems research, especially concerning new modern technologies. This study examines specific factors influencing the willingness to use smart contracts in supply chains, contributing to a deeper understanding.

The study also extends the literature by applying the UTAUT model to the context of smart contracts in supply chains. Previous research has predominantly focused on adopting other technologies, and the UTAUT model has been widely used in various domains. By adapting and testing the UTAUT model in the context of smart contracts, the study contributes to the understanding of technology adoption in supply chains and provides a comprehensive framework to examine the factors influencing adoption

behaviour. The results show that the model's assumptions can only be adopted to a limited extent for our specific case. We suspect that the novelty of the technology, in particular is the reason for this. In detail, a more nuanced understanding of how performance expectations influence technology adoption in different supply chain dependent industries is created. This extended application can help refine theoretical frameworks and improve their predictive power in different industrial contexts such as manufacturing, retail and transport.

Furthermore, the study compares its results with previous literature on technology adoption to identify similarities and differences. This comparative analysis underscores that different technologies and application areas can lead to varied employee perceptions and adoption behaviour. The study serves as an indicator that the adoption factors identified in previous research may not directly translate to the adoption of smart contracts in supply chains. This finding contributes to a more nuanced understanding of technology adoption and emphasizes the need for context-specific investigations.

3.6.2 Practical contribution

From a practical perspective, our findings offer actionable insights for managers in various industries with complex supply chains. The results underline that technologies can influence employees' perceptions even if they do not come into direct contact with them. Understanding the impact that these technologies have on their work and the company is crucial. Recognising that performance expectations significantly influence the adoption of smart contracts can help managers develop targeted strategies to drive the adoption of the technology. By taking user intentions into account, the successful implementation of smart contracts can promote more efficient and transparent supply chains in different industries. The following sections outline the key implications for managers and present strategies for achieving these benefits based on our research findings.

First, the results give a positive signal to managers regarding the willingness to use smart contracts in supply chains by employees. The basis for our assumption is the high intention to use, positive attitude and personal openness of employees and lower anxiety about using smart contracts. Programs should now be built upon that further strengthen this positive attitude. Initial prototypes could be tested or pilot projects initiated that involve using smart contracts on a limited scale and demonstrate the extent of the possibilities. Although it will hardly be technically possible to use distributed ledger based smart contracts to their full extent, employees and companies can still prepare to adapt them.

The focus of actions should be primarily on strengthening performance expectancy, as the influence of personal characteristics (gender, age, experience, attitude, anxiety, and personal openness) on behavioural intention could not be confirmed. This can be done by highlighting the benefits and advantages of using smart contracts in supply chain processes, emphasising potential efficiency gains, cost savings, and transparency. Implement educational programs and workshops to demonstrate how smart contracts can simplify business processes and improve job performance.

Also, the management perspective should consider the other success factors of technology adoption. The employees' intention to use the technology is only one of many factors (Fan & Fang, 2006; Taherdoost, 2019). Since the necessary technology readiness is not given (Dora et al., 2022), managers should focus on leadership (Pozzi et al., 2021) and knowledge transfer regarding the smart contract technology (Kumar et al., 2021). Effective leadership and management support can play a significant role in facilitating the adoption of smart contracts by fostering an environment that encourages learning and collaboration. By investing in these areas, managers can help raise performance expectations for smart contracts ultimately leading to a more successful integration of smart contract technology within their organisations.

Finally, conducting expert training programmes, workshops and seminars can educate employees on the features and capabilities of smart contracts. These training initiatives should include the latest developments and applications of smart contract technology to ensure that employees are well informed and prepared to use the technology effectively. Managers should involve their employees in the decision-making process regarding the introduction of smart contract technology. By communicating the strategic importance of smart contracts and actively involving employees in discussions and decisions, managers can increase the willingness of employees to adopt the technology. This

involvement will help employees feel more engaged in the process and gain a stronger understanding of performance capabilities.

3.6.3 Limitations

As with any research, there are limitations to our work, but they can also inspire further research. First, smart contract technology has evolved rapidly and will continue in the coming years. This can lead to the results changing significantly as the technology and use cases mature. To improve generalizability, it is advisable to use a broader and more representative sample in future studies, to consider different contexts and environments, and to identify and address possible limitations of the studied characteristics. Remembering that the present study examined only a specific sample is also important. The survey was conducted in Germany. Different results may be obtained in other countries due to cultural differences, regulatory requirements, technology infrastructure or general economic conditions.

Interpreting the study findings necessitates considering the sample size and potential biases that could influence the data. Careful evaluation of these factors is crucial when assessing the generalizability and robustness of the results. Our sample size of 125, while adequate for the analysis, may limit the generalizability of the findings and might restrict the findings' statistical power and general applicability. With a relatively small sample, there is a possibility that the study may not have had enough statistical power to detect small effects. Although the sample size was determined a priori using power analysis methods, it is prudent to recognise that a larger sample size would lead to greater confidence in the results. Therefore, caution should be exercised when extrapolating the findings to wider populations or contexts.

Furthermore, the study focused on hypothetical behavioural intentions rather than actual behaviour, as the adoption of smart contracts in supply chains is still in its early stages. This introduces the possibility of an intention-behaviour gap, wherein participants' stated intentions may not align with their actual adoption behaviours once the technology is implemented. To bridge this gap and achieve a more comprehensive understanding of the technology's impact, future research should investigate the actual adoption and usage of smart contracts in supply chains.

3.6.4 Future research

This study has made contributions to understanding smart contract adoption in supply chains, but there are several gaps and avenues for future research that can build upon these findings and expand knowledge in this area. The following are specific directions for future research: First of all, future research should consider alternative factors, utilise larger samples, and explore complex interactions to gain a better understanding of the non-significant effects. Future research can conduct comparative studies across different countries and industries to capture the diversity of supply chains and the influence of cultural, regulatory, and industry-specific factors. Future research should also consider organisational structure alongside industry type, and examine additional influencing factors such as organisational culture, regulatory environment and technological infrastructure to improve understanding of smart contract adoption. Qualitative research can be used to identify unique contextual factors by comparing adoption patterns and challenges and develop tailored strategies for smart contract adoption. Longitudinal research could provide insights into how performance expectations and other factors influencing smart contract adoption evolve over time.

We recommend a more comprehensive examination of the factors that influence performance expectancy. This includes investigating how constructs such as social influence, effort expectancy and other potential external factors not included in the UTAUT model could influence performance expectancy. This will help to develop a more detailed understanding of technology adoption processes in supply chains and help to better address users' performance expectations.

Also, future research can explore the integration of smart contracts with other emerging technologies such as the Internet of Things (IoT), artificial intelligence, and blockchain. Investigating the synergistic effects of combining these technologies can provide a holistic understanding of their potential to transform supply chain operations and enable new business models. Another future research topic is the essential role of collaboration and trust in smart contract adoption. When adopting smart contracts,

researchers can investigate how trust is established, maintained, and enhanced in supply chain relationships. Exploring the mechanisms that foster collaboration and trust among stakeholders and how they influence the willingness to adopt this technology can provide valuable insights.

Finally, the gap in organisational change processes associated with smart contract adoption should be investigated in more detail. Studying the organisational change processes associated with smart contract adoption is crucial. Researchers can investigate the challenges and opportunities of integrating smart contracts into existing supply chain systems and processes. Examining the role of change agents, communication strategies, and employee engagement in driving successful organisational change towards smart contract adoption can help understand the factors contributing to successful implementation.

3.7 References

- Adams, J., & Lennard, D. (2019). Data: To Share or Not To Share? Master Program in Business and Management].
- Agrawal, T. K., Angelis, J., Khilji, W. A., Kalaiarasan, R., & Wiktorsson, M. (2022). Demonstration of a blockchain-based framework using smart contracts for supply chain collaboration. *International Journal of Production Research*, 61(5), 1497-1516. <https://doi.org/10.1080/00207543.2022.2039413>
- Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., Omar, M., & Ellahham, S. (2021). Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies. *IEEE Access*, 9, 44905-44927. <https://doi.org/10.1109/access.2021.3066503>
- Alazab, M., Alhyari, S., Awajan, A., & Abdallah, A. B. (2021). Blockchain technology in supply chain management: an empirical study of the factors affecting user adoption/acceptance. *Cluster Computing*, 24(1), 83-101. <https://doi.org/10.1007/s10586-020-03200-4>
- Alnodel, A., Khlaifah, N., & Elnafabi, H. (2020). Evaluating the quality of services provided by the financial controller in governmental organizations: Using the SERVPERF model. *Journal of Governance and Regulation*, 9, 123-132. <https://doi.org/10.22495/jgrv9i2art10>
- Arinze, C. A., Ajala, O. A., Okoye, C. C., Ofodile, O. C., & Daraojimba, A. I. (2024). Evaluating the integration of advanced IT solutions for emission reduction in the oil and gas sector. *Engineering Science & Technology Journal*, 5(3), 639-652. <https://doi.org/10.51594/estj.v5i3.862>
- Ayu Sanjaya, Y. P., & Akhyar, M. A. (2022). Blockchain and Smart Contract Applications Can Be A Support For Msme Supply Chain finance Based On Sharia Crowdfunding. *Blockchain Frontier Technology*, 2(1), 44-49. <https://doi.org/10.34306/bfront.v2i1.108>
- Bäckstrand, J., & Fredriksson, A. (2022). The role of supplier information availability for construction supply chain performance. *Production Planning & Control*, 33(9-10), 863-874. <https://doi.org/10.1080/09537287.2020.1837933>
- Badi, S., Ochieng, E., Nasaj, M., & Papadaki, M. (2021). Technological, organisational and environmental determinants of smart contracts adoption: UK construction sector viewpoint. *Construction Management and Economics*, 39(1), 36-54. <https://doi.org/10.1080/01446193.2020.1819549>
- Baron, R. S., Vandello, J. A., & Brunsman, B. (1996). The forgotten variable in conformity research: Impact of task importance on social influence. *Journal of personality and social psychology*, 71(5), 915-927. <https://doi.org/10.1037/0022-3514.71.5.915>
- Bingzhang, L., & Zirianov, V. (2021). Blockchain in agricultural supply chain management. *E3S Web of Conferences*, 273(1), 1-10.
- Bouwman, H., & Wijngaert, L. v. d. (2009). Coppers context, and conjoints: a reassessment of TAM. *Journal of Information Technology*, 24(2), 186-201. <https://doi.org/10.1057/jit.2008.36>

- Casado-Vara, R., Prieto, J., De la Prieta, F., & Corchado, J. M. (2018). How blockchain improves the supply chain: Case study alimentary supply chain. *Procedia computer science*, 134(1), 393-398. <https://doi.org/10.1016/j.procs.2018.07.193>
- Celik, H. (2016). Customer online shopping anxiety within the Unified Theory of Acceptance and Use Technology (UTAUT) framework. *Asia Pacific Journal of Marketing and Logistics*, 28(2), 278-307. <https://doi.org/10.1108/APJML-05-2015-0077>
- Chatterjee, S., Rana, N. P., Khorana, S., Mikalef, P., & Sharma, A. (2023). Assessing Organizational Users' Intentions and Behavior to AI Integrated CRM Systems: a Meta-UTAUT Approach. *Information Systems Frontiers*, 25(4), 1299-1313. <https://doi.org/10.1007/s10796-021-10181-1>
- Chaveesuk, S., Khalid, B., & Chaikasoonthorn, W. (2020). Understanding Stakeholders Needs for Using Blockchain Based Smart Contracts in Construction Industry of Thailand: Extended TAM Framework. 2020 13th International Conference on Human System Interaction (HSI), 137-141. Retrieved 6-8 June 2020, from
- Chen, J. V., Wang, C.-L., & Yen, D. C. (2014). A causal model for supply chain partner's commitment. *Production Planning & Control*, 25(9), 800-813. <https://doi.org/10.1080/09537287.2013.764578>
- Chen, W., Botchie, D., Braganza, A., & Han, H. (2022). A transaction cost perspective on blockchain governance in global value chains. *Strategic Change*, 31(1), 75-87. <https://doi.org/10.1002/jsc.2487>
- Chowdhury, M. J. M., Ferdous, M. S., Biswas, K., Chowdhury, N., Kayes, A., Alazab, M., & Watters, P. (2019). A comparative analysis of distributed ledger technology platforms. *IEEE Access*, 7(1), 167930-167943. <https://doi.org/10.1109/ACCESS.2019.2953729>
- Cohen, J. (1977). Statistical power analysis for the behavioral sciences. *Applied Psychological Measurement*, 7(3), 249. <https://doi.org/10.1177/014662168300700301>
- Cohen, J. (1992). Quantitative methods in psychology: A power primer. *Psychological bulletin*, 112(1), 155-159.
- Cranor, L. F., & Wright, R. N. (2000). Influencing software usage. *Proceedings of the tenth conference on Computers, freedom and privacy: challenging the assumptions*, 45-55.
- da Silva, V. L., Kovaleski, J. L., & Pagani, R. N. (2019). Technology transfer in the supply chain oriented to industry 4.0: a literature review. *Technology Analysis & Strategic Management*, 31(5), 546-562. <https://doi.org/10.1080/09537325.2018.1524135>
- Dal Mas, F., Dicuonzo, G., Massaro, M., & Dell'Atti, V. (2020). Smart contracts to enable sustainable business models. A case study. *Management Decision*, 58(8), 1601-1619. <https://doi.org/10.1108/MD-09-2019-1266>
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 13(3), 319-340. <https://doi.org/10.2307/249008>
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace 1. *Journal of applied social psychology*, 22(14), 1111-1132. <https://doi.org/10.1111/j.1559-1816.1992.tb00945.x>
- Dietrich, F., Hoffmann, M., Mediavilla, M. A., Louw, L., & Palm, D. (2022). Towards a model for holistic mapping of supply chains by means of tracking and tracing technologies. *Procedia CIRP*, 107(1), 53-58. <https://doi.org/10.1016/j.procir.2022.04.009>
- Dora, M., Kumar, A., Mangla, S. K., Pant, A., & Kamal, M. M. (2022). Critical success factors influencing artificial intelligence adoption in food supply chains. *International Journal of Production Research*, 60(14), 4621-4640. <https://doi.org/10.1080/00207543.2021.1959665>
- El Ioini, N., & Pahl, C. (2018). A review of distributed ledger technologies. *On the Move to Meaningful Internet Systems. OTM 2018 Conferences: Confederated International Conferences: CoopIS*,

- C&TC, and ODBASE 2018, Valletta, Malta, October 22-26, 2018, Proceedings, Part II, 277-288.
- Ellram, L. M. (1991). Supply-chain management: the industrial organisation perspective. *International Journal of Physical Distribution & Logistics Management*, 21(1), 13-22. <https://doi.org/10.1108/09600039110137082>
- Fan, J. C., & Fang, K. (2006). ERP implementation and information systems success: a test of DeLone and McLean's model. *2006 Technology Management for the Global Future-PICMET 2006 Conference*, 3(1), 1272-1278.
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods*, 39(2), 175-191. <https://doi.org/10.3758/BF03193146>
- Ferri, L., Spanò, R., Ginesti, G., & Theodosopoulos, G. (2021). Ascertaining auditors' intentions to use blockchain technology: evidence from the Big 4 accountancy firms in Italy. *Meditari Accountancy Research*, 29(5), 1063-1087. <https://doi.org/10.1108/MEDAR-03-2020-0829>
- Goswami, A., & Dutta, S. (2015). Gender differences in technology usage—A literature review. *Open Journal of Business and Management*, 4(1), 51-59. <https://doi.org/10.4236/ojbm.2016.41006>
- Groschopf, W., Dobrovnik, M., & Herneth, C. (2021). Smart Contracts for Sustainable Supply Chain Management: Conceptual Frameworks for Supply Chain Maturity Evaluation and Smart Contract Sustainability Assessment [Hypothesis and Theory]. *Frontiers in Blockchain*, 4. <https://doi.org/10.3389/fbloc.2021.506436>
- Grosse, N., Guerpinar, T., & Henke, M. (2021). Blockchain-Enabled Trust in Intercompany Networks Applying the Agency Theory. *Blockchain and Internet of Things Conference*, 3(1), 8–14. <https://doi.org/10.1145/3475992.3475994>
- Hair, J. F., Henseler, J., Dijkstra, T. K., & Sarstedt, M. (2014). Common beliefs and reality about partial least squares: comments on Rönkkö and Evermann. *Organizational Research Methods* 17(2), 182-209. <https://doi.org/10.1177/1094428114526928>
- Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. *Journal of Marketing theory and Practice*, 19(2), 139-152. <https://doi.org/10.2753/MTP1069-6679190202>
- Hair Jr, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2021). A primer on partial least squares structural equation modeling (PLS-SEM). 38(2). <https://doi.org/10.1080/1743727X.2015.1005806>
- Hamledari, H., & Fischer, M. (2021). Measuring the impact of blockchain and smart contracts on construction supply chain visibility. *Advanced Engineering Informatics*, 50(1), 101444. <https://doi.org/10.1016/j.aei.2021.101444>
- Harter, J. K., Schmidt, F. L., Asplund, J. W., Killham, E. A., & Agrawal, S. (2010). Causal Impact of Employee Work Perceptions on the Bottom Line of Organizations. *Perspect Psychol Sci*, 5(4), 378-389. <https://doi.org/10.1177/1745691610374589>
- Henseler, J., Ringle, C. M., & Sinkovics, R. R. (2009a). The use of partial least squares path modeling in international marketing. *New challenges to international marketing*, 20(1), 277-319. [https://doi.org/10.1108/S1474-7979\(2009\)0000020014](https://doi.org/10.1108/S1474-7979(2009)0000020014)
- Henseler, J., Ringle, C. M., & Sinkovics, R. R. (2009b). The use of partial least squares path modeling in international marketing. In *New challenges to international marketing* (Vol. 20, pp. 277-319). Emerald Group Publishing Limited. [https://doi.org/10.1108/S1474-7979\(2009\)0000020014](https://doi.org/10.1108/S1474-7979(2009)0000020014)
- Kabir, M. R., & Islam, M. A. (2021). Behavioural intention to adopt blockchain technology in Bangladeshi banking companies. *AIP Conference Proceedings*, 2347(1), 020025. <https://doi.org/10.1063/5.0051654>

- Kajikawa, Y., Takeda, Y., Sakata, I., & Matsushima, K. (2010). Multiscale analysis of interfirm networks in regional clusters. *Technovation*, 30(3), 168-180. <https://doi.org/10.1016/j.technovation.2009.12.004>
- Kayikci, Y., Subramanian, N., Dora, M., & Bhatia, M. S. (2022). Food supply chain in the era of Industry 4.0: blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology. *Production Planning & Control*, 33(2-3), 301-321. <https://doi.org/10.1080/09537287.2020.1810757>
- Kock, N., & Hadaya, P. (2018). Minimum sample size estimation in PLS-SEM: The inverse square root and gamma-exponential methods. *Information systems journal*, 28(1), 227-261. <https://doi.org/10.1111/isj.12131>
- Kortmann, S. (2015). The mediating role of strategic orientations on the relationship between ambidexterity-oriented decisions and innovative ambidexterity. *Journal of Product Innovation Management*, 32(5), 666-684.
- Kumar, A., Choudhary, S., Garza-Reyes, J. A., Kumar, V., Rehman Khan, S. A., & Mishra, N. (2021). Analysis of critical success factors for implementing Industry 4.0 integrated circular supply chain – moving towards sustainable operations. *Production Planning & Control*, 1-15. <https://doi.org/10.1080/09537287.2021.1980905>
- Kumar, N. M., & Chopra, S. S. (2022). Leveraging Blockchain and Smart Contract Technologies to Overcome Circular Economy Implementation Challenges. *Sustainability*, 15(15), 9492. <https://doi.org/10.3390/su14159492>
- Kumarathunga, M. (2020). Improving farmers' participation in agri supply chains with blockchain and smart contracts. 2020 Seventh International Conference on Software Defined Systems (SDS), 139-144.
- Lee, C., Kriscenski, J., & Lim, H. S. (2019). AN EMPIRICAL STUDY OF BEHAVIORAL INTENTION TO USE BLOCKCHAIN TECHNOLOGY. *Journal of International Business Disciplines*, 14(1), 1-21.
- Leyer, M., & Oberländer, A. M. (2022). The Influence of Mental Models on Employee-Driven Digital Process Innovation during Times of a Crisis. 43rd International Conference on Information Systems (ICIS), 1-16.
- Li, C., Khaliq, N., Chinove, L., Khaliq, U., Popp, J., & Oláh, J. (2023). Cryptocurrency Acceptance Model to Analyze Consumers' Usage Intention: Evidence From Pakistan. *SAGE Open*, 13(1), 21582440231156360. <https://doi.org/10.1177/21582440231156360>
- Lombard, J. A. (2017). End-consumer trust and adoption of smart contracts in life insurance in South Africa University of Pretoria].
- Madhwal, Y., Borbon-Galvez, Y., Etemadi, N., Yanovich, Y., & Creazza, A. (2022). Proof of Delivery Smart Contract for Performance Measurements. *IEEE Access*, 10, 69147-69159. <https://doi.org/10.1109/ACCESS.2022.3185634>
- Magsamen-Conrad, K., Upadhyaya, S., Joa, C. Y., & Dowd, J. (2015). Bridging the divide: Using UTAUT to predict multigenerational tablet adoption practices. *Computers in Human Behavior*, 50(1), 186-196. <https://doi.org/10.1016/j.chb.2015.03.032>
- Merhi, M., Hone, K., Tarhini, A., & Ameen, N. (2021). An empirical examination of the moderating role of age and gender in consumer mobile banking use: a cross-national, quantitative study. *Journal of Enterprise Information Management*, 34(4), 1144-1168. <https://doi.org/10.1108/JEIM-03-2020-0092>
- Natanelov, V., Cao, S., Foth, M., & Dulleck, U. (2022). Blockchain smart contracts for supply chain finance: Mapping the innovation potential in Australia-China beef supply chains. *Journal of Industrial Information Integration*, 30, 100389. <https://doi.org/10.1016/j.jii.2022.100389>

- Nelaturu, K., Beillahit, S. M., Long, F., & Veneris, A. (2021). Smart Contracts Refinement for Gas Optimization. 2021 3rd Conference on Blockchain Research and Applications for Innovative Networks and Services, BRAINS 2021,
- Nguyen, L.-T., Nguyen, D.-T., Ngoc, K. N.-N., & Duc, D. T. V. (2023). Blockchain adoption in logistics companies in Ho Chi Minh City, Vietnam. *Cogent Business & Management*, 10(2), 2216436. <https://doi.org/10.1080/23311975.2023.2216436>
- Park, K. O. (2020). A Study on Sustainable Usage Intention of Blockchain in the Big Data Era: Logistics and Supply Chain Management Companies. *Sustainability*, 12(24), 10670. <https://doi.org/10.3390/su122410670>
- Pfohl, H.-C., & Gomm, M. (2009). Supply chain finance: optimizing financial flows in supply chains. *Logistics Research*, 1(3), 149-161. <https://doi.org/10.1007/s12159-009-0020-y>
- Phichitchaisopa, N., & Naenna, T. (2013). Factors affecting the adoption of healthcare information technology. *EXCLI journal*, 12(1), 413-436. <https://doi.org/10.19082/2713>
- Pieters, J. J., Kokkinou, A., & van Kollenburg, T. (2021). Understanding Blockchain Technology Adoption by Non-experts: an Application of the Unified Theory of Acceptance and Use of Technology (UTAUT). *Operations Research Forum*, 3(1), 1. <https://doi.org/10.1007/s43069-021-00113-9>
- Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *Journal of applied psychology*, 88(5), 879. <https://doi.org/10.1037/0021-9010.88.5.879>
- Pozzi, R., Rossi, T., & Secchi, R. (2021). Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies. *Production Planning & Control*, 1-21. <https://doi.org/10.1080/09537287.2021.1891481>
- Prause, G. (2019). Smart contracts for smart supply chains. *IFAC-PapersOnLine*, 52(13), 2501-2506. <https://doi.org/10.1016/j.ifacol.2019.11.582>
- Premm, M., & Kirn, S. (2015). A multiagent systems perspective on Industry 4.0 supply networks. *German Conference on Multiagent System Technologies*, 101-118. https://doi.org/10.1007/978-3-319-27343-3_6
- Puriwat, W., & Tripopsakul, S. (2021). Explaining Social Media Adoption for a Business Purpose: An Application of the UTAUT Model. *Sustainability*, 13(4), 2082. <https://doi.org/10.3390/su13042082>
- Queiroz, M., & Pereira, S. (2019). Intention to adopt big data in supply chain management: A brazilian perspective. *Revista de Administração de Empresas*, 59, 389-401. <https://doi.org/10.1590/s0034-759020190605>
- Raj, P. V. R. P., Jauhar, S. K., Ramkumar, M., & Pratap, S. (2022). Procurement, traceability and advance cash credit payment transactions in supply chain using blockchain smart contracts. *Computers & Industrial Engineering*, 167, 108038. <https://doi.org/10.1016/j.cie.2022.108038>
- Russell, D. M., & Hoag, A. M. (2004). People and information technology in the supply chain. *International Journal of Physical Distribution & Logistics Management*, 34(2), 102-122. <https://doi.org/10.1108/09600030410526914>
- Sánchez-Gómez, N., Morales-Trujillo, L., & Torres-Valderrama, J. (2019). Towards an approach for applying early testing to smart contracts. *WEBIST 2019 - Proceedings of the 15th International Conference on Web Information Systems and Technologies*,
- Schultz, T. L. (2020). Certified crop advisers' intention to use smartphones for mobile learning Iowa State University].
- Schwarze, R., & Sushchenko, O. (2022). Climate Insurance for Agriculture in Europe: On the Merits of Smart Contracts and Distributed Ledger Technologies. *Journal of Risk and Financial Management*, 15(5), 211. <https://doi.org/10.3390/jrfm15050211>

- Scott, P. J. (2010). Technology and organisations.
- Sheel, A., & Nath, V. (2020). Antecedents of blockchain technology adoption intentions in the supply chain. *International Journal of Business Innovation and Research*, 21(4), 564-584.
- Shi, Y., Siddik, A. B., Masukujjaman, M., Zheng, G., Hamayun, M., & Ibrahim, A. M. (2022). The Antecedents of Willingness to Adopt and Pay for the IoT in the Agricultural Industry: An Application of the UTAUT 2 Theory. *Sustainability*, 14(11), 6640. <https://doi.org/10.3390/su14116640>
- Taherdoost, H. (2019). Importance of Technology Acceptance Assessment for Successful Implementation and Development of New Technologies. *Global Journal of Engineering Sciences*, 1(3). <https://doi.org/10.33552/GJES.2019.01.000511>
- Van Dun, D., & Kumar, M. (2021). Enablers of Industry 4.0 Technology Adoption: Transformational Leadership and Emotional Intelligence. *Academy of Management Proceedings*, 2021(1), 13696. <https://doi.org/10.5465/AMBPP.2021.13696abstract>
- van Geldere, E. (2023). Determinants influencing user resistance and the usage intention of smart contracts within the public sector. A status-quo bias perspective Tilburg School of Economics and Management (TISEM)].
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 27(3), 425-478. <https://doi.org/10.2307/30036540>
- Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. *MIS quarterly*, 157-178.
- Vo, K. T., Nguyen-Thi, A. T., & Nguyen-Hoang, T. A. (2021). Building Sustainable Food Supply Chain Management System Based On Hyperledger Fabric Blockchain. *International Conference on Advanced Computing and Applications (ACOMP)*, 15(1), 9-16. <https://doi.org/10.1109/ACOMP53746.2021.00008>
- Wamba, S. F., & Queiroz, M. M. (2019). The Role of Social Influence in Blockchain Adoption: The Brazilian Supply Chain Case. *IFAC-PapersOnLine*, 52(13), 1715-1720. <https://doi.org/10.1016/j.ifacol.2019.11.448>
- Wang, S., Li, D., Zhang, Y., & Chen, J. (2019). Smart contract-based product traceability system in the supply chain scenario. *IEEE Access*, 7(1), 115122-115133. <https://doi.org/10.1109/ACCESS.2019.2935873>
- Xu, L., Tu, P., & Tang, Q. (2020). Contract design for cloud logistics (cl) based on blockchain technology (BT). *Complexity*, 2020(4), 1-13. <https://doi.org/10.1155/2020/5305808>
- Xue, Y., Liang, H., & Wu, L. (2011). Punishment, Justice, and Compliance in Mandatory IT Settings. *Information systems research*, 22(2), 400-414. <https://doi.org/10.1287/isre.1090.0266>

3.8 Appendix

The questionnaires, collected data, statistical tests and study results can be found online in a permanent open-access data repository: <https://doi.org/10.17605/OSF.IO/53F2W>

4 Smart contracts as enabler for trustless transactions in supply chain networks? Modelling trust towards distributed ledger-based smart contracts: A dual study analysis⁷

Wieland Müller and Michael Leyer

Abstract

This paper explores the dynamics of trust in supply chain management facilitated by distributed ledger-based smart contracts. The research combines two quantitative studies from the United States to gain a comprehensive understanding of trust, risk and behaviour in the context of smart contract adoption. The first study establishes a multidimensional trust model for smart contracts, while the second examines the relationship between trust and risk behaviour in smart contract usage. The results highlight the influence of specific trust dimensions, in particular situational social trust and trust in information technology, on influencing risk behaviour. Furthermore, the study shows the moderating role of perceived situational risk and the positive influence of risk propensity on risk behaviour. This research improves the theoretical understanding of trust towards smart contracts and provides insights into this emerging field through the multidimensional trust model and the integrative approach to the study of trust and risk behaviour.

Keywords: Trust Dynamics, Trust Model, Smart Contracts, Supply Chain Management, Dimensions of Trust, Technology Adoption

⁷ The article is currently under review at Technological Forecasting & Social Change.

4.1 Introduction

There is no doubt that the introduction of new technologies, including smart contracts and distributed ledger technology, will change supply chain practices, disrupt business strategies and could solve common problems (Goldsby et al., 2019). Findings of Shahzad et al. (2024) suggest that supply chain professionals believe that the application of blockchain in supply chain management improves transparency in the supply chain processes, which can be particularly valuable in supply chain management where transparency and trust are crucial. With smart contracts, transactions can be executed automatically based on predefined rules and conditions, eliminating the need for intermediaries or third-party authorities to oversee or guarantee transactions (López Vivar et al., 2020). This reduces the risks associated with fraud and human error and enhances process efficiency and transparency (Zheng et al., 2020). Risk plays a decisive role in confidence in a matter and is subject to a close interaction with it, influencing both confidence and subsequent behaviour (Mayer et al., 1995; Stuck et al., 2022). Distributed ledgers support multiple decision levels and enhance customer-company relationships by ensuring data integrity and enabling smart contracts for process regulation, from design to logistics (Pessot et al., 2023). Applying smart contracts in supply chains offers benefits such as product tracking and tracing, reducing instances of counterfeiting and fraud, and improving transaction efficiency and speed (Q. Wang et al., 2019).

In theory, smart contracts and distributed ledger technologies enable a 'trustless' network and transaction processes through network architecture (Christidis & Devetsikiotis, 2016), which reduce information asymmetry, increase control and consequently minimise the need for trust (Jeanneret Medina et al., 2024). Despite the notion that technology aims at removing the need for trust (Treiblmaier, 2018), it offers a new approach to substitute information from other sources to build trust towards something or someone and act on that trust (Lemieux et al., 2019). Consequently, a trustless system is not necessarily a trust-free system but a system in which trust is redefined and based on verifiable and automated mechanisms. Therefore, a comprehensive understanding of trust and its various dimensions and the impact of trust on behaviour is crucial for developing and implementing smart contracts in supply chains. Furthermore, when studying how trust dimensions affect the risk-taking behaviour in technologies, it's crucial to consider the closely related factor of risk (Stuck et al., 2022). This allows a complete understanding of how trust and risk elements work together to influence the decision to use smart contracts.

In previous literature, different trust models in an organisational context can be found (Das & Teng, 2001; Mayer et al., 1995; Rousseau et al., 1998; Yamagishi & Yamagishi, 1994). There are also more specific models regarding trust towards technology (McKnight et al., 2011; Pavlou, 2003). However, none of these models consider different smart contract dimensions or fully account for the unique characteristics of this technology. Furthermore, there is insufficient research in the general literature on digital information based on blockchain technologies for supply chains (Surucu-Balci et al., 2024). Therefore, a research gap needs to be filled by developing and empirically testing a multidimensional model of trust towards smart contracts.

Given this background and to address the research gap, the following research question can be derived: How can a trust model for trust towards smart contracts be realised that takes into account the multidimensionality of the trust construct as well as the technology-specific characteristics and the consequences regarding the risk-taking behaviour? To develop such a model, a two-stage approach is necessary. First, the dimensions of trust towards smart contracts are to be considered in Study 1 as there is no conceptualisation available. Second, the results lead to Study 2, in which we embed the trust dimensions in a multidimensional trust construct. For both studies, two quantitative surveys were conducted in the US, allowing employees from companies involved in a supply chain.

The paper is organised as follows: The subsequent section presents the fundamental background of trust in supply chain networks and distributed ledger-based smart contracts. Following this, studies 1 and 2 are given consecutively. Jointly for studies 1 and 2, a critical discussion takes place afterwards. In the conclusion, we summarise the theoretical and practical implications of both studies, along with their limitations and avenues for future research.

4.2 Theoretical Background

4.2.1 Trust in supply chain networks

Trust plays a crucial role in supply chains because of the complex relationships between the actors involved. Trust influences actors' willingness to share information, minimise risks and pursue innovation opportunities to increase supply chain efficiency and effectiveness (Gligor & Holcomb, 2013). Trust is essential for creating strong relationships between supply chain network participants, as highlighted by Halldorsson et al. (2007). Treiblmaier (2018) suggests that complete transparency of information flow could eliminate the need for trust in client-contractor relationships. This indicates that transparency can be crucial in building trust in supply chains. Treiblmaier (2018) also argues that the transparency and non-repudiation of data can make personal relationships redundant in building trust. Finally, Treiblmaier (2018) indicated that technology can play a role in mitigating trust issues in supply chains. Trust remains a critical factor in effective supply chain management, and strategies such as transparency and technology can help address trust issues in complex supply chains.

4.2.2 Models of trust

In the previous literature, different trust models in an organisational context can be found. The Model of Trust by Yamagishi and Yamagishi (1994) suggests that trust is a complex phenomenon influenced by structural and cognitive factors. Structural factors refer to the social structure that affects the opportunities and incentives for trust. Cognitive factors refer to the individual's beliefs, perceptions, and experiences that shape their propensity to trust others (Yamagishi & Yamagishi, 1994). Another fundamental model is the integrative model of trust from Mayer et al. (1995), which is based on ability, benevolence, and integrity. In addition, trust is influenced by trustor propensity, the tendency of a decision-maker to take or avoid risks (Sitkin & Pablo, 1992). Perceived risks influence behaviour in risk situations and the outcome (Mayer et al., 1995). Another one is the model of trust from Rousseau et al. (1998). It suggests that trust in organisations is based on two factors: cognitive trust (based on perceptions of competence and reliability) and affective trust (based on emotions and feelings of security) (Rousseau et al., 1998). Das and Teng's Game-Theoretic model of trust suggests that trust in organisations is based on rational decision-making, where individuals weigh the potential benefits and risks of trusting others (Das & Teng, 2001).

Key findings from the studies examined include the need for a multidimensional understanding of trust, which encompasses different structural, cognitive, emotional and rational elements and has a significant influence on a person's subsequent behaviour. It is important for organisations to understand the importance of building trust at both an individual and structural level. The models illustrate the complex interplay of factors that influence trust and highlight the dynamic nature of trust in organisational relationships. Nevertheless, future work should aim to further refine and extend these models in order to adapt them to evolving organisational structures and the specific contexts of particular activities.

There are already some more specific models regarding trust towards technologies. The model of trust in a specific technology from McKnight et al. (2011) proposes that trust towards a specific technology is based on three main components: system trust, information trust, and vendor trust. The model emphasises the importance of these factors in shaping users' willingness to use the technology and their overall satisfaction with it. The model of trust in technology adoption from Pavlou (2003) is based on Cognitive and affective trust. Like Knight's model, Pavlou's model emphasises the importance of cognitive and affective factors in shaping trust in a specific technology. However, Pavlou's model also includes the notion of integrity, which reflects the technology's reliability and honesty and can be crucial in building and maintaining trust (Pavlou, 2003). These studies contribute to examining trust in the specific context of technology use and therefore extend existing studies on general trust. However, the consideration of technology-specific characteristics would enable even more concrete implications.

4.2.3 Distributed ledger-based smart contracts and trust

Distributed ledgers utilise encryption technology to store and transmit information securely. The system relies on cryptographic evidence rather than trust (Nakamoto, 2008). Besides data immutability,

complete traceability and transparency are common characteristics of distributed ledger technologies (El Ioini & Pahl, 2018). Distributed ledger technologies differ mainly in how transactions are stored and validated, translating into different scalability, flexibility, transaction speed, energy consumption and transaction costs (Chowdhury et al., 2019).

Routine escrow mechanisms can be implemented easily (Nakamoto, 2008) and ensure, through automatic penalties, that the actors involved are interested in fulfilling contracts (Xu et al., 2020). These mechanisms, as well as other agreements, can be specified in smart contracts. Smart contracts are digital contracts written by an "if-this-then-that" code in the network structure. They refer to conditions previously agreed upon by the network actors and are automatically executed when these contractual conditions are fulfilled. Once established, these contracts do not require further management (Vo et al., 2021). The automatic execution and assurance of smart contracts, including automatic penalties for non-fulfilment of contracts, lead to no or less need for trust for transactions in networks (Grosse et al., 2021; Treiblmaier, 2018). Smart contracts can also be used in various types of auction processes, often with multiple sellers and one buyer to provide a transparent and secure way to automatically execute functions without intermediaries (Omar et al., 2021). In addition, mutual trust is increased due to the complete transparency of the information flow for the client and the contractor (S. Wang et al., 2019). Thus, according to Christidis and Devetsikiotis (2016), distributed ledger networks enable the creation of a trustless network.

However, there are controversial opinions regarding the conceptual meaning of trust towards distributed ledger systems. While some works argue that the underlying distributed ledger technology enables coordination without interpersonal trust, other recognises that trust plays a crucial role in distributed ledger networks (Becker & Bodo, 2020). The second assumption is consistent with more general views that information systems have both social and technological aspects, which must both be taken into account (Stanton, 2022; Trist, 1981). According to Lemieux et al. (2019), distributed ledger systems rely on three interdependent "trust layers" to achieve trusted transactions: the social, data and technical.

4.3 Study 1: Model of trust dimensions

4.3.1 Model conceptualisation

As discussed in the prior section on trust models, most models of trust see trust as a one-dimensional construct that is not subdivided into different levels. Although there are some trust models that divide trust into different layers, these are rather general and rarely take context-specific requirements into account. We want to close this gap by developing a model that considers both the automation characteristics and the characteristics of the underlying distributed ledger technology and thus reflects different dimensions of trust. To incorporate the attributes of distributed ledger technology as the underlying infrastructure for smart contracts, the model has been designed to encompass various levels of this technology. According to Lemieux et al. (2019), the social trust layer of distributed ledger technology deals with how actors interact and determine the types and sources of information needed to establish trust and take action. The data layer provides the information that actors have deemed necessary to obtain from the distributed ledger system to give them confidence to act. Finally, the technical layer pertains to how actors create, store, and retrieve tamper-resistant and non-repudiable proof of facts about their interactions (Lemieux et al., 2019). Dispositional trust serves as a fundamental aspect of a person's overall trust framework and forms the basis for their attitudes and perceptions in various areas. As it does not relate to the use of a specific technology, it is not subdivided into the trust layer of the technology, unlike the two following trust dimensions, but is considered independently as a independent dimension. Situational and learned trust can be regarded from the perspectives of the three distributed ledger layers (social, data and technical). As can be seen in Figure 9, this results in a total of seven different dimensions of trust regarding smart contract use.

Since smart contracts are essentially automation processes, we have considered different levels of trust towards automation technologies in the model. Hoff and Bashir (2014) empirically established three different layers of trust towards automation: The first is dispositional trust, which refers to a person's general inclination to trust automation, regardless of the situation or the specific system. It is used to describe long-term tendencies. The second layer is situational trust, which considers external factors and

the operator's context-dependent characteristics. The third layer is learned trust, which reflects an operator's assessments of a system based on prior experience or current interaction. Since the automation of contracts characterises smart contracts, these differentiated dimensions are also suitable for our model (Hoff & Bashir, 2014). Based on the different layers, we created a multidimensional trust model with seven dimensions, visualised in Figure 9.

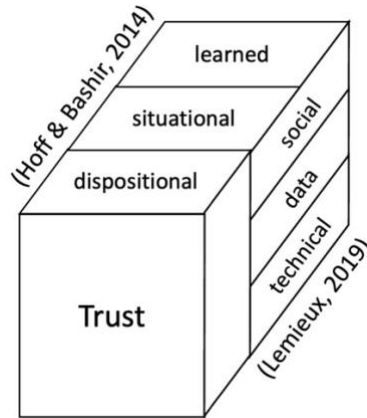


Figure 9: Dimensions of trust towards smart contracts based on Hoff and Bashir (2014) and Lemieux et al. (2019).

According to Hoff and Bashir (2014) and Lemieux et al. (2019), the seven dimensions can be defined as follows: Dispositional trust refers to an individual's general tendency to trust others over the long term, irrespective of the context or a particular system. Situational trust in the social layer relates to how social actors interact based on their trust in the external environment and the operator's internal context, such as required information amount and form. Situational trust in the data layer refers to social actors' trust in the distributed ledger technology system's information to act confidently based on the operator's internal and external context. Situational trust on the technical layer refers to social actors' trust in the blockchain platform's internal and external characteristics for creating, storing, and exchanging information. Learned trust on the social layer is social actors' developed trust based on past experiences or current interactions regarding how they interact with each other and the required information amount or form. Learned trust in the data layer is social actors' developed trust based on past experiences or current interactions with the information provided by the system, which is crucial for them to act confidently. Finally, learned trust on the technical layer is the social actors' developed trust based on past experiences or current interactions at a technical level with the platform used for creating, storing, and exchanging information. This leads to the following hypotheses:

- H1: Dispositional trust is an independent dimension of trust.*
- H2: Situational trust on the social layer is an independent dimension of trust.*
- H3: Situational trust on the data layer is an independent dimension of trust.*
- H4: Situational trust on the technical layer is an independent dimension of trust.*
- H5: Learned trust on the social layer is an independent dimension of trust.*
- H6: Learned trust on the data layer is an independent dimension of trust.*
- H7: Learned trust on the technical layer is an independent dimension of trust.*

4.3.2 Research Method

4.3.2.1 Questionnaire

To test the hypotheses, the model first needs to be conceptualised. A critical need for trust concepts is an improved scale development and validation (Whipple et al., 2013). For this reason, we have referred to and adapted proven scales. For our study, the following constructs are necessary: Dispositional Trust, situational trust on the three layers, and learned trust on the three layers.

We use the five-item scale by MacCarthy (1983), to measure dispositional trust. For measuring situational trust, the six-item scale of Holthausen et al. (2020) was adapted and applied to each of the three distributed ledger trust layers characteristics according to Lemieux et al. (2019). Since the original scale referred partly to decision-making by automated systems, we removed two unsuitable items, resulting in a four-item scale.

For the measurement of learned trust, no scale in the current literature could be adopted. However, the literature shows that learned trust is based on previous experiences, similar to the trustor's propensity (Hoff & Bashir, 2014). If no direct experience has been made, there is a recourse to similar situations (Gonzalez et al., 2003). However, the propensity refers to general tendencies; the learned trust is based on learned experiences regarding a specific context (Mayer & Davis, 1999). Therefore, we have adopted the propensity scale from Mayer and Davis (1999) in a revised form. The items no longer refer to general trust tendencies but to previous experiences and situations with automation technologies. In addition, we have assigned the items of the scale to the matching layers of trust towards distributed ledger technologies to differentiate between them. The complete survey can be found in the appendix.

4.3.2.2 Distribution and Sample

The questionnaire was administered to participants via the online platform Clickworker to supply chain employees in the United States of America. The US is a suitable location for a survey on technologies in supply chain management due to many companies with crucial supplier relationships and the diversity of industries and supply chains in the country (Tan, 2019). Initially, an attention test filtered participants who did not read properly.

The questionnaire was answered completely by 193 persons. The minimum sample size according to (Tinsley & Kass, 1979) of 5-10 cases per item is thus achieved, as is the total minimum of 100 cases for factor analysis according to Gorsuch (1990). 34.2% were women, 65.2% were men, and 0.6% were diverse. On average, participants were 36.6 years old.

4.3.2.3 Statistical analysis

By conducting a detailed assessment of the measurement model as the first part of our analysis, we can ensure that the requirements for a confirmatory factor analysis are met and that the analysis results are reliable and interpretable. We followed a five-step process for validating a formative measurement construct in structural equation models according to Cenfetelli and Bassellier (2009). In our study, however, we have only conducted the first four steps, as the fifth step concerns the creation of a structural equation model, which is not the focus of this study. Steps 1 and 2 passed without violating the assumptions, but in step three, we found suppression effects were present for items DT4, SS2, SD2 and ST2. These four items were eliminated. In step four, all criteria were fulfilled.

As a second part of the analysis, we conducted a Confirmatory factor analysis (CFA) using Varimax rotation. The evaluation of the factor analysis reveals very good sample adequacy for conducting the factor analysis, as indicated by a Kaiser-Meyer-Olkin measure of sample adequacy of 0.869 (Kaiser, 1974). Furthermore, the significance value of Bartlett's test of sphericity, which is $< .001$, indicates that the sample data are suitable for factor analysis (Bartlett, 1954). The rotated sum of squared loadings shows that factor 1 accounts for the highest share of the total variance, with 20.39%. The other factors' shares are distributed between 3.33% and 8.38%.

4.3.3 Results

4.3.3.1 Descriptive results

Table 14 below shows the descriptive results of the items examined in the factor analysis of the first study.

Table 14: Descriptive results

Item	Mean	Standard deviation	Variance
DT1	3,66	1,52	2,30
DT2	4,04	1,41	1,98

DT3	4,24	1,35	1,83
DT5	3,90	1,45	2,11
SS1	4,32	1,47	2,17
SS3	4,10	1,49	2,23
SS4	4,17	1,42	2,03
SD1	4,62	1,47	2,15
SD3	4,56	1,61	2,58
SD4	4,64	1,35	1,82
ST1	4,74	1,31	1,71
ST3	4,40	1,55	2,39
ST4	4,91	1,31	1,72
LS1	4,10	1,60	2,55
LS2	4,69	1,29	1,67
LD1	4,53	1,41	2,00
LD2	4,58	1,42	2,03
LT1	5,24	1,40	1,97
LT2	4,90	1,21	1,45
DT	3,96	1,00	1,00
SS	4,20	1,19	1,43
SD	4,60	1,27	1,61
ST	4,68	1,19	1,41
LS	4,40	0,88	0,78
LD	4,55	1,19	1,42
LT	5,07	0,89	0,78

4.3.3.2 Hypotheses results

Table 15 shows the rotated factor loadings, which indicate the strength and direction of the correlation between the variables and the factors. All values show a positive direction of the correlation. We followed the Budaev (2010) procedure for relatively small sample sizes and set the minimum for interpretable loadings to higher than 0.4 (loadings below 0.4 are shown in Table 15, if no higher were available).

Table 15: Rotated factor matrix: Confirmatory factor analysis using maximum likelihood.

	1	2	3	4	5	6	7
DT1		.740					
DT2		.693					
DT3		.342		.357			
DT5		.385					
SS1				.432			
SS3	.439			.471			
SS4				.772			
SD1	.770						
SD3	.699						
SD4	.772						
ST1	.697						
ST3	.689						.688
ST4	.672						
LS1					.929		

LS2						.442	
LD1			.418				
LD2			.881				
LT1					.381		
LT2						.564	

DT3 was excluded due to its cross-loadings on Factor 2 and 4, following the criteria outlined by (Hair, 2009). Despite LT1 and DT5 falling just below the 0.4 threshold, we retained them. This decision was based on our assessment not to violate the content validity of the scale (Fornell & Larcker, 1981), coupled with consistently positive outcomes in all previous statistical tests. ST3 also refers to cross-loadings, but since factor 7 would represent a single dimension with a single factor, the item was retained and assigned to factor 1. In addition, we also refer here to the content validity of the scale according to Fornell and Larcker (1981).

We found empirical evidence for hypotheses 1, 2 and 6. Hence, the results lead to adaptations in the trust dimensions. The five trust dimensions are shown to result from allocating the items to the factors of the analysis. In the case of items correlating to different factors, the factor with the highest loading was selected. Since LT1 did not have a value above the 0.4 limit, we checked for the next highest, 0.381. Since the item proves conceptually important that it represents only one of the two items of learned trust, and it is only slightly below the limit, it may be justified to keep it (Mayer, 2018). Since the LS and LT load on a mutual factor with one item each, we have combined them into one common dimension. This is possible due to the similarity in the content of the items and scales (Hair, 2009), which all refer to learned trust and thus facilitate interpretation of the dimensions. The contribution of the factors to the total variance of the established trust construct is as follows: 14.74% for dispositional trust, 14.32% for situation social trust, 35.88% for situational data and situational technical trust, 20.24% for learned social and learned technical trust and 14.72% for learned data trust.

As can be seen in Table 16, the results reveal the following dimensions with associated items regarding trust towards smart contracts.

Table 16: Dimensions of trust towards smart contracts.

Dimension	Items
Dispositional trust	DT1, DT2, DT5
Situation social trust	SS1, SS2, SS4
Situational data and situational technical trust	SD1, SD3, SD4, ST1, ST3, ST4
Learned social and learned technical trust	LS1, LS2, LT1, LT2
Learned data trust	LD1, LD2

4.3.4 Summary Study 1

The results of the CFA support the existence of multiple dimensions of trust towards smart contracts. The analysis revealed the presence of five distinct dimensions: dispositional trust, situational social trust, situational data and situational technical trust, learned social and learned technical trust, and learned data trust. These dimensions capture different aspects of trust in the context of smart contracts, demonstrating the complexity and multidimensionality of trust towards this technology-enabled setting.

- The dimension combining situational trust on the data layer and situational trust on the technical layer reflects the intertwined trust in the information provided by the distributed ledger system and the characteristics of the distributed ledger platform. This dimension can be labelled as "Information-Technology Trust" to capture the intertwined nature of trust in the technical aspects of the system and the reliability and accuracy of the data.
- The dimension merging learned trust on the social layer and learned trust on the technical layer indicates the importance of past experiences and interactions in shaping trust perceptions. This dimension can be named "Interaction-Informed Trust" to highlight the

role of previous interactions and learning in establishing trust in both the social dynamics and the technical aspects of smart contract-enabled supply chains.

4.4 Study 2: Integrative model of trust towards smart contracts

4.4.1 Model conceptualisation and hypotheses

In the current literature, no article refers to trust regarding distributed ledger technology and smart contracts, which we outlined in the theoretical background. Therefore, we have decided to use the general and widely used trust model from Mayer et al. (1995) as the basis for our integrated model. It includes the essential features of other trust models: trust propensity cognitive and affective components. It comprehensively covers the entire process, from perceived factors to the outcome of a situation, and also considers the individual's perceived risks. To apply the factors of perceived trustworthiness to automation technologies, Lee and See (2004) translated the original factors by Mayer et al. (1995) from ability, benevolence and integrity into performance, process and purpose. Using the results of Study 1, we extend the model with conceptualisation and measurements of trust concerning smart contracts in five dimensions.

Trust seems to be an example of how feelings can control behaviour when rules do not apply, and cognitive resources are not available to make a calculated, rational decision (Barley, 1988). The discussion on trust between parties and institutions was accompanied by the realisation that one can also trust a technical environment (Eenmaa-Dimitrieva & Schmidt-Kessen, 2019). Trust towards technology was found to be an essential factor influencing the user's behaviour (Wu et al., 2011). McKnight et al. (2011) pointed out that trust in information technology is critical to developing IT-related beliefs and behaviour. Similar to institutions, technology has the potential to foster relationships by establishing a nurturing environment marked by a level of assurance regarding the relevant procedures (Eenmaa-Dimitrieva & Schmidt-Kessen, 2019). More specifically, technological systems like smart contracts could serve as trusted environments and positively influence contract agreements (Eenmaa-Dimitrieva & Schmidt-Kessen, 2019). Previous research has not distinguished between different trust dimensions about the effect of risk-taking behaviour. However, due to the strong correlation between the five individual dimensions and the superordinate trust construct, we assume that these assumptions apply both to the particular trust dimensions and the trust construct as a whole and have therefore developed the following hypotheses:

H1.1: Trust towards smart contracts increases risk-taking behaviour.

H1.2: Dispositional trust towards smart contracts increases risk-taking behaviour.

H1.3: Situational social trust towards smart contracts increases risk-taking behaviour.

H1.4: Information-technology trust towards smart contracts increases risk-taking behaviour.

H1.5: Interaction-informed trust towards smart contracts increases risk-taking behaviour.

H1.6: Learned data trust towards smart contracts increases risk-taking behaviour.

Risk is a critical component of trust as trust encompasses concepts such as the possibility of negative consequences, the willingness to make oneself vulnerable and the trust in another party to fulfil an important task (Mayer et al., 1995). Regarding technology-influenced risk, Stuck et al. (2022) found that participants' subjective confidence and trust in automation decreased as perceived relational risk increased. Consistent with that, Nienaber and Schewe (2014) found that increased perceived risk is negatively related to relationship commitment, implying that it reduces trust. This assumption also aligns with Luhrmann's (2017) initial statement that trust positively influences perceived risk reduction, meaning that a high perceived risk leads to a lower level of trust. Das and Teng (2004) also assumed that trust and perceived risk mirror each other. Empirical results show that perceived risk also determines the level of trust in e-government solutions (Ejdys et al., 2019), which, similar to smart contracts, is expected to provide a high level of security for use. We, therefore, assume that perceived risk has an effect on trust towards smart contracts. According to Nienaber and Schewe's (2014) assumptions, we expect this to be negative. This leads to the following hypothesis:

H2: An increased perceived relational risk has a reducing effect on trust towards smart contracts.

In addition to the direct influence of perceived risk on trust, various studies have identified perceived risk as a moderator between trust and behaviour. For instance, perceived risk moderated between brand trust and brand loyalty (Paulssen et al., 2014). According to Stuck et al. (2022), a moderator relationship exists for perceived situational risk regarding the trust and behavioural risk relationship. Featherman and Fuller (2003) found a moderator relationship between situational risk and technology usage in general. Dalmolin et al. (2019) identified that perceived situational risk increasingly moderates trust and, investment and financing decisions. Based on this finding, we assume that situational perceived risk moderates the relationship between trust and risk-taking behaviour towards smart contract use in an increasing way. Therefore, we developed the following hypothesis:

H3: Perceived situational risk positively moderates the trust towards smart contracts and risk-taking behaviours relationship.

Furthermore, and next to the trustor's characteristics that affect the impact of perceived trustworthiness, the model also accounts for risk-taking propensity for context-specific risk-taking behaviour. This behaviour is not necessarily related to the level of trust. It is solely based on the user's perception of the risks associated with interacting with a specific entity, be it a robot, person, or organisation (Stuck et al., 2022). In our model, risk-taking or behavioural trust represents using smart contracts. Risk-taking is strongly rooted in personality (Nicholson et al., 2005), and the risk-taking propensity is positively correlated with various behaviour patterns like dishonest behaviour (Xu et al., 2019) or bargaining behaviour (Harnett et al., 1968). Risk propensity determines the situation's actual and perceived characteristics as a factor for risk-taking behaviour (Sitkin & Pablo, 1992). Regarding the use of technologies, Merritt et al. (2013) also found a positive association between a person's general attitude towards machines and their use in different situations. According to Jedlička et al. (2019), the users' personality influences using a different distributed ledger-based cryptocurrency application. In line with the results, we assume that the individuals' risk-taking propensity influences the risk-taking behaviour towards smart contract use. We therefore propose the following hypothesis:

H4: Risk-taking propensity increases risk-taking behaviour.

The integration of the characteristics in the original model is visualised in Figure 10.

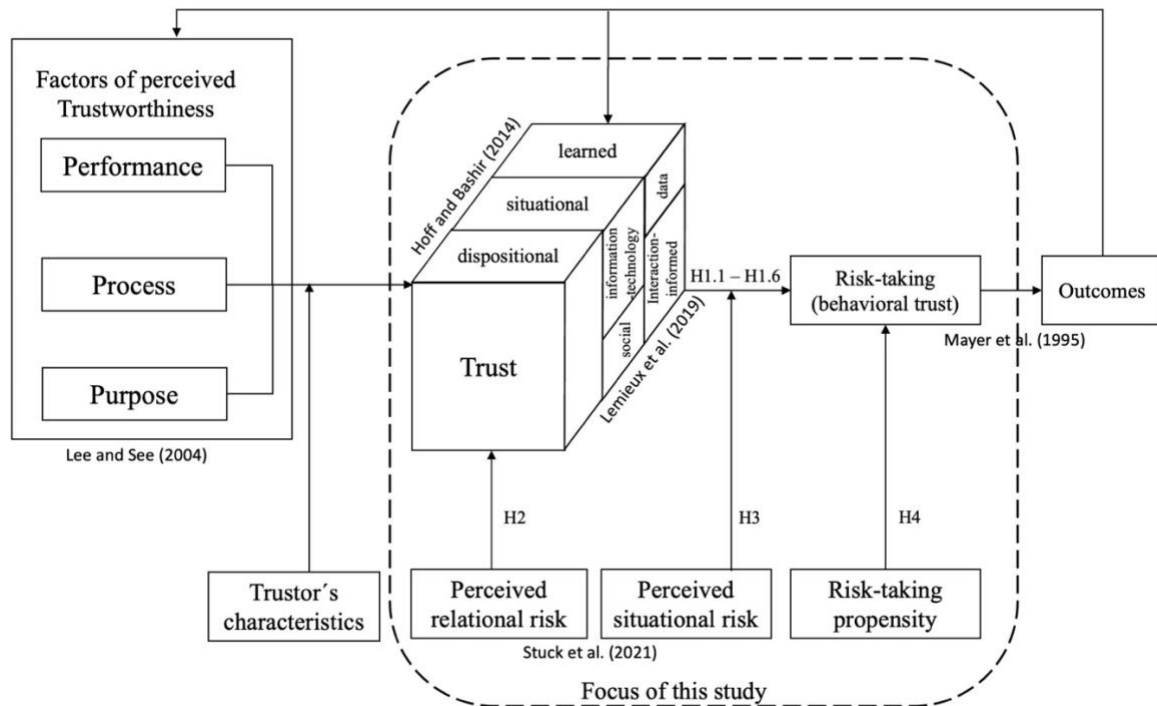


Figure 10: Theoretical integrative model of trust towards smart contracts based on the findings following Mayer et al. (1995), Hoff and Bashir (2014), Lemieux et al. (2019), Stuck et al. (2021), Lee and See (2004) and results of Study 1.

4.4.2 Research Method

4.4.2.1 Questionnaire

To build the model, the following constructs are necessary: Trust, perceived relational risk, perceived situational risk, risk-taking propensity, and risk-taking behaviour. In study 1, we combined models from Hoff and Bashir (2014) and Lemieux et al. (2019) to identify different trust dimensions in smart contracts. As a result of the research, five dimensions of trust were identified, which we adopted for our study. We used the trust dimension items from Study 1 to measure trust. Initially, they were adapted from dispositional, situational and learned trust from scales by MacCarthy (1983), Holthausen et al. (2020), Mayer and Davis (1999). Relational and situational perceived risk was measured using the perceived risk scale regarding technology use by Im et al. (2008). For measuring risk-taking propensity, we used the general risk propensity scale from (Mayer & Davis, 1999). Since the propensity needs to be context-specific (Stuck et al., 2022), we applied the items to the use in the context of automation technology. Finally, to measure risk-taking behaviour, the behavioural manifestation of the willingness to be vulnerable (Mayer et al., 1995), we adopted the behavioural intention scale from the Unified Theory of Acceptance and Use of Technology by Venkatesh et al. (2003). The detailed items can be found in the questionnaire in the data repository.

4.4.2.2 Distribution and Sample

To mitigate potential common method bias, the survey posed questions related to the independent variables (Trust, perceived relational and situational risk, risk-taking propensity) and the dependent variable (risk-taking behaviour) on two separate occasions, with a time gap of four weeks in between. This temporal separation and the utilisation of anonymous user identifiers allowed for the linkage of both segments to individual participants.

The questionnaire was administered again to participants via the online platform Clickworker similar to the approach in Study 1, but excluding every participant of Study 1 with a blacklist. We employed the 'A Priori Calculator for SEM' (Soper, 2023) to determine the appropriate sample size. The significance was set to 0.05, as recommended by Fisher (1970) and the desired statistical power level to 0.8, as suggested by Cohen (1977). Cohen's r , as anticipated effect size was set to a medium size of $r = 0.4$, since different literature sources found similar effect sizes for trust towards automation technology. For example, Schaefer et al. (2016) reported an overall medium effect size for factors influencing trust in automation. Hancock et al. (2011) found a large effect size for robot performance factors in trust development in human-automation interaction. Additionally, Liu and Weistroffer (2022) examined the practical significance of trust in technology, analyzed reported effect sizes and found medium to large effect sizes. The minimum sample size resulting from the calculation is 88 (Soper, 2023). With a final sample size of 102 participants, the actual statistical power of this study is 0.88 for the indicated parameters (Soper, 2023). 40.2% of the participants were women, 59.8% were men, and 0% were diverse. On average, participants were 38.3 years old.

4.4.2.3 Statistical analysis

We employed the partial least squares (PLS) method to analyse our research model. We followed Becker et al. (2019) for the higher-construct structure and Henseler et al. (2009) for the PLS model evaluation to check the quality of the model. With some adaptations on the item level, the model fulfilled all quality criteria. A comprehensive overview of all statistical tests and their results can be found in the data repository. To minimise common bias, we adhered to the procedural guidelines outlined by Kortmann (2015). This encompassed ensuring anonymity, upholding confidentiality, appropriately situating variables, and employing diverse scale types. Furthermore, we implemented the recommendations defined by Podsakoff et al. (2003) by introducing a time gap of several weeks between the assessment of independent and dependent variables.

4.4.3 Results

4.4.3.1 Descriptive results

Table 17 presents the descriptive statistics of all variables in the structural equation model of the second study, the correlations among variables can be found in the data repository.

Table 17: Descriptive statistics.

Construct	Mean	Standard Deviation
Dispositional trust	3.63	1.26
Situation social trust	4.63	1.43
Information-technology trust	5.06	1.11
Interaction-informed trust	4.51	1.16
Learned data trust	5.17	1.37
Trust	4.59	0.60
Perceived relational risk	4.11	1.36
Perceived situational risk	4.00	1.29
Risk-taking propensity	4.84	0.98
Risk-taking behaviour	4.42	1.26
Age	38.20	9.69
Gender	1.4	0.49

Note: N=102

4.4.3.2 Hypotheses results

In the following Figure 11, the results from testing the hypotheses are presented within the research model:

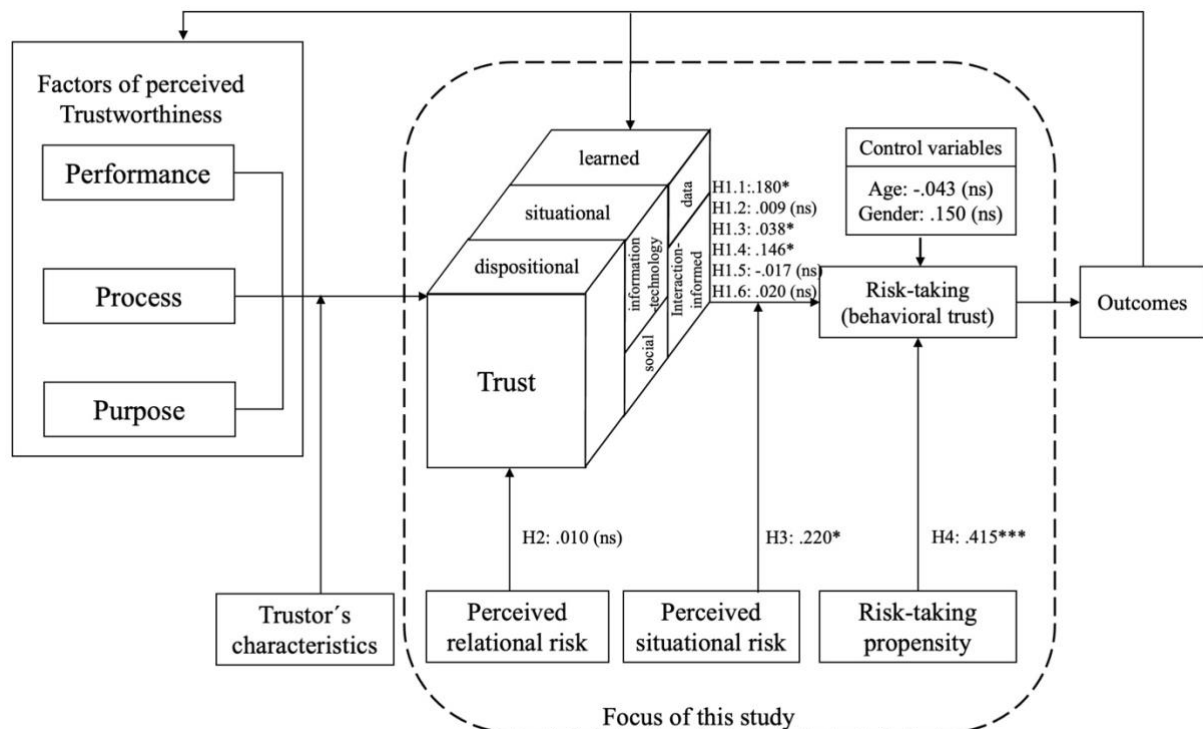


Figure 11: Results regarding the research model (Note: * $p < .05$; ** $p < .01$; *** $p < .001$; one-tailed).

H1.1 stated that trust towards smart contracts increases risk-taking behaviour; this hypothesis could be confirmed ($\beta = .180$, $p = .047$). H1.2 to H1.6 show that the five specific trust dimensions have an impact on risk-taking behaviour. This could only be confirmed for situational social trust (H1.3: $\beta = .038$, $p = .046$) and information technology trust (H1.4: $\beta = 0.146$, $p = .039$). For the other trust dimensions, the

hypotheses could not be confirmed (H1.2: $\beta = .009$, $p = .354$; H1.5: $\beta = -.017$, $p = .223$; H1.6: $\beta = .020$, $p = .102$). H2 stated, that an increased perceived relational risk has a reducing effect on trust towards smart contracts. However, the hypothesis could not be confirmed ($\beta = .010$, $p = .140$). H3 stated, that perceived situational risk moderates the trust towards smart contracts and risk-taking behaviours relationship positively. This assumption could be confirmed ($\beta = .220$, $p = .012$). The last hypothesis, H4, stated that risk-taking propensity increases risk-taking behaviour. Again, the hypothesis could be confirmed ($\beta = .415$, $p < .001$). However, for the control variables age and gender, no significant influence on risk-taking behaviour could be confirmed (Age: $\beta = -.043$, $p = .303$; Gender: $\beta = .150$, $p = .178$). In addition to the hypotheses, for the control variables age and gender, no significant influence on risk-taking behaviour could be confirmed (Age: $\beta = -.043$, $p = .303$; Gender: $\beta = .150$, $p = .178$).

4.4.4 Summary Study 2

The results show a general correlation between trust and risk-taking behaviour. However, a significant correlation regarding the specific dimensions could only be verified for situational social and information technology trust. A moderating effect of perceived situational risk on trust and risk-taking behaviour, and a positive influence of risk propensity on risk-taking behaviour. As smart contracts continue to reshape supply chains, the findings are consistent with the insight that "a trustless system is not necessarily a trust-free system". Trust, a deeply human and inherently complex facet, remains essential for successful digital transformation.

4.5 Discussion

One main finding from the factor analysis is the mixing of theoretical dimensions in practice. Specifically, the original hypothesis that situational trust on the data layer and situational trust on the technical layer would be independent dimensions of trust was not supported. Instead, the items from these two layers formed a mutual dimension. Similarly, the hypothesis that learned trust on the social layer and learned trust on the technical layer would be independent dimensions was also not supported. These two dimensions merged into a single dimension. The loading of the formerly separated dimensions onto one factor suggests that, about smart contract use, technology and humans are equated in terms of experience learned. The three trust layers of Hoff and Bashir (2014) could be confirmed, while the three layers of Lemieux et al. (2019) were partly recognised only in mixed forms. The mixing of theoretical dimensions in practice can be attributed to the interconnectedness and interdependence of trust factors in smart contract-enabled supply chains. While theoretical models often attempt to separate trust into distinct dimensions, the practical reality is that trust is a complex construct influenced by various factors that interact and influence each other. In the context of smart contracts, the distributed ledger technology and the social interactions among actors create a dynamic environment where trust dimensions overlap and intertwine. Considering the merging of theoretical dimensions in the empirical analysis, it is essential to propose appropriate names for the new mixed dimensions based on their underlying characteristics.

The confirmation of the assumption that trust towards smart contracts influences risk-taking behaviour aligns with theoretical foundations and previous empirical findings. It resonates with the technology adoption literature, which consistently emphasises trust's role in influencing users' willingness to engage with innovative technologies (McKnight et al., 2011; Wu et al., 2011). The empirical verification strengthens the model's credibility and supports the notion that while smart contracts may be based on "trustless" technology (Christidis & Devetsikiotis, 2016), the human factor of trust remains paramount for adoption. This aligns with research that underscores the nuanced nature of technology adoption, highlighting that human psychology and social factors fundamentally shape the success of technological innovations (Becker & Bodo, 2020; Stanton, 2022; Trist, 1981).

In contrast to previous studies, however, we did not consider trust a one-dimensional construct but analysed the impact of various individual dimensions of trust. The study shows that of the five trust dimensions analysed, only situational social trust and information technology trust significantly influence risk-taking behaviour. Interestingly, both of these are subordinate dimensions of the situational trust layer according to Hoff and Bashir (2014). This emphasises the relevance of the situational relevance of trusts towards smart contracts. The dimensions with non-significant effects (dispositional

trust, interaction-informed trust and learned data trust) may not be as influential in shaping risk-taking behaviour in the context of smart contracts. This emphasises the need for a nuanced understanding of trust in the distributed ledger space.

In our study, it could not be confirmed that increased perceived relationship risk reduces trust towards smart contracts. This contrasts prior research across various domains (Das & Teng, 2004; Luhmann, 2017; Nienaber & Schewe, 2014). One possible explanation could be the unique characteristics of smart contracts and distributed ledgers. The decentralised and automated nature of smart contracts may diminish the impact of perceived relational risk. Users might perceive the technology as more reliable than their human counterparts, leading to a limited effect of relational risk on trust. Additionally, the novelty of smart contracts in supply chain management may create a perception that relational risk is less relevant than other forms of risk, such as situational risk.

The validation that perceived situational risk moderates the relationship between trust and risk-taking behaviour highlights the dynamic interplay between contextual risk perceptions and trust's influence on behaviour. While previous research has examined moderating effects of perceived risk (Dalmolin et al., 2019; Paulssen et al., 2014), this study extends this understanding to smart contracts, demonstrating that the trust-behaviour linkage is contingent upon specific situational contexts. Identifying contextual complexity emphasises that risk perceptions are not static but adapt to situational nuances. This discovery underscores the need for adaptive strategies in managing smart contract adoption for supply chains, tailoring trust-building efforts to the unique characteristics of each situation. This nuanced approach acknowledges the evolving nature of technology adoption and cautions against one-size-fits-all solutions.

The research results highlight that trust in smart contracts has a decisive influence on risk behaviour. In this context, it is important to emphasise that the identified changes in the distribution of power within supply chains, especially for smaller companies, may pose additional challenges in dealing with the risks of smart contracts. Although not core to this study, it should nevertheless be recognised that the introduction of smart contracts can make a significant contribution to changing the distribution of power in supply chains. Smaller and less technology-orientated companies in particular may find it difficult to actively engage with this technology due to limited resources. There is also the possibility that such companies may be reluctant to engage with what is perceived as a "trustless" system due to their lower technological confidence. This dynamic could lead to an unequal sharing of the benefits of smart contracts.

4.6 Conclusion

4.6.1 Theoretical contribution

The first study of this work contributes to the theoretical understanding of trust in distributed ledger-based smart contracts within supply chain management in several ways. It goes beyond existing one-dimensional models by developing a multidimensional model of trust that represents the unique characteristics of smart contracts and distributed ledger technology. This multidimensional model captures the complexity and multidimensionality of trust in the context of smart contracts, highlighting the interplay between social and technical factors. The findings of the confirmatory factor analysis support the existence of five distinct dimensions of trust: dispositional trust, situational social trust, information-technology trust, experience-based trust, and learned data trust. This expands the understanding of trust dimensions in smart contracts and underscores the intertwined relationships among trust factors. The multidimensional model and the identified dimensions contribute to advancing the design, implementation, and governance of smart contract-enabled supply chains.

The second study's theoretical contribution lies in establishing an integrative model of trust towards smart contracts. It provides a valuable framework for understanding how trust influences individuals' risk-taking behaviour and actions when engaging with smart contracts. The second study makes a significant contribution to the field of trust theory by investigating the intricate interplay of trust dynamics of emerging technologies, such as smart contracts. In terms of its theoretical implications, the study enriches our comprehension of the concept of trust and the multifaceted factors that influence it.

Instead of a generalised approach, the study delves into a comprehensive analysis of the nuanced relationship between trust and risk. This third extends the understanding of trust beyond human-to-human interactions and highlights the significance of trust in shaping user behaviour in technologically mediated environments. This study synthesised insights from diverse streams of research. The empirical validation of these hypotheses resonates mostly with existing literature, reinforcing prior findings while providing a tailored application within the realm of smart contracts. The confirmation of relationships identified in previous studies showcases the robustness of the model and contributes to the generalizability of findings across different contexts.

As a third important theoretical contribution, the study also emphasises the important role of risk in the relationship with trust and confirms this for the context of smart contract technology use. The interplay between perceived situational risk and individual risk-taking propensity strengthens the existing understanding of the relationships between trust and risk in the context of smart contract usage. This underscores once again the relevance of context-specific and personal factors influencing decision-making processes in the utilization of smart contracts.

4.6.2 Practical contribution

The practical implications of this study have significant relevance for supply chain practitioners and decision-makers. The identified trust dimensions and their implications offer actionable insights that can be applied to enhance supply chain operations and foster trust towards smart contract-enabled networks. Furthermore, our study is useful for companies because we show how trust and risk influence the intention to use smart contracts. This work can provide different specific recommendations to supply chain managers in terms of supply chain management.

Understanding the different dimensions of trust enables organizations to improve collaboration and mitigate transactional risks in supply chain networks. By assessing the strengths and weaknesses of each dimension, supply chain managers can identify areas that require attention and implement targeted strategies to strengthen trust. For instance, if the dimension of learned trust on the technical layer exhibits a low level of trust among participants, efforts can be made to enhance technological literacy, provide training programs, and improve the user experience of smart contract platforms.

The findings emphasize the importance of adopting a holistic approach to trust-building in supply chains. While ensuring the reliability and security of smart contracts is crucial, attention should also be given to fostering social aspects of trust. Supply chain managers can cultivate a trust-oriented culture by promoting open communication, transparency, and collaboration among participants. Establishing strong relationships and maintaining effective communication channels can significantly contribute to building trust and facilitating the successful implementation of smart contracts.

Furthermore, the results highlight the influence of both technological and social factors on trust towards smart contracts. This implies that supply chain managers should consider not only the technical aspects of implementing smart contracts but also the social dynamics and human factors involved. Effective change management strategies, comprehensive training programs, and targeted communication initiatives can help address potential resistance to adopting smart contracts and build trust among supply chain participants.

Our second study highlights the importance of trust in driving risk-taking behaviour in supply chain stakeholders regarding smart contracts. This suggests that higher perceived trust towards the technology leads to increased engagement. Organisations should prioritise building trust through transparent communication, audibility, and a reliable track record to succeed in integrating smart contracts. Given that only situational social trust and information technology trust demonstrated significant impacts on risk-taking behaviour, practitioners should prioritize these dimensions in trust-building efforts. Tailoring strategies to enhance situational social trust, emphasizing interpersonal aspects, and ensuring robust information-technology trust through transparent and reliable systems can contribute significantly to fostering trust in smart contracts and increase the technology adoption.

The results also underscore the significance of risk mitigation strategies in establishing and maintaining trust among supply chain stakeholders. In particular, resolving situational risks that are not necessarily related to the use of technology is critical to fostering an environment that favours the adoption of smart

contracts. This could include addressing risk of contractual agreements, compliance checks or communication. Clearly defined contract terms, effective dispute resolution mechanisms, and collaborative approaches can help alleviate perceived risks and create a trustworthy ecosystem for smart contract implementation.

Furthermore, the findings suggest that the context in which smart contracts are deployed significantly influences the relationship between trust and risk-taking behaviour. This finding has important implications, indicating that deployment strategies should be tailored to account for unique situational factors. Industry norms, transaction complexities, and stakeholder dynamics must be considered to build trust and determine the most suitable contexts for smart contracts.

Finally, the study highlights the need to consider individual risk preferences when developing smart contract implementation strategies. Stakeholders with a higher inclination for risk-taking may embrace smart contracts as tools for innovation and efficiency. Conversely, risk-averse stakeholders might require customised approaches to address concerns and demonstrate benefits. Adapting communication and training to resonate with different risk profiles can promote a more inclusive and successful smart contract implementation.

4.6.3 Limitations

This study has certain limitations that should be acknowledged. The sample used in both empirical analyses was limited to supply chain employees in the United States, which may restrict the generalizability of the findings to other industries and geographical regions. The data collected in this study relied on self-report measures subject to potential biases such as social desirability and respondent interpretation. Also, the hypothetical nature of the study, wherein the participants were asked to envision themselves in a situation involving smart contract utilisation, introduces a level of abstraction that might not fully capture the nuances of actual behaviour.

Furthermore, trust is a dynamic construct that can fluctuate over time due to changing circumstances and experiences. This study captured trust perceptions at a specific time, but it is essential to recognise that trust can evolve and be influenced by ongoing interactions, system performance, and external events.

While the second study's statistical power is deemed sufficient based on established guidelines, it's imperative to acknowledge that the generalizability of the findings might be constrained due to the sample size. With a relatively moderate sample size, caution should be exercised when extrapolating the results to larger populations or diverse contexts.

It's important to highlight that using single scales for specific trust dimensions, specifically DT1 and LD2, potentially compromises the comprehensiveness of the trust measurement. This selective approach, driven by a need for dimension retention, raises questions about whether the retained items adequately capture the entire trust construct and its various facets. This decision could impact the richness and depth of the trust assessment.

4.6.4 Future research

The study opens up avenues for further research. Future studies could investigate the role of other contextual factors, such as organisational culture and regulatory environment, in shaping trust and risk perceptions. Additionally, examining the longitudinal dynamics of trust and behaviour in evolving technological landscapes would offer more profound insights.

Beyond the scope of smart contracts, our theoretical model holds the potential to serve as a framework for investigating the dynamics of trust, risk, and behaviour in the adoption of various emerging or future technologies. As technology advances, reshapes industries, and influences human interactions, the insights gleaned from our model can be extended to illuminate the complexities of trust-based decision-making in diverse contexts.

To enhance the generalizability of the findings, future research should expand the study to include participants from diverse industries beyond supply chain management. Different industries may have unique characteristics and trust dynamics in the context of smart contracts. Examining trust dimensions

and their relative importance across various sectors such as finance, healthcare, energy, and manufacturing would provide valuable insights and enable the development of industry-specific frameworks for trust towards smart contract-enabled environments.

Exploring strategies for building and fostering trust in the context of smart contracts represents a promising avenue. Organisations could implement interventions to enhance trust and mitigate perceived situational risks, potentially influencing risk-taking behaviour. Investigating the effectiveness of these strategies would provide actionable insights for stakeholders aiming to optimise technology adoption processes. These interventions could include strategies to improve transparency, establish reputation mechanisms, enhance contractual governance, and address potential trust breaches. Evaluating the effectiveness of such interventions in building and maintaining trust would provide practical guidance for supply chain practitioners and policymakers.

4.7 References

- Barley, S. R. (1988). The social construction of a machine: Ritual, superstition, magical thinking and other pragmatic responses to running a CT scanner. In *Biomedicine examined* (pp. 497-539). Springer.
- Bartlett, M. S. (1954). A note on the multiplying factors for various χ^2 approximations. *Journal of the Royal Statistical Society. Series B (Methodological)*, 16(2), 296-298.
- Becker, M., & Bodo, B. (2020). Trust in blockchain-based systems. *Internet Policy Review*, 10(2), 1-10. <https://doi.org/10.14763/2021.2.1555>
- Budaev, S. V. (2010). Using principal components and factor analysis in animal behaviour research: caveats and guidelines. *Ethology*, 116(5), 472-480. <https://doi.org/10.1111/j.1439-0310.2010.01758.x>
- Cenfetelli, R. T., & Bassellier, G. (2009). Interpretation of Formative Measurement in Information Systems Research. *MIS quarterly*, 33(4), 689-707. <https://doi.org/10.2307/20650323>
- Chowdhury, M. J. M., Ferdous, M. S., Biswas, K., Chowdhury, N., Kayes, A., Alazab, M., & Watters, P. (2019). A comparative analysis of distributed ledger technology platforms. *IEEE Access*, 7(1), 167930-167943. <https://doi.org/10.1109/ACCESS.2019.2953729>
- Christidis, K., & Devetsikiotis, M. (2016). Blockchains and smart contracts for the internet of things. *IEEE Access*, 4(1), 2292-2303. <https://doi.org/10.1109/ACCESS.2016.2566339>
- Cohen, J. (1977). Statistical power analysis for the behavioral sciences. *Applied Psychological Measurement*, 7(3), 249. <https://doi.org/10.1177/014662168300700301>
- Dalmolin, D., Basso, K., Reck, D., Laimer, C. G., & Corte, V. F. D. (2019). Effect of risks perceived on trust and decisions of investment and financing. *Contabilidade, Gestão e Governança*, 22(2), 243-260. https://doi.org/10.21714/1984-3925_2019v22n2a6
- Das, T., & Teng, B.-S. (2004). The Risk-Based View of Trust: A Conceptual Framework. *Journal of Business and Psychology*, 19(1), 85-116.
- Das, T. K., & Teng, B.-S. (2001). Trust, control, and risk in strategic alliances: An integrated framework. *Organization studies*, 22(2), 251-283. <https://doi.org/10.1177/0170840601222004>
- Eenmaa-Dimitrieva, H., & Schmidt-Kessen, M. J. (2019). Smart contracts: reducing risks in economic exchange with no-party trust? *European Journal of Risk Regulation*, 10(2), 245-262. <https://doi.org/10.1017/err.2019.37>
- Ejdys, J., Ginevičius, R., Rózsa, Z., & Janoskova, K. (2019). The Role of Perceived Risk and Security Level in Building Trust in E-government Solutions. *E+M Ekonomie a Management*, 22(3), 220-234. <https://doi.org/10.15240/tul/001/2019-3-014>
- El Ioini, N., & Pahl, C. (2018). A review of distributed ledger technologies. On the Move to Meaningful Internet Systems. OTM 2018 Conferences: Confederated International Conferences: CoopIS,

- C&TC, and ODBASE 2018, Valletta, Malta, October 22-26, 2018, Proceedings, Part II, 277-288.
- Featherman, M., & Fuller, M. A. (2003). Applying TAM to e-services adoption: the moderating role of perceived risk. 36th Annual Hawaii International Conference on System Sciences, 2003. Proceedings of the, 1-11. <https://doi.org/10.1109/HICSS.2003.1174433>
- Fisher, R. A. (1970). Statistical methods for research workers. In *Breakthroughs in statistics: Methodology and distribution* (pp. 66-70). Springer.
- Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of marketing research*, 18(1), 39-50.
- Gligor, D., & Holcomb, M. (2013). The role of personal relationships in supply chains: An exploration of buyers and suppliers of logistics services. *The International Journal of Logistics Management*, 24(3), 328-355. <https://doi.org/10.1108/IJLM-07-2012-0067>
- Goldsby, T. J., Zinn, W., Closs, D. J., Daugherty, P. J., Stock, J. R., Fawcett, S. E., & Waller, M. (2019). Reflections on 40 years of the journal of business logistics: from the editors. *Journal of Business logistics*, 40(1), 4-29. <https://doi.org/10.1111/jbl.12208>
- Gonzalez, C., Lerch, J. F., & Lebiere, C. (2003). Instance-based learning in dynamic decision making. *Cognitive Science*, 27(4), 591-635. [https://doi.org/10.1016/S0364-0213\(03\)00031-4](https://doi.org/10.1016/S0364-0213(03)00031-4)
- Gorsuch, R. L. (1990). Common factor analysis versus component analysis: Some well and little known facts. *Multivariate behavioral research*, 25(1), 33-39. https://doi.org/10.1207/s15327906mbr2501_3
- Grosse, N., Guerpinar, T., & Henke, M. (2021). Blockchain-Enabled Trust in Intercompany Networks Applying the Agency Theory. *Blockchain and Internet of Things Conference*, 3(1), 8-14. <https://doi.org/10.1145/3475992.3475994>
- Hair, J. F. (2009). *Multivariate data analysis* (7 ed.).
- Halldorsson, A., Kotzab, H., Mikkola, J. H., & Skjøtt-Larsen, T. (2007). Complementary theories to supply chain management. *Supply Chain Management: An International Journal*, 20(6), 574-586. <https://doi.org/10.1108/SCM-06-2015-0228>
- Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y. C., de Visser, E. J., & Parasuraman, R. (2011). A Meta-Analysis of Factors Affecting Trust in Human-Robot Interaction. *Human Factors*, 53(5), 517-527. <https://doi.org/10.1177/0018720811417254>
- Harnett, D. L., Cummings, L. L., & Hughes, G. D. (1968). The influence of risk-taking propensity on bargaining behavior. *Behavioral science*, 13(2), 91-101. <https://doi.org/10.1002/bs.3830130202>
- Hoff, K. A., & Bashir, M. (2014). Trust in Automation: Integrating Empirical Evidence on Factors That Influence Trust. *Human Factors*, 57(3), 407-434. <https://doi.org/10.1177/0018720814547570>
- Holthausen, B. E., Wintersberger, P., Walker, B. N., & Riener, A. (2020). Situational trust scale for automated driving (STS-AD): Development and initial validation. *International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 12(1), 40-47. <https://doi.org/10.1145/3409120.3410637>
- Im, I., Kim, Y., & Han, H. (2008). The effects of perceived risk and technology type on users' acceptance of technologies. *Information & Management*, 45, 1-9. <https://doi.org/10.1016/j.im.2007.03.005>
- Jeanneret Medina, M., Baudet, C., & Lebraty, J.-F. (2024). Blockchain and agency theory in supply chain management: A question of trust. *International Journal of Information Management*, 75, 102747. <https://doi.org/10.1016/j.ijinfomgt.2023.102747>
- Jedlička, P., Marešová, P., & Soukalov, I. (2019). Impact of personality traits (BFI-2-XS) on use of cryptocurrencies. *Hradec Economic Days* 2019, 363-369. <https://doi.org/10.36689/uhk/hed/2019-02-037>

- Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, 39(1), 31-36. <https://doi.org/10.1007/BF02291575>
- Kortmann, S. (2015). The mediating role of strategic orientations on the relationship between ambidexterity-oriented decisions and innovative ambidexterity. *Journal of Product Innovation Management*, 32(5), 666-684. <https://doi.org/10.1111/jpim.12151>
- Lee, J. D., & See, K. A. (2004). Trust in Automation: Designing for Appropriate Reliance. *Human Factors*, 46(1), 50-80. https://doi.org/10.1518/hfes.46.1.50_30392
- Lemieux, V., Hofman, D., Batista, D., & Joo, A. (2019). Blockchain Technology & Recordkeeping. <https://doi.org/10.13140/RG.2.2.28447.56488>
- Liu, D., & Weistroffer, H. R. (2022). Statistically Significant! But Is Trust of Practical Significance? *Journal of Computer Information Systems*, 62(2), 247-258. <https://doi.org/10.1080/08874417.2020.1783723>
- López Vivar, A., Castedo, A. T., Sandoval Orozco, A. L., & García Villalba, L. J. (2020). An Analysis of Smart Contracts Security Threats Alongside Existing Solutions. *Entropy*, 22.
- Luhmann, N. (2017). *Trust and power*. John Wiley & Sons.
- MacCarthy, B. (1983). Measuring Social Life Feelings. *The British Journal of Psychiatry*, 143(2), 206-207. <https://doi.org/10.1192/S0007125000117246>
- Mayer, R. C., & Davis, J. H. (1999). The effect of the performance appraisal system on trust for management: A field quasi-experiment. *Journal of applied psychology*, 84(1), 123-136. <https://doi.org/10.1037/0021-9010.84.1.123>
- Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An Integrative Model of Organizational Trust. *The Academy of Management Review*, 20(3), 709-734. <https://doi.org/10.2307/258792>
- Mayer, S. J. (2018). Hauptkomponentenanalyse und explorative Faktorenanalyse. In C. Wagemann, A. Goerres, & M. Siewert (Eds.), *Handbuch Methoden der Politikwissenschaft* (pp. 1-26). Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-16937-4_31-1
- McKnight, D. H., Carter, M., Thatcher, J. B., & Clay, P. F. (2011). Trust in a specific technology: An investigation of its components and measures. *ACM Transactions on management information systems (TMIS)*, 2(2), 1-25. <https://doi.org/10.1145/1985347.1985353>
- Merritt, S. M., Heimbaugh, H., LaChapell, J., & Lee, D. (2013). I Trust It, but I Don't Know Why: Effects of Implicit Attitudes Toward Automation on Trust in an Automated System. *Human Factors*, 55(3), 520-534. <https://doi.org/10.1177/0018720812465081>
- Nakamoto, S. (2008). A peer-to-peer electronic cash system. 4(2), 1-15. <https://bitcoin.org/bitcoin.pdf>
- Nicholson, N., Soane, E., Fenton-O'Creevy, M., & Willman, P. (2005). Personality and domain-specific risk taking. *Journal of Risk Research*, 8(1), 157 - 176. <https://doi.org/10.1080/1366987032000123856>
- Nienaber, A.-M., & Schewe, G. (2014). Enhancing trust or reducing perceived risk, what matters more when launching a new product? *International Journal of Innovation Management*, 18. <https://doi.org/10.1142/S1363919614500054>
- Omar, I. A., Hasan, H. R., Jayaraman, R., Salah, K., & Omar, M. (2021). Implementing decentralized auctions using blockchain smart contracts. *Technological Forecasting and Social Change*, 168, 120786. <https://doi.org/10.1016/j.techfore.2021.120786>
- Paulssen, M., Roulet, R., & Wilke, S. (2014). Risk as moderator of the trust-loyalty relationship. *European Journal of Marketing*, 48(5/6), 964-981. <https://doi.org/10.1108/EJM-11-2011-0657>
- Pavlou, P. (2003). Consumer Acceptance of Electronic Commerce: Integrating Trust and Risk with the Technology Acceptance Model. *International Journal of Electronic Commerce*, 7(3), 101-134. <https://doi.org/10.1080/10864415.2003.11044275>

- Pessot, E., Zangiacomi, A., Marchiori, I., & Fornasiero, R. (2023). Empowering supply chains with Industry 4.0 technologies to face megatrends. *Journal of Business logistics*, 1-32. <https://doi.org/10.1111/jbl.12360>
- Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *Journal of applied psychology*, 88(5), 879. <https://doi.org/10.1037/0021-9010.88.5.879>
- Rousseau, D. M., Sitkin, S. B., Burt, R. S., & Camerer, C. (1998). Not so different after all: A cross-discipline view of trust. *Academy of management review*, 23(3), 393-404. <https://doi.org/10.5465/amr.1998.926617>
- Schaefer, K. E., Chen, J. Y. C., Szalma, J. L., & Hancock, P. A. (2016). A Meta-Analysis of Factors Influencing the Development of Trust in Automation: Implications for Understanding Autonomy in Future Systems. *Human Factors*, 58(3), 377-400. <https://doi.org/10.1177/0018720816634228>
- Shahzad, K., Zhang, Q., Ashfaq, M., Zafar, A. U., & Ahmad, B. (2024). Pre- to post-adoption of blockchain technology in supply chain management: Influencing factors and the role of firm size. *Technological Forecasting and Social Change*, 198, 122989. <https://doi.org/10.1016/j.techfore.2023.122989>
- Sitkin, S. B., & Pablo, A. L. (1992). Reconceptualizing the Determinants of Risk Behavior. *The Academy of Management Review*, 17(1), 9-38. <https://doi.org/10.2307/258646>
- Soper, D. (2023). A-priori Sample Size Calculator for Structural Equation Models [Software]. <https://www.danielsoper.com/statcalc>
- Stanton, N. A. (2022). Systems-thinking for safety: a short introduction to the theory and practice of systems-thinking. *Ergonomics*, 65, 327 - 327. <https://doi.org/10.1080/00140139.2021.1992965>
- Stuck, R. E., Holthausen, B. E., & Walker, B. N. (2021). Chapter 8 - The role of risk in human-robot trust. In C. S. Nam & J. B. Lyons (Eds.), *Trust in Human-Robot Interaction* (pp. 179-194). Academic Press. <https://doi.org/10.1016/B978-0-12-819472-0.00008-3>
- Stuck, R. E., Tomlinson, B. J., & Walker, B. N. (2022). The importance of incorporating risk into human-automation trust. *Theoretical Issues in Ergonomics Science*, 23(4), 500-516. <https://doi.org/10.1080/1463922X.2021.1975170>
- Surucu-Balci, E., Iris, Ç., & Balci, G. (2024). Digital information in maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities. *Technological Forecasting and Social Change*, 198, 122978. <https://doi.org/10.1016/j.techfore.2023.122978>
- Tan, C. (2019). *Supply Chain Management: A Survey of Current Practice in the US*.
- Tinsley, H. E., & Kass, R. A. (1979). The latent structure of the need satisfying properties of leisure activities. *Journal of Leisure Research*, 11(4), 278-291. <https://doi.org/10.1080/00222216.1979.11969406>
- Treiblmaier, H. (2018). The impact of the blockchain on the supply chain: a theory-based research framework and a call for action. *Supply Chain Management: An International Journal*, 23(6), 545-559. <https://doi.org/10.1108/SCM-01-2018-0029>
- Trist, E. L. (1981). *The evolution of socio-technical systems (Vol. 2)*. Ontario Quality of Working Life Centre Toronto.
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 27(3), 425-478. <https://doi.org/10.2307/30036540>
- Vo, K. T., Nguyen-Thi, A. T., & Nguyen-Hoang, T. A. (2021). Building Sustainable Food Supply Chain Management System Based On Hyperledger Fabric Blockchain. *International Conference on*

- Advanced Computing and Applications (ACOMP), 15(1), 9-16.
<https://doi.org/10.1109/ACOMP53746.2021.00008>
- Wang, Q., Lau, R., & Mao, X. (2019). Blockchain-Enabled Smart Contracts for Enhancing Distributor-to-Consumer Transactions. *IEEE Consumer Electronics Magazine*, 8, 22-28.
- Wang, S., Li, D., Zhang, Y., & Chen, J. (2019). Smart contract-based product traceability system in the supply chain scenario. *IEEE Access*, 7(1), 115122-115133.
<https://doi.org/10.1109/ACCESS.2019.2935873>
- Whipple, J. M., Griffis, S. E., & Daugherty, P. J. (2013). Conceptualizations of trust: Can we trust them? *Journal of Business logistics*, 34(2), 117-130.
- Wu, K., Zhao, Y., Zhu, Q., Tan, X., & Zheng, H. (2011). A meta-analysis of the impact of trust on technology acceptance model: Investigation of moderating influence of subject and context type. *International Journal of Information Management*, 31(6), 572-581.
<https://doi.org/10.1016/j.ijinfomgt.2011.03.004>
- Xu, L., Tu, P., & Tang, Q. (2020). Contract design for cloud logistics (cl) based on blockchain technology (BT). *Complexity*, 2020(4), 1-13. <https://doi.org/10.1155/2020/5305808>
- Xu, Z. X., Wang, Y., Zhu, M., & Ma, H. K. (2019). Is risk-taking propensity associated with unethical behaviors? An experimental study. *Ethics & Behavior*, 29(7), 557 - 571.
<https://doi.org/10.1080/10508422.2019.1585854>
- Yamagishi, T., & Yamagishi, M. (1994). Trust and commitment in the United States and Japan. *Motivation and emotion*, 18(2), 129-166. <https://doi.org/10.1007/BF02249397>
- Zheng, Z., Xie, S., Dai, H.-N., Chen, W., Chen, X., Weng, J., & Imran, M. (2020). An overview on smart contracts: Challenges, advances and platforms. *Future Generation Computer Systems*, 105, 475-491. <https://doi.org/10.1016/j.future.2019.12.019>

4.8 Appendix

The questionnaires, collected data, statistical tests and study results can be found online in a permanent open-access data repository: <https://doi.org/10.17605/OSF.IO/53F2W>

5 Metaverse, ubi es? A Transaction Cost-Based Analysis of the State of the Art of Smart Contracts in the Metaverse⁸

Wieland Müller, Shahper Richter, Alexander Richter and Michael Leyer

Abstract

Fueled by recent technological developments and reinvigorated through the hype around the Metaverse concept, virtual worlds are becoming increasingly popular as platforms for social interaction, entertainment, and commerce. This study applies transaction cost theory to explore smart contracts' potential in virtual worlds, specifically Decentraland, Sandbox, and Roblox. By assessing process costs, we gauge the feasibility and usability of these decentralized worlds in line with the Metaverse vision. Our findings indicate that the concept and implementation of smart contracts are still nascent and require enhancements from technical, organizational, and user standpoints. Our study contributes to a better understanding of smart contracts' current value in virtual worlds and points to future research directions for optimizing their use.

Keywords: Metaverse, Smart Contracts, Virtual World, Transaction Costs.

⁸ The article is published in the Proceedings of the 57th Hawaii International Conference on System Sciences.

5.1 Introduction

The development of virtual reality (VR) and augmented reality (AR) technologies, alongside the emergence of blockchain and smart contracts, has contributed to an increased interest in virtual worlds for living, learning, and working (Dincelli & Yayla, 2022; Oppenlaender, 2022; Richter & Richter, 2023; Vatiero, 2022). The concept of the Metaverse enables users to engage within three-dimensional virtual worlds through virtual characters (Dolata & Schwabe, 2023; Dwivedi et al., 2022; Park et al., 2023). Within the latter domain, smart contracts, which are self-executing contracts with the terms of the agreement directly written into code, have emerged as a promising tool for secure, transparent, and automated transactions in virtual worlds (Oppenlaender, 2022; Zheng et al., 2020).

However, the adoption of smart contracts varies widely across different virtual worlds, and the factors that drive this variation need to be better understood (Albizri & Appelbaum, 2021; Malik et al., 2022).

To address this knowledge gap, we employ a theoretical framework that can help analyze the use of smart contracts in virtual worlds. Transaction cost theory, which deals with the cost of exchanging resources, goods, or services, is a suitable framework for this purpose (Shahab, 2022; Vatiero, 2022). It can provide systematic insights into the factors that influence the adoption of smart contracts, such as search costs, bargaining costs, and enforcement costs. By applying transaction cost theory to the study of smart contracts in virtual worlds, researchers can better understand the factors driving their adoption, as well as the challenges and opportunities associated with their implementation. This understanding is critical for the development of more efficient, secure, and transparent virtual environments that leverage the full potential of smart contracts and blockchain technologies.

Hence, our research question is how smart contracts can be designed in metaverse from a transaction cost perspective.

We base our analysis of adoption of smart contracts on three of the most prominent virtual worlds. Two of them are blockchain-based virtual worlds (Decentraland and Sandbox) and one platform is not using blockchain (Roblox). Instead, of blockchain, Roblox relies on a centralized server infrastructure to manage its vast array of user-generated content and in-game transactions.

We selected these virtual worlds for their diverse use of blockchain technology and smart contracts within their virtual economy. In addition, we also analyze Roblox to better understand the boundaries and benefits of blockchain-based platforms, i.e., to compare the results with a platform that is not using blockchain.

Blockchain technology can significantly reduce transaction costs through decentralization, eliminating intermediaries and automating agreements through smart contracts. We look at the use of smart contracts in virtual worlds from a systematic transaction cost theory perspective to understand these efficiencies compared to traditional transaction methods.

We compare and contrast the adoption of smart contracts across these virtual worlds, identifying similarities and differences in their respective approaches. While the metaverse is a hot topic, our study reveals that smart contracts still have a long way to go. Though implemented, they haven't fully proven their concept, especially in the metaverse context. From a transaction cost theory standpoint, smart contracts have significant drawbacks that need to be addressed before they become relevant in virtual worlds.

The contribution of this study is significant for its detailed investigation of smart contract adoption factors in virtual worlds, such as Decentraland and Sandbox. By providing insights for developers, policymakers, and researchers, our research enhances understanding of challenges and opportunities in integrating blockchain technology into virtual environments. Additionally, by comparing smart contract adoption in Decentraland and Sandbox, the study contributes to academic discussions on blockchain technology's role in shaping virtual economies. Moreover, this study offers a nuanced examination of smart contract adoption factors in virtual worlds and enriches the ongoing dialogue on the impact of blockchain technology on virtual economies.

The rest of the paper is organized as follows: We start with outlining related work with regard to metaverses and blockchain technology followed by smart contracts. We then describe our method for

analysis from a theoretical perspective, namely transaction cost theory. The results of our analysis are presented and discussed. We conclude the paper with theoretical and practical implications as well as outlining future research.

5.2 Related Work

5.2.1 The Metaverse

The concept of the Metaverse, a virtual realm that coexists with the physical world, has gained significant attention from organizations and academics (Dwivedi et al., 2022). The Metaverse represents a next-level virtual experience, providing users with a fully immersive environment that blends physical and virtual spaces (Richter & Richter, 2023). Cutting-edge technologies offer seamless, believable, multi-sensory experiences. Game engines like Unity and Unreal Engine facilitate the creation of sophisticated virtual environments, while Web 3.0 principles, such as decentralization and interoperability, ensure a more open and accessible metaverse. The integration of VR, AR, AI, and haptic feedback generates immersive experiences that blur the line between physical and virtual worlds, delivering unprecedented engagement and interaction opportunities for users. As fantastic as this all sounds, it is important to remember that at the time of writing this article, this concept of the Metaverse, remains just that, a concept. Significant challenges remain between the current and the utopian vision of what the Metaverse could be. One of these challenges is the level of interoperability between different virtual platforms.

5.2.2 Blockchain in the Metaverse

The Metaverse uses technologies to create a digital representation of the real world, while blockchain technologies are used to build an economic system. It enables close integration of the virtual and real worlds in areas such as business, social and identity, and allows users to create and edit content (Ning et al., 2023).

Due to its characteristics, blockchain can serve as the basis of the infrastructure for the metaverse on which the virtual world is built and through which user content can be generated and traded virtually (Duan et al., 2021). Previous research already discusses the potential correlation between virtual worlds and blockchain technology through the multi-layered architecture of data, network, consensus, incentive, contract and application layers (Yang et al., 2022).

Some common characteristics of the different blockchain types are Indestructibility, immutability, security and transparency of data (Vo et al., 2021). The differences are mainly the way how transactions are stored and validated, which translates into different scalability, flexibility, transaction speed, energy consumption and transaction costs (Chowdhury et al., 2019).

The role of blockchain technology in metaverses would be ensuring data privacy, security and quality, enabling seamless and secure data exchange, enabling data interoperability, ensuring data integrity, building a financial system as well as enabling the use of smart contracts and NFTs (Gadekallu et al., 2022). There is also an impact of the technology on other key enabling technologies in metaverses: Blockchain technology will enable IoT devices to securely exchange and store real data across multiple virtual worlds. Incorporating blockchain technology into digital twins allows metaverse actors to address concerns about the trust, integrity and security of data. The combination of AI and blockchain will secure the highly sensitive data that AI-driven systems need to collect, store and use. The blockchain holds great potential for the future of Big Data analytics. Users will be able to maintain complete control over their personal data and financial activities in the metaverse (Gadekallu et al., 2022).

5.2.3 Smart Contracts in Metaverses

Smart contracts are digital contracts that can be written by an "if-this-then-that" code in the blockchain structure. They refer to conditions that have previously been jointly set by the actors of a network and are automatically executed as soon as these contract conditions are fulfilled. Once established, no further management of contracts is required if the conditions are not changing. Smart contracts can thus

automate processes and eliminate the need for intermediaries; once defined, direct contract discussions are no longer necessary (Vo et al., 2021).

One potential use case for smart contracts in metaverses is for fundraising and project management. A proposed ecosystem that integrates smart contracts would enable stakeholders to participate in and monitor the progress of a project. Once a shareholder participates in a project through a smart contract, they can keep track of its progress through a digital twin in their respective metaverse. To gain access to this metaverse, participants need to have prepared the necessary token, and they can do so through technologies like augmented reality, virtual reality, or 3D graphics spaces, such as computer games. Progress updates for the project would be collected from IoT-based devices, BIM, and artificial intelligence networks, all of which would be integrated through a software interface and ultimately modelled (Moradi et al., 2022).

There are different concepts on how Smart Contracts can be integrated into metaverses. By using smart contracts, MetaChain (a novel blockchain-based framework for Metaverse applications) can effectively manage and automate complex interactions between the Metaverse Service Provider (MSP) and Metaverse Users (MUs). In particular, thanks to smart contract mechanisms, the blockchain can manage and automate complex interactions between different entities in the metaverse, e.g., between metaverse service providers (MSPs), users and digital content creators (Nguyen et al., 2022). MetaManagement rules are automatically enforced by smart contracts in MetaSocieties (virtual companies and cities that operate parallel to real companies and cities). Depending on the operational results, the MetaManagement rules are continuously adjusted to achieve the expected MetaManagement effect (Wang et al., 2022).

In practice, there are currently only a few actual use cases. Decentraland is a blockchain-based virtual world where users can buy, own, and develop parcels of digital land represented as Non-Fungible Tokens (NFTs) on the Ethereum blockchain. Smart contracts enable decentralized governance of the platform, allowing users to make collective decisions about its development and management. Smart contracts play a pivotal role in enforcing community voting decisions, ensuring that governance processes within the virtual world are transparent, tamper-proof, and decentralized (Oppenlaender, 2022). These contracts provide a trustless mechanism for users to collectively shape the development and management of the Metaverse. Also, in Decentraland, the utilization of smart contracts extends to recording ownership of valuable assets like virtual land parcels and NFTs, creating an immutable and auditable ledger of ownership rights (Dowling, 2022). This application enhances the security and provenance of digital assets, critical in a virtual world where ownership and scarcity are essential.

The CUHKSZ Metaverse showcases an even broader implementation of smart contracts, leveraging this technology to support its ecosystem's core components, including tokens, decentralized autonomous organizations (DAOs), and the trading system (Duan et al., 2021). Smart contracts here facilitate not only asset management but also enable the automation of complex interactions, fostering a self-sustaining virtual environment. It can be seen that smart contracts are primarily used for management and background activities in metaverses so far.

5.2.4 Transaction Cost Theory

In this study, we apply the Transaction Cost Theory (TCT) as a lens to examine transaction costs in virtual worlds: TCT, as conceptualized by North and North (1992) and (Williamson, 1981), is employed to understand the nature and implications of transactions within these platforms, where transactions are inextricably bound by smart contracts.

Since smart contracts focus on automating transactions, TCT is the best fitting theory that not only provides the necessary theoretical background but also the relevant conceptual framework for our analysis. Our selection, Decentraland and Sandbox, are representative platforms within the realm of Ethereum-based virtual environments. Both platforms facilitate a multitude of interactions that can be understood and analyzed under the premises of TCT. Roblox serves as a comparable virtual environment without employing smart contracts.

The key concept of transaction cost theory aims to increase economic efficiency in the process of exchanging products or services through the market. In addition to the production costs of goods,

transaction costs play a decisive role in the search for an efficient economic unit and its decision boundaries (Williamson, 1983). Transaction costs can be divided into (1) information and selection phase with search and initiation aspects, (2) negotiation phase (with contract and communication aspects), (3) the decision-making phase with process aspects and (4) the post-contractual phase with monitoring and enforcement costs (Dahlman, 1979).

5.3 Research Method

We first develop a conceptual framework that links TCT to Metaverse transactions. We identify the equivalent of the phases for (1) information and selection, (2) negotiation, (3) decision making and (4) post-contractual and then analyze how they are implemented. Our methodological approach, which is conceptual in nature, is well-suited for examining the complex transactional dynamics within the virtual worlds. As Gioia, Corley, and Hamilton (2013) suggested, a conceptual analysis allows for a qualitative rigor in inductive research, and it is especially fitting when studying complex systems, such as blockchain-based virtual worlds. Building upon Jabareen's (2009) approach to constructing a conceptual framework, we systematically explore the principles, definitions, and processes that govern these platforms' transactional structures and mechanisms. By engaging with the data and structures like the expanded sourcebook by Miles and Huberman (1994), we can holistically comprehend these virtual environments and delve deeper into the underlying structure and functional rationale. Table 18 provides an overview on the main characteristics of the three platforms.

Table 18: Comparison of the analyzed virtual worlds.

	Decentraland	Sandbox	Roblox
Daily active users	Under 1,000	Around 8,000	Around 66.1 million
Launched	2015	2012	2006
Focus	Development of a decentralized and economic platform	Building and sharing content	Create and publish games
Type	Ethereum based decentralized platform	Ethereum based decentralized platform	Centralized online platform, not blockchain based

We delineate the transactional procedures, understand the operational logic of smart contracts, and tease out how these interact with the principles of transaction cost theory. In analyzing the transaction data, we focus on the transaction cost indicators: search and information costs, contracting and communication costs, process costs as well as enforcement and monitoring costs (Dahlman, 1979). These cost variables offer a comprehensive framework to navigate the myriad transactions unfolding in Decentraland, Sandbox and Roblox.

Drawing on these principles, our research involved two primary data collection methods: We created user accounts within each of the virtual worlds and actively engaged in different transactions and interactions within these digital environments. This approach allowed us to immerse ourselves in the platforms, gaining firsthand experience of the transactional processes and challenges users face. Furthermore, we gathered official information provided by the organizations that operate and manage these virtual worlds. This included studying documentation, policies, and materials shared by the organizations to gain insights into their intended operational structures and transactional procedures.

With the transparent nature of blockchain technology, we could access and scrutinize transaction logs and the terms of smart contracts, which were the primary materials for our research. Quantitative analysis of transaction data, including recording, categorizing, and analyzing transaction types and costs, was complemented by qualitative document analysis of smart contracts' terms.

Our focus lies in understanding the 'rules of the game', and how they influence transaction costs in these platforms. The transaction logs and the terms of the smart contracts, both publicly available due to the transparent nature of blockchain technology are the primary documents scrutinized in our research. Our method thus intertwines TCT's analytical potential and the transactional architecture of Ethereum-based

virtual worlds, providing a novel perspective on transaction efficiency in these nascent digital spaces. Our conceptual approach allows for a comprehensive understanding of these spaces, and of their structural and operational logic.

5.4 Results

Transaction cost theory aims to improve economic efficiency in the exchange of products or services through the market. Using the phases of TCT, we assess the three virtual worlds based on own transactions in as well as information provided by the organizations about fees incurred.

The overall results are depicted in Table 19 and described in detail in the following. In the information and selection phase, Decentraland and Sandbox users navigate the complexities of their respective blockchain-based marketplaces, which includes tasks such as searching for listings and comparing listings. In contrast, Roblox, as a non-blockchain platform, simplifies this phase as users do not need to interact with blockchain-based marketplaces.

Table 19: Comparison of transaction costs in virtual worlds.

Phase	Aspects	Decentraland	Sandbox	Roblox
Information and selection	Search	Offer comparison on the marketplace		
	Initiation	Platform account, crypto wallet and currency exchange necessary		Platform account and currency exchange necessary
Negotiation	Contract	Smart Contract creation (ERC-721 standard: Only fungible tokens)	Smart Contract creation (ERC-1155 standard: fungible and non-fungible)	(Traditional) Contract creation
	Communication	Through the marketplace platform		Through the marketplace platform
Decision Making	Process	Transaction time (30 sec. up to 30 minutes), Ethereum Platform Fee, Listing Fee (100MANA), Marketplace fee (2.5%)	Transaction time (30 sec. up to 30 minutes), Ethereum Platform Fee, Listing Fee (0,05ETH), Marketplace fee (5%)	Marketplace fee (30%)
Post-contractual	Enforcement	Regulation trough Decentralized Autonomous Organization (DAO)	Centralized regulation	Regulation trough company management/ employees
	Monitoring	Control trough DAO	Central control	Support Services

Decentraland and Sandbox introduce additional complexity in the initiation phase as users need to set up accounts on the platform and engage in cryptocurrency activities, including owning crypto wallets and potentially participating in currency exchanges. In contrast, Roblox works with a centralized currency system that simplifies the adoption process.

In the negotiation phase, Decentraland and Sandbox use smart contracts for transactions, but with different standards and token types. In Roblox, transactions are governed by traditional contracts. Communication during trading takes place in all three virtual worlds via the respective marketplace platforms.

The decision phase is characterized by transaction times, Ethereum platform fees, listing fees and marketplace fees. Decentraland and Sandbox have similarities in transaction times and listing fees and

differ mainly in their marketplace fees. Roblox, on the other hand, charges a much higher marketplace fee, which affects the overall cost structure.

Decentraland is characterized by its use of decentralized autonomous organizations (DAOs) for regulation and control, embodying a decentralized approach to corporate governance. Roblox, on the other hand, relies on centralized regulation and control by management and employees. Sandbox represents an intermediate approach that has a mix of decentralized and centralized elements in its governance.

The results show, on the example of smart contracts, that the concept of the blockchain based virtual worlds is still in early stages. The current implementation of smart contracts on the platforms studied is far from being a proof-of-concept.

5.5 Discussion

We used transaction cost theory to systematically illustrate how smart contracts are implemented and to provide a good understanding of the processes behind them. Our research on transaction cost theory provides some new insights in the context of blockchain-based metaverses. Overall, blockchain technology presents both opportunities and challenges in the context of transaction cost theory.

Currently, the transaction costs are high which sets up the bar for non tech savvy users. Especially in the initiation phase, a high level of technical affinity is required in order to create the necessary crypto wallets.

One of the findings concerns the negotiation phase in the iterative implementation of smart contracts. The difficulty of creating smart contracts is directly related to the risk posed by errors in the code. Since the contract code is immutable, the cost of reviewing and testing the code is significantly higher and may even preclude the feasibility of complex smart contracts (due to the exponential probability of errors relative to the code size) (Szczerbowski, 2018). It becomes clear that the costs and risks of creating smart contracts in virtual worlds are higher compared to traditional contracts.

Due to the technical requirements of the blockchain architecture, many transaction costs also arise in the decision phase, which cannot be reduced even if the processes are automated. The decision phase also includes process aspects, such as the maintenance of smart contracts, which are decided by a majority vote of the participating nodes. Depending on the architecture, there are different consensus mechanisms that require different amounts of time and cost. Especially in the case of recurring processes, this could lead to a rejection of the use of smart contracts, as quantity effects cannot be used here. This is a huge disadvantage compared to non-blockchain-based virtual worlds. In addition to blockchain technology, there are other distributed technologies that can reduce or eliminate transaction costs at this point. However, there are no implementations of these yet.

Post-contractual enforcement and monitoring include that the resulting transactions and the new state information are stored in the blockchain and confirmed according to the consensus protocol. Enforcement costs are reduced by the use of smart contracts, as there is almost complete information about the "history" of contract performance (Zheng et al., 2020). However, there are also additional monitoring costs for auditing the smart contract code (Zheng et al., 2020). Furthermore, a smart contract has the disadvantage that it cannot be legally adjusted afterwards. The consensus mechanism is a central problem of transaction cost economics in traditional blockchains. It limits the legally secured application and can thus lead to high ex-post transaction costs (Vatiero, 2022).

5.6 Research Agenda

Our research agenda is derived from the insights gained so far. It revolves around assessing and refining the integration and usability of smart contracts in virtual worlds on blockchain platforms, identifying areas for improvement, and establishing possible solutions, both technical and otherwise. The application of smart contracts promises to reduce administrative and service costs while enhancing efficiency, security, and transparency. However, the high transaction costs and barriers currently involved pose a significant deterrent. Notably, users require a crypto wallet, must often handle high transaction fees, and need to transfer cryptocurrencies into the virtual platform. The fluctuating

exchange rates of cryptocurrencies further amplify the uncertainty surrounding transaction costs. Another layer of complexity is added due to the potential for programming errors and security issues in Ethereum-based virtual worlds utilizing smart contracts.

5.6.1 Technical Perspective

Key research questions that future studies should aim to address from a technical perspective include:

- *How can the costs associated with executing smart contracts in blockchain-based virtual worlds be effectively reduced and mitigated to promote wider accessibility and adoption?*
- *How can different use cases in virtual worlds influence the design and instantiation of smart contracts?*
- *How can smart contracts be designed to connect the virtual and real world seamlessly, and what would be the implications of such integration?*

In order to address these research questions, we elaborate and extend these as follows. Our study found that the use of smart contracts in blockchain-based virtual worlds incurs high fees compared to non-blockchain alternatives. This highlights an important technical consideration, as these fees can limit the accessibility and adoption of smart contracts within virtual worlds. Researchers should discuss potential ways to mitigate these costs, such as exploring scalability solutions (e.g., layer 2 protocols) or alternative blockchain architectures that offer lower fees.

By leveraging layer 2 protocols, virtual worlds can accommodate a larger user base and support a higher volume of transactions without sacrificing efficiency. To enhance scalability and throughput of smart contracts in virtual worlds, researchers should investigate and compare different layer 2 scaling solutions, such as state channels and sidechains, and develop practical strategies for integrating them into virtual world platforms.

Gas optimization techniques can be employed to minimize the costs associated with executing smart contracts in virtual worlds. This involves optimizing the code and reducing unnecessary computations to decrease the amount of gas consumed per transaction. Research should focus on identifying best practices for gas optimization in smart contract development, developing automated tools for optimization suggestions, measuring gas savings and their impact on transaction fees, and striking a balance between optimization and code readability, maintainability, and security.

Exploring alternative consensus algorithms that offer better efficiency and scalability can be beneficial for virtual worlds. Traditional Proof-of-Work mechanisms can be resource intensive and limit scalability. Moving to more efficient consensus mechanisms such as Proof-of-Stake or delegated Proof-of-Stake can reduce computational requirements and improve the scalability of virtual world platforms. Researchers should evaluate the suitability of different consensus algorithms, design mechanisms tailored for virtual worlds, measure their performance and resource requirements, and consider their impact on governance and decision-making processes within virtual worlds.

The discussion should touch upon the interoperability challenges faced by virtual worlds utilizing smart contracts. Researchers should explore the importance of industry-wide standards, protocols, and interoperability frameworks to enable seamless interaction and asset transfer between different virtual worlds and ecosystems. The potential benefits of cross-chain communication protocols or standardized smart contract templates can be discussed in this context.

5.6.2 Organizational perspective

Key research questions that future studies should aim to address from an organizational perspective include:

- *What are the essential considerations for companies to effectively offer their products and services through smart contracts in virtual worlds?*
- *What are the organizational strategies and practices that enable continuous improvement within virtual worlds, ensuring the evolution of the virtual world according to user needs and market dynamics?*

Future research should identify requirements for designing smart contracts, considering different virtual products and services. Furthermore, as more companies venture into the virtual space, it is crucial to understand the requirements for offering products and services via smart contracts. An in-depth analysis of how automated contracts are designed, possibly linking the virtual and real worlds, is necessary.

Emphasizing continuous improvement and feedback loops within the organization ensures that the virtual world evolves according to user needs and market dynamics. Regularly soliciting feedback from users, developers and stakeholders enables iterative improvement of virtual world, user experience and smart contract features. This iterative approach would allow companies to adapt to changing requirements, overcome new challenges and create an optimized experience for users and should therefore be explored and implemented for use in virtual worlds.

This endeavor necessitates the examination of specific use cases for these virtual worlds, ranging from attending concerts or lectures to gaming. Each use case may necessitate a unique instantiation of smart contracts, a topic that warrants a detailed investigation.

Optimizing the use of smart contracts in blockchain-based virtual worlds from an organizational perspective involves implementing effective strategies and practices that enhance collaboration, governance, and ecosystem development. Building strategic partnerships and collaborations with other projects, platforms, or blockchain networks can enhance the capabilities and reach of the virtual world. Specifically, synergistic benefits should be explored, such as the shared user base and cross-platform functionality that can be achieved through partnerships. The role of partnerships in accelerating ecosystem growth and the diffusion of smart contracts in virtual worlds should also be explored.

Regulatory and legal considerations are vital for the responsible and compliant use of smart contracts in virtual worlds. Researchers should highlight the need for clear regulatory frameworks that address data privacy, intellectual property rights, and jurisdictional challenges. Collaborative efforts involving policymakers, legal experts, and blockchain industry stakeholders can help establish guidelines and regulations that foster innovation while safeguarding the rights and interests of users.

5.6.3 User perspective

Key research questions that future studies should aim to address from a user perspective include:

- *What is the role and acceptance of intermediaries, like banks or financial service providers, in managing virtual accounts and facilitating transactions in the virtual world?*
- *What are the unique requirements for setting up smart contracts based on the type of user (occasional, permanent, purpose-specific)?*

As the popularity of these virtual worlds expands beyond the technologically adept users, it becomes essential to understand diverse user groups' requirements and expectations. Similar to the evolution of real-world payment options, such as Apple Pay and Google Pay, transaction processes need to be simplified, keeping in mind the technical necessities of smart services. Our research findings pertaining to distinct transaction phases can provide a foundation for designing targeted questionnaires to understand varied user groups' requirements for smart contracts.

Moreover, intermediaries, such as banks or other financial service providers, could play a significant role in facilitating the interaction between users and smart contracts. Research exploring the viability and acceptance of these mediators managing virtual accounts for individuals or groups could provide valuable insights into improving user interaction in virtual worlds.

It is important to recognize that an intuitive and user-friendly interface is crucial for wider adoption. Researchers should discuss the importance of designing user interfaces that facilitate interaction with smart contracts and consider the potential for collaboration between UX designers and blockchain developers to create seamless experiences.

The study identified the complexity involved in creating smart contracts for virtual worlds. This complexity stems from the need for a high level of technical understanding and expertise. Researchers should discuss the implications of this finding, such as the potential barriers it presents to users or developers who may lack the necessary skills or resources to create or interact with smart contracts

effectively. Possible solutions, such as user-friendly development frameworks or improved developer tooling, can also be discussed.

For the use of blockchain-based virtual worlds, an elaborate procedure is necessary to gain access to the world and to be able to carry out transactions. In addition to the account for the virtual world, a crypto wallet must be created and currencies exchanged. Future research should focus on developing user-friendly solutions that reduce technical barriers. One possibility is to explore new wallet solutions that simplify the process of creating and managing crypto wallets. The development of intuitive and user-friendly interfaces could also enable non-technical users to use smart contracts more easily.

In addition, future studies should examine the impact of cryptocurrency volatility on user experience and transaction costs. Developing mechanisms to mitigate or minimize currency risks could help reduce uncertainty in transaction costs and increase user trust. Besides technical aspects, it is also important to investigate the legal and regulatory framework for the use of smart contracts in virtual worlds. The development of legal standards and best practices could increase user trust and enable the smooth operation of smart contracts.

5.7 Conclusion

Theoretical implications of our study first provide insights from a TCT perspective that can be used to better understand the role of smart contracts in the metaverse (Halaburda et al., 2019). Our application on the three dominating virtual worlds reveals additional insights beyond purely theoretical analyses. Second, we provide a detailed research agenda on the topics to be researched with regard to smart contracts in virtual worlds. Third, our study establishes a foundation for future research in blockchain technology and its applications in virtual worlds, offering a comprehensive framework for assessing the viability and impact of smart contracts. This includes the potential for reducing transaction costs (Eickstädt et al., 2020), improving operational efficiency, and enabling seamless interaction between the virtual and real-world environment.

Practical implications are that virtual worlds can use our results to further explore how to develop their platforms further with the aim of attracting new customers. Our research agenda also provides avenues for practical evaluation in which direction smart contracts and the underlying blockchain usage should be developed. For service providers who are present in the metaverse, transforming their products and services from the real world to metaverse can be informed by our analysis. And for financial transaction providers, the analysis offers the potential to explore new service models that are not present so far (Masla et al., 2021).

Limitations of our study include the following: The study only investigated three virtual worlds, of which two were based on similar blockchain technology. This limited sample size raises concerns about the generalizability of the findings, as there may be other virtual worlds with different characteristics or features that were not included in the analysis.

Another limitation is the focus on Ethereum as the primary blockchain technology in the study. While Ethereum is widely used, other distributed ledger or blockchain technologies might offer lower transaction costs. However, these alternative technologies were not implemented in the virtual worlds examined in this study, and their potential impact remains unexplored. It is important to acknowledge that these limitations reflect the scope of the present study and may not encompass all possible constraints associated with virtual worlds and their blockchain technologies.

5.8 References

- Albizri, A., & Appelbaum, D. (2021). Trust but verify: The oracle paradox of blockchain smart contracts. *Journal of Information Systems*, 35(2), 1-16.
- Chowdhury, M. J. M., Ferdous, M. S., Biswas, K., Chowdhury, N., Kayes, A., Alazab, M., & Watters, P. (2019). A comparative analysis of distributed ledger technology platforms. *IEEE Access*, 7(1), 167930-167943. <https://doi.org/10.1109/ACCESS.2019.2953729>
- Dahlman, C. J. (1979). The problem of externality. *The journal of Law and Economics*, 22(1), 141-162.

- Dincelli, E., & Yayla, A. (2022). Immersive virtual reality in the age of the Metaverse: A hybrid-narrative review based on the technology affordance perspective [Review]. *Journal of Strategic Information Systems*, 31(2), Article 101717. <https://doi.org/10.1016/j.jsis.2022.101717>
- Dolata, M., & Schwabe, G. (2023). What is the Metaverse and who seeks to define it? Mapping the site of social construction. *Journal of Information Technology*, 1-28. <https://doi.org/10.1177/02683962231159927>
- Dowling, M. (2022). Is non-fungible token pricing driven by cryptocurrencies? *Finance Research Letters*, 44(1), 102097. <https://doi.org/10.1016/j.frl.2021.102097>
- Duan, H., Li, J., Fan, S., Lin, Z., Wu, X., & Cai, W. (2021). Metaverse for social good: A university campus prototype. *Proceedings of the 29th ACM international conference on multimedia*, 153-161. <https://doi.org/10.48550/arXiv.2108.08985>
- Dwivedi, Y., Hughes, L., Baabdullah, A., Ribeiro-Navarrete, S., Giannakis, M., Al-Debei, M. M., Dennehy, D., Metri, B., Buhalis, D., Cheung, C., Conboy, K., Doyle, R., Dubey, R., Dutot, V., Felix, R., Goyal, D., Gustafsson, A., Hinsch, C., Jebabli, I., . . . Wamba, S. F. (2022). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, 66, 102542. <https://doi.org/10.1016/j.ijinfomgt.2022.102542>
- Eickstädt, A., Horsch, A., & Seidel, E. (2020). Potentials and Limitations of Smart Contracts: A Primer from an Economic Point of View. *European Business Law Review*, 169-183. <http://www.kluwerlawonline.com/api/Product/CitationPDFURL?file=Journals\EULR\EULR2020007.pdf>
- Gadekallu, T. R., Huynh-The, T., Wang, W., Yenduri, G., Ranaweera, P., Pham, Q.-V., da Costa, D. B., & Liyanage, M. (2022). Blockchain for the metaverse: A review. *arXiv preprint arXiv:2203.09738*, 1-17. <https://doi.org/10.48550/arXiv.2203.09738>
- Halaburda, H., Levina, N., & Semi, M. (2019). Understanding smart contracts as a new option in transaction cost economics *Proceedings of the 40th International Conference on Information Systems*, Munich, Germany,
- Jabareen, Y. (2009). Building a conceptual framework: philosophy, definitions, and procedure. *International journal of qualitative methods*, 8(4), 49-62. <https://doi.org/10.1177/160940690900800406>
- Malik, N., Wei, M. Y., Appel, G., & Luo, L. (2022). Blockchain Technology for Creative Industry: Current State and Research Opportunities. *International Journal of Research in Marketing*, 40(1), 38-48. <https://doi.org/j.ijresmar.2022.07.004>
- Masla, N., Vyas, V., Gautam, J., Shaw, R. N., & Ghosh, A. (2021). Reduction in Gas Cost for Blockchain Enabled Smart Contract. *2021 IEEE 4th International Conference on Computing, Power and Communication Technologies (GUCON)*, 1-6.
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. sage.
- Moradi, M. A., Niazkari, N., & Dehmardan, A. (2022). Blockchain, a transformation of new financing and management progress of megaprojects in the context of smart contracts with the usage of metaverse and oracle. *EC3 Conference 2022*, 3, 1-5. <https://doi.org/10.35490/EC3.2022.214>
- Nguyen, C. T., Hoang, D. T., Nguyen, D. N., & Dutkiewicz, E. (2022). Metachain: A novel blockchain-based framework for metaverse applications. *2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring)*, 1-5. <https://doi.org/10.48550/arXiv.2201.00759>
- Ning, H., Wang, H., Lin, Y., Wang, W., Dhelim, S., Farha, F., Ding, J., & Daneshmand, M. (2023). A Survey on the Metaverse: The State-of-the-Art, Technologies, Applications, and Challenges. *IEEE Internet of Things Journal*, 1-34. <https://doi.org/10.48550/arXiv.2111.09673>
- North, D. C., & North, D. C. (1992). *Transaction costs, institutions, and economic performance*. ICS Press San Francisco, CA.

- Oppenlaender, J. (2022). The Perception of Smart Contracts for Governance of the Metaverse. Proceedings of the 25th International Academic Mindtrek Conference, 1-8. <https://doi.org/10.1145/3569219.3569300>
- Park, H., Ahn, D., & Lee, J. (2023). Towards a Metaverse Workspace: Opportunities, Challenges, and Design Implications. Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, 1-20. <https://doi.org/10.1145/3544548.3581306>
- Richter, S., & Richter, A. (2023). What is novel about the Metaverse? International Journal of Information Management, 73, 102684. <https://doi.org/10.1016/j.ijinfomgt.2023.102684>
- Shahab, S. (2022). Transaction Costs in Planning Literature: A Systematic Review. Journal of Planning Literature, 37(3), 403-414. <https://doi.org/10.1177/08854122211062085>
- Szczerbowski, J. J. (2018). Transaction costs of blockchain smart contracts. Law and forensic science, 16(2), 1-6.
- Vatiero, M. (2022). Smart contracts vs incomplete contracts: A transaction cost economics viewpoint. Computer Law & Security Review, 46(1), 105710. <https://doi.org/10.1016/j.clsr.2022.105710>
- Vo, K. T., Nguyen-Thi, A. T., & Nguyen-Hoang, T. A. (2021). Building Sustainable Food Supply Chain Management System Based On Hyperledger Fabric Blockchain. International Conference on Advanced Computing and Applications (ACOMP), 15(1), 9-16. <https://doi.org/10.1109/ACOMP53746.2021.00008>
- Wang, F.-Y., Qin, R., Wang, X., & Hu, B. (2022). Metasocieties in metaverse: Metaeconomics and metamanagement for metaenterprises and metacities. IEEE Transactions on Computational Social Systems, 9(1), 2-7. <https://doi.org/10.1109/TCSS.2022.3145165>
- Williamson, O. E. (1981). The economics of organization: The transaction cost approach. American journal of sociology, 87(3), 548-577.
- Williamson, O. E. (1983). Credible commitments: Using hostages to support exchange. The American economic review, 73(4), 519-540.
- Yang, Q., Zhao, Y., Huang, H., Xiong, Z., Kang, J., & Zheng, Z. (2022). Fusing blockchain and AI with metaverse: A survey. IEEE Open Journal of the Computer Society, 3, 122-136. <https://doi.org/10.48550/arXiv.2201.03201>
- Zheng, Z., Xie, S., Dai, H.-N., Chen, W., Chen, X., Weng, J., & Imran, M. (2020). An overview on smart contracts: Challenges, advances and platforms. Future Generation Computer Systems, 105, 475-491. <https://doi.org/10.1016/j.future.2019.12.019>