Examining the Effect of Self-selection Bias on Consumer Satisfaction: A Product Type Perspective

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From Block to TOE: Analyzing Opportunities of Blockchain Technologies in the Automotive Industry

Completed Research Paper

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Abstract

Through the lens of the technology-organization-environment framework, this study aims to identify the relevant influencing factors and future opportunities for blockchain technology (BCT) adoption in the automotive industry. By applying an exploratory qualitative empirical study with semi-structured interviews with blockchain experts from the German automotive industry, a revised TOE framework is proposed in this context, confirming previous findings while also incorporating the newly discovered contextual factors of education & skills and sustainability. The analysis of a subsequent quantitative study reveals that while all factors affect BCT adoption, not all context factors have an equally strong impact. The most emphasized emerging BCT opportunities are autonomous driving, decentralized network, digital identity management, and traceability of the supply chain. The findings of this study provide guidance to organizations, politicians, consultants, and managers for defining strategies that aid in the successful adoption and value creation of BCT applications.

Keywords: Blockchain technology, Technology-Organization-Environment framework, automotive industry

Introduction

Blockchain first gained notoriety through a white paper published over ten years ago by Nakamoto (2008). According to market researchers the global blockchain market should reach $67 billion by 2026 from $4 billion in 2021 (MarketsandMarkets, 2021). Blockchain can be defined as “a shared, distributed ledger that facilitates the process of recording transactions and tracking assets” in a network (Gupta, 2017, p.3). While interest initially focused on cryptocurrencies, the reinvention of smart contracts triggered a turning point; they enabled applications beyond the financial industry. In particular, scholars and practitioners highlight the benefits of cost reduction, process simplification, security and integrity of blockchain enabled applications (Helo and Hao, 2019). Despite the expected advantages and testing of initial pilot projects, few projects have been implemented on a large scale. Little is known empirically about the factors that influence blockchain technologies (BCT) adoption, particularly in specific industries (Orji et al., 2020). With the rise of smart contracts applications, the research on blockchain accelerated from 2014 onwards (Sternberg et al., 2021). Due to the hype of Bitcoin and many cryptocurrencies related applications, finance research on the application of blockchain technologies dominates the current body of literature (De Castro et al., 2020; Suwanposri et al., 2021), followed by logistics (Kouhizadeh et al., 2021; Wong et al., 2019), and healthcare (Agbo et al., 2019; Yoon, 2019). Indeed, a significant body of literature has called for additional industry-specific research (Orji et al., 2020; Clohessy et al., 2020).

Surprisingly, BCT in the automotive industry has received little attention in the past regardless of its great importance in the global economy. The automotive industry is one of the most important pillars of the economy in many countries, especially in Germany (Puls and Fritsch, 2020). Since the automotive industry is affecting a wide range of business segments and adjacent industries due to its strong connections upstream and downstream adjacent to their value chain, there is a multiplier effect regarding its effects on economic growth and development (OICA, 2022). The focus of the automotive industry has evolved from the production of a vehicle to the overarching topic of mobility (Grebe et al., 2021). Mobility, in turn, plays an important role and is accordingly reflected in the various areas of the United Nations' sustainable development goals (United Nations, 2022). Mobility is in fact a decisive factor for the prosperity of society. However, this prosperity is endangered due to limited resources and the resulting ever-increasing energy prices. Accordingly, research and development in mobility and thus in the automotive industry are imperative. Moreover, hardly any other industry offers such a diverse and broad-based stakeholder landscape as that of the automotive industry (Zhang et al., 2021). These circumstances are constantly giving rise to new business models, solutions for working with or satisfying the demands of stakeholders, and ideas for the mobility of the present and future. This breadth and diversity simultaneously offers and requires a wide range of innovations and the application of innovative technologies, such as the blockchain technology. Despite the strong interest in gaining a competitive advantage, the actual adoption of BCT in the automotive industry has hardly gone beyond pilot projects (Gösele and Sandner, 2019). This lack of adoption, combined with a lack of in-depth empirical research about why this might be the case, motivates this study to explore the relevant BCT factors and emerging opportunities in the German automotive industry. An initial step to explore the automotive industry was taken by Upadhyay et al. (2020) who did a literature review investigating the challenges and opportunities of blockchain adoption for operational excellence in the UK automotive industry based on the technology-organization-environment (TOE) framework. Upadhyay et al. (2020) suggested that future research in the automotive industry is needed. Likewise, Fraga-Lamas and Fernandez-Carames (2016) called in their study about blockchain application in the automotive industry for more studies that identify the challenging factors for BCT adoption in conceptual and empirical approaches. Although prior research examined the effects of TOE-specific factors on blockchain adoption (Cheng et al., 2021; Clohessy and Acton, 2019; Clohessy et al., 2020; Suwanposri et al., 2021; Wong et al., 2019), Malik et al. (2021) made the first step to extend the model to include BCT-specific factors such as disintermediation and transparency. In particular, this study aims to build on the research of Malik et al. (2021) and Upadhyay et al. (2020) to apply BCT-specific factors in the automotive industry. Hence, the following research questions are pivotal to close the gap in the existing research:

RQ1: *What are the technological, organizational, and environmental context factors for adopting BCT in the automotive industry?*

RQ2: *What are the opportunities of BCT adoption in the automotive industry?*

This work applies the TOE framework to theorize which factors impact the successful adoption of blockchain in the automotive industry. Novel insights are provided by making the first attempt to rank the individual factors according to their impact and identify additional factors. Further, utilizing an exploratory qualitative approach allows to gain a deeper understanding of this nascent technology. In particular, this study analyzes the context factors through the TOE framework lens with semi-structured interviews with blockchain experts from the German automotive industry. Rather than focusing on technical specifications, this study examines the influence of the environment on possible use cases that determine the adoption decision. In order to evaluate the level of impact of the identified factors influencing BCT adoption, a subsequent quantitative study with 30 additional experts is undertaken. The article is organized as follows. The first section gives an overview of the underlying theoretical basics and introduces the empirical research done in this field. The following section introduces the methodology the study revolves around. This is followed by the analysis of the results and implications for theory and practice. The study terminates with concluding remarks.

Technology-Organization-Environment Framework

Most papers have drawn for their research on the adoption of new technologies on the TOE framework developed by Tornatzky and Fleischer (1990) (Rogers, 2003). Recently, however, the TOE framework has also been recognized as a reliable framework for research on blockchain technology related contexts, adapting criteria and terminology to fit the relevant backgrounds (Clohessy and Acton, 2019; Holotiuk and Moormann, 2018; Holotiuk et al., 2018; Kouhizadeh et al., 2021; Malik et al., 2021; Suwanposri et al., 2021; Wong et al., 2019). Likewise, Zhu and Kraemer (2005) confirmed that the TOE framework is suitable for analyzing technological innovations with an uncertain future status, which fits the current notion of BCT. Therefore, the TOE framework is used to underpin this study's research. The TOE framework considers three contextual elements that have an impact on the adoption and implementation of new technologies in organizations, namely, the technology context, the organization context, and the environment context (Tornatzky and Fleischer, 1990). First, the technology context alludes to the internal and external availability of technologies to the organization and it includes characteristics of technologies such as compatibility, relative advantage, and complexity (Grover, 2007; Holotiuk and Moormann, 2018; Ramdani et al., 2009; Wang et al., 2016). For example, complexity is described as "the degree to which an innovation is perceived as [...] difficult to understand and use" (Rogers, 2003, p.15). According to Grover (2007), lower perceived complexity of new technologies is correlated to a higher likelihood of successful implementation in the organization. Second, the organization context refers to features and resources of an organization such as size, communication processes, and linking structures between employees and slack (Tornatzky and Fleischer, 1990). While lateral communication processes and top management support have proven to foster technology adoption, scholars have not found unambiguous evidence for the influence of slack and organization size (Baker, 2011; Oliveira et al., 2014; Ramdani et al., 2009; Tornatzky and Fleischer, 1990). For example, Zhu and Kraemer (2005) claimed that larger firms were more likely to adopt a new technology due to the ability to absorb more risk and having a higher flexibility. Third, the environment context comprises industry and market structure, competitive pressure, the presence of technology support providers, and the regulatory environment (Tornatzky and Fleischer, 1990). With regard to regularities, it is argued that governments can, for instance, support new technologies by providing tax advantages but can also make the adoption of a new technology less attractive through data security constraints or stringent safety and testing requirements (Baker, 2011). The TOE framework is depicted in Figure 1.

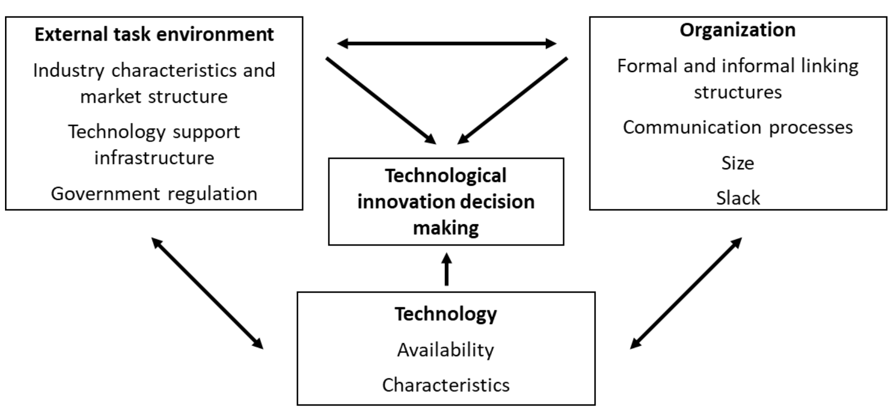

Figure 1. Technology-organization-environment (TOE) framework (Tornatzky and Fleischer, 1990)

BCT adoption based on the TOE framework has been studied in various directions, including finance (De Castro et al., 2020; Suwanposri et al., 2021), sustainable supply chain management (Kouhizadeh et al., 2021; Wong et al., 2019), the architecture, engineering, and construction (AEC) industry (Cheng et al., 2021), and general adoption (Clohessy and Acton, 2019; Malik et al., 2021). De Castro et al. (2020) found in their study among asset and wealth management companies in South Africa that the relative advantages, complexity, supportive technological environment, characteristics of the industry, and regulations were the most critical factors driving the organizational adoption of BCT. Similarly, Cheng et al. (2021) pointed out in their study about BCT in AEC industries that a perceived high complexity of BCT negatively impacts blockchain adoption. Additionally, privacy, security, scalability and transparency occurred as challenging technological factors for BTC adoption. However, in line with Baker (2011), they demonstrated that the support of senior leaders and enhanced flexibility facilitates BCT adoption. Moreover, Suwanposri et al.'s (2021) qualitative study of finance and supply chain companies in Thailand extended Baker's (2011) findings; indicating for future studies to include factors in the TOE framework such as operational efficiency (technology context), stakeholder involvement (environment context) and appropriate application (organization context). In addition, while an organization may benefit from BCT application through, e.g., increased transparency, Suwanposri et al. (2021) found that it is crucial to examine beforehand whether the task is suitable for BCT application. However, their study is limited in terms of the experimental design; conducted only in large companies, the results might not be generalized to other companies. Notwithstanding, their results clearly confirmed their drawn hypotheses that the TOE framework needs to be expanded to research BCT. Clohessy and Acton (2019) found evidence that top management support is the most important factor for successful BTC adoption, and the lack of it poses a tremendous challenge to adoption in an organization. On the contrary, surprisingly, Wong et al. (2019) observed no significant influence of top management support for the likelihood to implement BCT successfully. Wong et al. (2019) proposed as an explanation for this contradicting result a possible lack of awareness about the potential benefits of BCT at the management level. Malik et al. (2021) further extended the TOE framework to fit the BCT context. In their quantitative study among Australian companies, they identified additional factors essential for BCT adoption: perceived information transparency, perceived disintermediation, organizational innovativeness, and standards uncertainty. A similar conclusion was drawn by O'Dair and Beaven (2017) who discovered information transparency and perceived disintermediation as important factors for successful BCT adoption. This was contradicted by Montecchi et al. (2019), who indicated that full transparency may not be desired by all stakeholders along a supply chain.

To summarize (Table 1), a growing body of literature is exploring the BCT application from the lens of the TOE framework, however there is a gap in research for the automotive industry and its unique characteristics, therefore the following research question is proposed:

RQ1: *What are the technological, organizational, and environmental context factors for adopting BCT in the automotive industry?*

TOE Context	Research Factors	Sources
Technology context	Complexity, disintermediation, external availability, IT compatibility, internal availability, operational efficiency, relative advantage, security, scalability, transparency	Baker, 2011; Cheng et al., 2021; De Castro et al., 2020; Grover, 2007; Holotiuk and Moorman, 2018; Malik et al., 2021; Ramdani et al., 2009; Suwanposri et al., 2021; Thong, 1999; Tornatzky and Fleischer, 1990
Organization context	Communication processes, linking structures between employees, organization innovativeness, size, slack, top management knowledge, top management support	Baker, 2011; Cheng et al., 2021; Clohessy and Acton, 2019; De Castro et al., 2020; Malik et al., 2021; Ramdani et al., 2009; Suwanposri et al., 2021; Tornatzky and Fleischer, 1990; Wong et al., 2019; Zhu and Kraemer, 2005
Environment context	Competive pressure, industry structure, market structure, presence of technology, regulatory, standardization, support proivders	Baker, 2011; Cheng et al., 2021; De Castro et al., 2020; Malik et al., 2021; Ramdani et al., 2009; Suwanposri et al., 2021; Tornatzky and Fleischer, 1990

Table 1. Factors that influence BCT application based on TOE framework drawn from previous literature

Blockchain Technology in the Automotive Industry

BCT's main advantages are decentralization, cryptographic security, transparency, and immutability (Attaran and Gunasekaran, 2019). The automotive industry is facing radical changes not only due to the development of electric actuators and autonomous driving, but new business models such as car-sharing and ridesharing will have a long-term impact (Winkelhake, 2017). In addition, the demand for more sustainable solutions is also increasing, and scandals such as the Dieselgate are bringing the supply chain and car production to the public's attention (Kamble et al., 2021). BCT has the potential to support automotive manufacturers with tackling these challenges and create competitive advantages for them. Having noticed the successful pilots in other industries, automotive manufacturers soon started to set up their own BCT focused teams, for example, Daimler has set up a team called “Blockchain Factory” to work on mobility solutions based on BCT, and BMW established a team concentrating on distributed ledger and emerging technologies (BMW, 2019; Daimler Mobility AG, n.d.). Consider the used car market, where the price of the car is based on many factors, like current odometer value, age, number of accidents, and more, which are usually not easy for buyers to verify (Chen et al., 2020). What is more, according to Daimler Mobility AG (n.d.), more than 33% of odometers have been tampered within the German car market, adding to buyers' distrust. Consequently, traceability and tamper-proof registration of the information stored in the blockchain could mitigate the trust issues and improve the buying experience (Chen et al., 2020; Daimler Mobility AG, n.d.). Therefore, Daimler is currently working on an application called smartVIN, aiming to store all important information along the car life cycle in blockchain (Daimler Mobility AG, n.d.). Similarly, Bosch proposed a digital logbook based on BCT, in which the vehicle regularly transmits the mileage to the logbook, providing reliable certification for subsequent sales (Bosch, 2017). Of course, one of the biggest OEMs (Original Equipment Manufacturer) in the automotive industry, BMW, followed suit and introduced a pilot for an own BCT based app that could hold all essential car information (BMW, 2019). Automotive manufacturers are facing lower sales numbers with the rise of business models like car and ride sharing. Therefore, new business models have to be explored (Winkelhake, 2017). The leading automotive supplier Continental has introduced a blockchain-based data trading platform to gain easier and legally compliant access to data. In exchange to the data collected by the vehicle, the customer, who agrees on supplying the data, can receive a virtual token based on BCT, which can be exchanged for rewards at the car manufacturer or money (Continental, 2019). This way, companies can utilize the gained data to improve their current systems and implement new data-driven business models such as analytics-as-a-service (Hartmann et al., 2016). Moreover, enabling easier data exchange is a key driver for improved safety and comfort, for example, real-time traffic information (Continental, 2019). Furthermore, the potential for the supply chain which has been evaluated above, also applies to the automotive industry. Traditionally, the automotive industry uses technologies such as RFID to manage the supply chain; however, the application of blockchain would take this further and create end-to-end transparency, informing all involved stakeholders quickly and with confidence (Winkelhake, 2017). This leads to one of the biggest opportunities for electric vehicle manufacturers: the sustainable production of high-voltage batteries. With the rise of electric cars and following scandals about child labour in cobalt mines, people criticized especially the origin of this material. Volvo was the first car manufacturer to tackle this problem by using BCT to ensure and showcase a sustainable supply chain of their products (Volvo, 2019). Volvo (2019) collaborated with the technology companies Circulor and Oracle and their high-voltage battery suppliers to enforce a private BCT based system that tracks 100% of the supply chain.

Moreover, a tamper-proof system based on BCT decreases fraud and counterfeit risks for component production (Dujak and Sajter, 2019). More recent evidence by Kamble et al. (2021) indicated that BCT can improve relationships with suppliers, increase the quality of products and thus, strengthen the whole supply chain. A limitation with these results, however, is that only top manager were approached for their opinion, which narrows the scope of knowledge. In addition, Fraga-Lamas and Fernandez-Carames (2016) cited operational efficiency and resilience as other strengths of BCT in the automotive supply chain: eliminating intermediaries can simplify transactions and reduce costs. Similar to findings for other industries, Supranee and Rotchanakitumnuai (2017) pointed out that the acceptance of BCT in the automotive industry is dependent on the perceived benefit and interorganizational trust within the organization. A growing body of literature has examined potential use cases of financial payment solutions in the automotive industry (Gösele and Sander, 2019; Winkelhake, 2017; Zivic, 2020). Zivic (2020) proposed to utilize smart contracts to simplify the payment of monthly rates when financing, leasing or insuring a car. Every month the smart contract enforces itself automatically and transfers the payment from the buyer’s account to the seller’s account until the car price has been paid or indefinitely until the insurance contract is terminated. Smart contracts have the potential to reduce personnel costs for the administration of payments and therefore, make the process more efficient. However, smart contracts are limited to what has been considered in the technical implementation, therefore, human intervention might be needed in case of unforeseen scenarios (Zivic, 2020). Likewise, Gösele and Sander (2019) described a suggestion for a usage-based car insurance solution in their research. Not only automatically enforcing payments via smart contract, but offering tariffs based on individual driving behavior like travel frequency, average speed, which would enable a entirely new business model based on BCT. In addition, they acknowledged the idea, that the car could lock itself automatically, if the smart contract is not able to debit the payment from the buyer's account, limiting the amount of insurance fraud.

Furthermore, due to increasing environmental concerns, changing living situations (e.g., less space for a vehicle due to urbanization), and more open mindsets due to globalization, the desire for private ownership is decreasing and the demand for ride and car-sharing solutions rises (Richter et al., 2017). Dorri et al. (2017) discussed the application of BCT in ride and car sharing and found that transparency and increased data security through the decentralized system can improve the user experience. Being able to conduct business in a secure manner without a middle man, also lowers costs and increases trust. Vazquez and Landa-Silva (2021) extended the research of Dorri et al. (2017) and conducted a pilot on Ethereum in an empirical study to test the feasibility of BCT. With the use of smart contracts and IoT, Vazquez and Landa-Silva (2021) ensured that the payment is automatically transferred from the passenger's account to the driver's account when the selected journey has been completed. The successful implementation also requires the use of a phone with GPS technology (e.g., to track the traveled distance) and internet connection. While research has tended to focus on the application of BCT for corporate companies, Rosado et al. (2019) demonstrate use cases for government services. Rosado et al. (2019) focused on car registration, e.g., when first registering a vehicle or changing ownership. Traditionally, these transactions must be done in person at the authority for each change and are often associated with long waiting times and slow processes. Introducing BCT to this process would enable the new car owner to request an ownership change via an app, which is then verified from the current owner. The national authority would only need to intervene in case of complications (Bossauer et al., 2018). Implementing a private blockchain is proposed, where the national authority can keep control over the transactions and participants and ensure privacy and confidentiality. However, the car owner or manufacturer still needs to initiate the process; a completely automatic procedure is not feasible yet. The main advantages are more efficient and faster processes and improved data availability and interoperability between states (Rosado et al., 2019).

In conclusion, while many technical applications and pilot projects are explored, there is a lack of empirically validated literature addressing the opportunities that arise from potential broad range solutions that can be suitable for day-to-day application in the automotive industry. Consequently, the following research question is derived from this gap.

RQ2: *What are the opportunities of BCT adoption in the automotive industry?*

Methodology

Given the novelty of BCT, the current lack of knowledge of a large mass, and the open research questions, a qualitative research approach as a first step is most suitable for this study (Surjandy et al., 2020). Mayring (2015) and Kuckartz (2014) demonstrate that meaningful results for qualitative methods can be produced through a content analysis that is systematic, rule-based, and theory-driven. Consequently, an exploratory qualitative approach which will be evaluated through a content analysis has been chosen for this study. Moreover, to be able to adequately depict the different applications and impact factors of BCT, expert interviews were conducted. The motivation to choose semi-structured in-depth interviews was to give the interviewees the opportunity to formulate their answers in their own words instead of providing limited standardized answers and to be able to develop new questions or elaborate on additional topics during the interview to acquire a broader range of expert knowledge (Longhurst, 2010).

For the interview guideline, categories were formed deductively from the theoretical foundation, the TOE framework, the literature review, and the research questions. In addition, the "SPSS principle" proposed by Helfferich (2009, p.182) was applied to create the interview guideline. The advantage of guideline-based interviews is their flexibility. The questions do not have to be worked through rigorously, but provide scope for finding out other relevant aspects that could be useful for the research subject that is investigated (Helfferich, 2009). All interviews were taking place between November and December 2021 in virtual sessions via Microsoft Teams. Every interview was audio recorded and later transcribed. Moreover, the interviews were conducted in German or English language. The interviews lasted from 29 to 49 minutes with an average length of 39 minutes. Additionally, no financial or material incentives were offered, other than gaining insight into the research subject. Subsequently, a content-structuring content analysis was applied to evaluate the expert interviews. According to Kuckartz (2014), a content-structuring content analysis is recommended, if a relatively little researched topic is approached. Therefore, this study applied the seven-step process proposed by Kuckartz (2014). In the center of the content analysis is the category system, which can be formed inductively as well as deductively.

In order to verify the results of the interviews and test the factors impacting BCT adoption derived from the interviews, a quantitative survey was subsequently conducted among additional 30 experts. These experts were recruited using our professional network. At the beginning of the survey, three questions were asked about BCT, which the participants had to answer correctly in order to continue with the survey, thus verifying their expert status. Subsequently, the experts were asked to evaluate the level of influence of the factors ranging from low over medium to high impact on BCT adoption in the automotive industry. These results are combined with the derived factors within the underlying TOE framework indicating the level of impact of each factor.

Interview Guideline

For the underlying research questions of the study, it is appropriate to conduct independent guided interviews. This term is used in literature to describe a qualitative data collection instrument that is conducted with the help of a previously structured interview guideline (Helfferich, 2009). The interview guideline can be used for all interviews in order to present a comparative view of all. The guideline consists of pre-formulated questions and elements of the narrative prompt and can be structured in a differentiated way depending on the research field (Kuckartz and Rädiker, 2019). The interview guideline for this study was created based on two methods, first, Helfferich's (2009) SPSS principle and second, deductive categories. First, this study followed the guideline of Helfferich (2009, p.182), who recommends the "SPSS principle" for the creation of interview guidelines, including four work steps: (1) Collect, (2) Examine, (3) Sort and (4) Subsume. In the first step ("collect"), as many relevant questions as possible about the BCT topic were collected by brainstorming. The focus should be on creating a broad catalogue of questions without considering relevance yet. In the second step, ("examine") the collected questions were checked for content relevance and question type, e.g., closed questions, purely factual questions or suggestive questions were excluded. After a number of appropriate questions have been found, the order of the questions is considered in the third step ("sort"). Here, a sequence was created that links related content and ensures a natural flow for the interview. Finally, in the last step ("subsume"), the questions were subsumed into large blocks of questions.

Second, to develop the guideline, deductive categories were formed from the existing material. As a starting point, the research question was broken down into its components and essential aspects and concepts were filtered out. Similarly, the theoretical basis, the TOE framework, was used to derive additional categories. Finally, the literature review serves as a source for deriving and defining further categories. Consequently, both methods were combined to obtain an optimal result. The guideline is divided into five topic blocks with different numbers of questions and sub-questions. The open guideline, which invites communication, gives both questioner and interviewee flexibility. The sequence of questions can be adapted throughout the interview, for instance to gather more detail for a particular topic block. Compared to standardized surveys, the guided interview offers the advantage to provide additional information on the research subject (Bogner et al., 2014). Furthermore, prior to the first interview, a pilot interview with one person was conducted to test the quality of the interview regarding possible misunderstandings or shortcomings. However, no adaptions to the interview guideline were necessary. The developed guideline was sent to the interview partners in advance if they requested it. In all interviews, the interviewer disclosed the interview's reason and topic to the experts. In addition, consent was obtained to record and use the interview for this study.

Sampling

Expert sampling, a form of purposive sampling, has been established in qualitative research as an effective method for gathering detailed knowledge about a research topic (Patton, 2014). Expert sampling was chosen as the form of sampling because it allows the researcher to gain an in-depth understanding (Bogner et al., 2014). However, the attribution of expert knowledge is not an individual property; instead, it takes place through attribution. The attribution occurs when the researcher samples the experts, and it is reinforced during the interview by encouraging interviewees to present themselves as experts (Bogner et al., 2014). According to Patton (2014), sampling aims to obtain a group of individuals that resemble each other in terms of specific characteristic values. However, to ensure diversity, the interview partners should come from different companies and organizational forms (Mayring, 2002).

The first step in sampling was to use a literature review to become familiar with the topic and identify relevant criteria (Bogner et al., 2014). For this study, it was crucial that the interviewees were familiar with blockchain on the one hand and that they worked in the automotive industry or had a connection to the automotive industry on the other. Regarding sample size, Helfferich (2011) attests that a minimum number of six interviewees is sufficient, considering resource-limiting constraints. The second step consisted of searching the platform Linkedin with relevant keywords such as "blockchain", "automotive AND blockchain", and "OEM AND blockchain" to identify potential experts. Given the broad topic this study explores, it was important to include experts with different backgrounds who focus on different BCT applications and have different experience levels. Therefore, a thorough review of Linkedin profiles was conducted to determine that the selected individuals fit the search criteria. As a result, 24 experts were approached via message or email and were invited for an interview. Finally, five experts were recruited for an interview. Additionally, the snowball sampling method was applied, meaning that interviewees were asked for potential other interviewees at the end of an interview. Through this method, another additional interviewee was approached and interviewed. The final sample consisted of six experts from various backgrounds and companies. Importantly, it was possible to recruit experts from different types of organizations - from start-ups to large corporations - and different BCT application areas. Table 2 provides an overview of the sample along with their role in the organization, organization size, and automotive sector the individual is active in. Due to internal communication policies, the names of the organizations will not be published or used throughout this study.

Interview ID	Current role in the organization	Organization size	Organization focus	Perceived blockchain knowledge
1	Freelancing as special advisor for Digital Markets & AI for the European Parliament	-	Governance	High
2	Researcher	Large, 100.000 – 300.000 employees	Manufacturing	High
3	Head of Digital Energy Management	Large, 100.000 – 300.000 employees	Manufacturing	High
4	CEO	Small, 1 – 100 employees	Information Technology & Services	High
5	Platform Owner	Large, 100.000 – 300.000 employees	Manufacturing	High
6	Platform Owner	Large, 100.000 – 300.000 employees	Manufacturing	High

Table 2. Descriptive overview of the interviewees

Qualitative Content Analysis

Qualitative content analysis is an evaluation method used to analyze text-based data. The seven step procedure of Kuckartz (2014) has been experiencing an increase in popularity and is also applied in this study for two reasons: First, the more open approach allows for a more flexible procedure and evaluation of the data, which can lead to obtaining additional information and to discover new themes. Second, the approach supports the use of CAQDAS software, e.g., MAXQDA, which allows to identify thematic connections and provides visualization options. First of all, all interviews were transcribed in the languages in which they were collected. The transcription in the source language is a prerequisite for disclosing the subsequent placement and transfer services. This was followed by the translation into English if the interview has not been conducted in English. In order to ensure validity of the translation, a native speaker controlled the accuracy of the translation and made adaptions if necessary. The transcription followed the fifteen widely recognized rules of Dresing and Pehl (2015); for example, it was transcribed literally, e.g., not phonetically or summarized. Next, the seven-step process of Kuckartz (2014) was applied. Initially, all interviews were read through carefully and any special remarks were made in the margins. In the following step, the main categories were derived, inductively as well as deductively. While the categories already formed for the interview guideline can be used for deductive categories, further categories were obtained from the interview material, which is referred to as the inductive approach, which were then also used for the category building during the content analysis (Kaiser, 2014; Kuckartz and Rädiker, 2019).

Category	Creation	Definition	Anchor example	Coding rule
Complexity	Deductive	Includes all statements related to the perception of dificulty in understanding and using blockchain.	"If you go down to the core element of blockchain, it's actually not complex. But there are some big changes in terms of coding and security and error-proneness and immutability, which are new and where experts are needed." (I5, 2021, pos. 16)	Statements that go beyond technological complexity of blockchain are also included.
Disintermediation	Deductive	Includes all statements that highlight any references according to the enabled disintermediation through blockchain adoption.	"Difficult. (...) In many use cases, you often end up needing a superuser who mediates or manages, and that then contradicts the disintermediation that is actually intended. Likewise, the system depends on who set it up and who programmed the sy"tem" (I6, 2021, pos. 16)	
Education and Skills	Inductive	Includes all statements that highlight any references to the education or skill set of employees working with blockchain.	"Also, always the question, how many blockchain experts do have in your company? There are few people who are really very proficient with it, and that problem should be addressed even further." (I6, 2021, pos. 10)	Statements that address all education-related issues such as the development of expertise, the availability of personnel, and existing skills.
IT Compatibility	Deductive	Includes all statements that refer to the existing IT infrastructure in an organization.	"Well, first of all, that there are already many processes for many systems in the automotive industry, there are also already long-existing systems and you would then have to make immigrations to the systems, where the question is then whether it pays off."" (I5, 2021, pos. 14)	
Maturity	Deductive	Includes all statements that refer to the maturity of blockchain technology.	"Second point that directly follows is technology maturity. It has to be so easy to use that someone without deeper technological knowledge, can operate the blockchain based solution." (I3, 2021, pos. 10)	Highlighting statements that refer to the direct impact of blockchain maturity.
Regulatory	Deductive	Includes all statements that refer to the regulatory about blockchain	"And when it comes to regulation, you have to be sure that the technology can really be used, that it won't simply be abolished or banned." (I2, 2021, pos. 14)	Statements that address all legal issues, including the impact of the Ministry's personnel.

Table 3. Extract from the deductively and inductively formed category system

In inductive category formation, categories are extracted from the collected literature material. Consequently, for topics that were identified as novel in step two, an additional category was created. Subsequently, the entire text material was worked through line by line and thematically fitting lines were assigned to the categories. As a guiding rule for the length of the coded line, Kuckartz (2014) recommends to choose a length that allows the meaning to still be understood out of context. The next steps involve merging the coded text segments and differentiating the main categories. This involves assigning new subcategories to the main categories if necessary. MAXQDA software was used for category building and subsequent coding. A category definition must contain at least the name of the category and a description of its content. In addition, concrete anchor examples from the data and coding rules such as delimitations to neighboring categories can be included (Kuckartz, 2014). In the next step, the entire interview material is again analyzed and coded with the help of the differentiated main and subcategories. Table 3 subsumes an extract of the final category system as well as the specific anchor examples and coding rules. The last phase of the qualitative content analysis, phase seven, presentation and analysis of results, is presented in the results section.

Analysis of Results and Discussion

First, it was discovered that all context factors have an impact on BCT adoption. However, not all of them are equally strong in their impact on adoption. Figure 2 presents the revised model of the TOE framework across the three dimensions technology, organization, and environment, the associated levels of impact ranging from low to high impact and the identified opportunities emerging from BCT adoption.

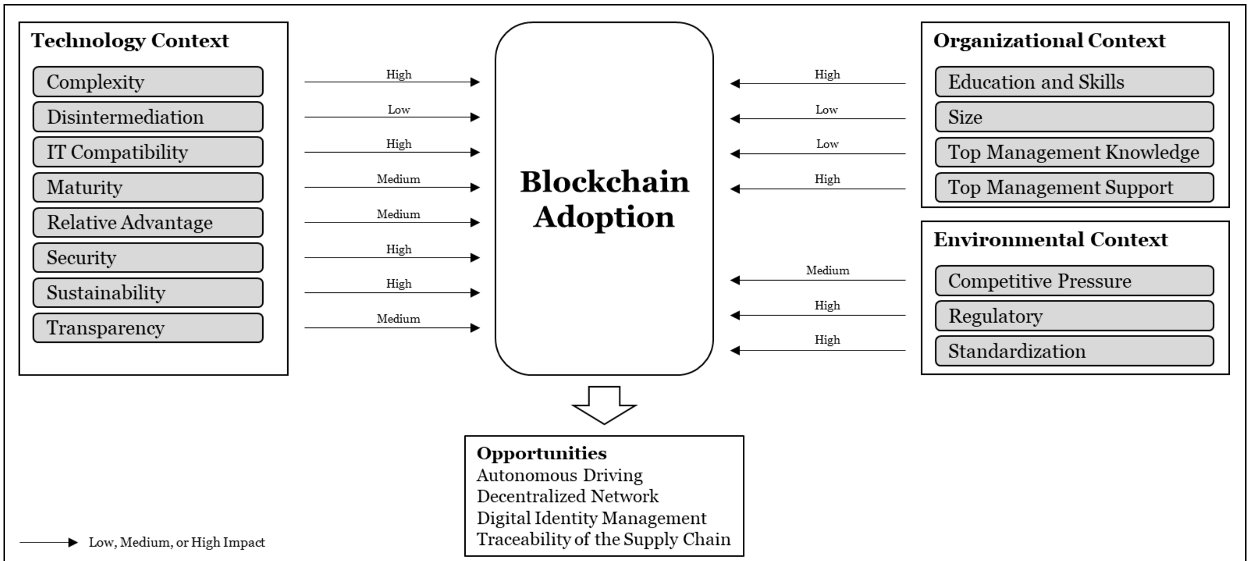

Figure 2. Revised TOE framework and the emerging opportunities from BCT adoption

Already in the interviews, it became apparent that some factors have a higher impact on blockchain adoption than others. Accordingly, a subsequent quantitative survey was conducted among BCT experts in the automotive industry to verify the model derived and to assess the importance of the factors in terms of their influence on BCT adoption. Following the work of Al Hadwera et al (2021), the surveyed experts were asked to categorize the impact of the respective factors on BCT adoption into low, medium, and high impact. The factors were assigned the impact level, which was indicated by the majority of the experts in each case. This work is the first to cluster the factors within the TOE framework according to their impact to symbolize the importance of the factors and dimensions.

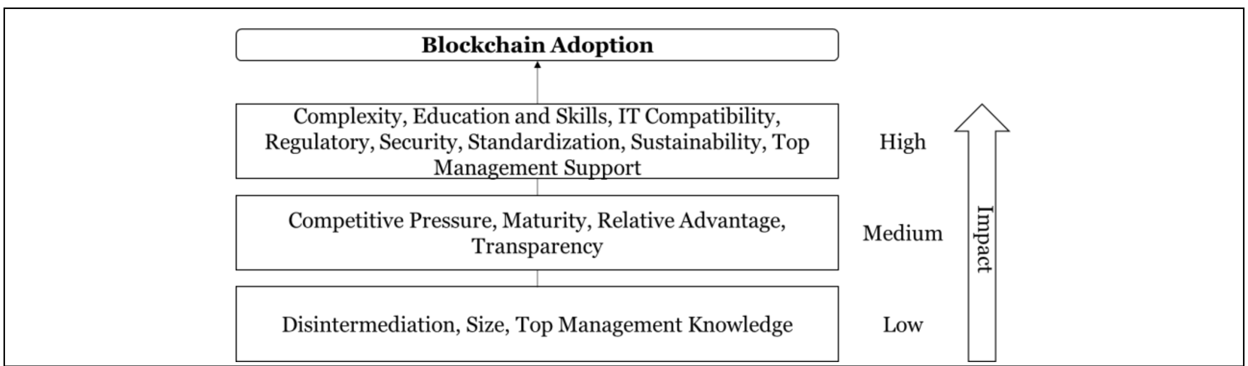

Figure 3. Context factors clustered according to their level of impact

In the high impact cluster (Figure 3), complexity, education and skills, IT compatibility, regulatory, security, standardization, sustainability, and top management support were considered as pivotal factors for BCT adoption. For instance, current research has mostly found that top management support is vital for blockchain adoption (Baker, 2011; Cheng et al., 2021; Clohessy and Acton, 2019; De Castro et al., 2020; Malik et al., 2021; Oliveira et al., 2014). This study supports and extends this finding by connecting it with the recurrent theme of a positive business case calculation. Interviewees stated that the top management will always make resources available as long as the business case outcome is profitable. This is in line with Holotiuk et al. (2018), who asserted the importance of proven cases for blockchain adoption in the financial sector. However, this study revealed that this is something that blockchain is lacking in at the moment. Difficulties in cost calculation, uncertainties in regulations and technology standardization make it hard to calculate the business case and, therefore, challenging to receive top management support. As a consequence, a slowdown of BCT projects in the automotive industry in the past year, compared to 2019, occurred. To conclude, top management is a high impact driver for blockchain adoption through the provision of the required resources. Furthermore, BCT enabled security offers an important benefit for organizations and is therefore regarded as very impactful for BCT adoption. The automotive industry deals with many applications that require high security, a trend that will be increasing with next level autonomous driving in the future. Therefore, evaluating the security of a technology like BCT is highly important. This finding has been consistently found in the literature (Cheng et al., 2021; Kouhizadeh et al., 2021; Suwanposri et al., 2021; Wong et al., 2019) demonstrating that the BCT enabled security is a compelling enabler for the adoption of BCT. This study's findings on security provide an underlying reason for this.

With respect to complexity, the empirical study's results support the findings of previous work from Cheng et al. (2021), Cohessy and Acton (2019) and Malik et al. (2021), that complexity strongly impacts blockchain adoption. Nevertheless, the automotive industry is operating with highly complex technologies, such as autonomous driving and as long as a value is seen, complexity might not be a barrier to adoption but does play a role. Interestingly, through perceived complexity another novel context factor emerged: Education and skills. The reasons for the high importance of education and skills are twofold: First, the perceived complexity of BCT depends on the skills of the employees who work with it. Therefore, organizations that actively seek to train their employees and build technology competence are more likely to adopt blockchain. Second, the employment of qualified internal employees compared to expensive external sourcing lowers the costs of BCT projects. This finding agrees with Holotiuk and Moormann (2018), who noted that lower project costs are an important factor for the adoption of new technologies.

Another newly discovered theme was the sustainability of the technology, which has not yet received any attention in the TOE literature but has a high impact on the consideration of adoption nowadays. Today, technologies are measured not only by their technical performance, but also by their impact on the environment (Böhler et al., 2021). The high energy consumption of consensus mechanisms such as PoW is problematic for the automotive industry, which is already struggling with criticism regarding the sustainability of combustion engines. It follows that for future BCT adoption the criterion of sustainability needs to be considered. This finding offers an extension to the existing TOE framework by Tornatzky and Fleischer (1990). IT compatibility, as part of the high impact cluster, of BCT was perceived as a fundamental factor for adoption by all interviewees. Especially in the automotive industry, where many processes already exist and systems are strongly networked, a lot has already been invested in the IT infrastructure. Consequently, new technologies must be compatible with the existing IT infrastructure, which, according to the study's findings, is currently not the case with BCT. Besides, the IT infrastructure extends beyond the organization's own systems; hence, compatibility with suppliers' systems must also be ensured, further complicating BCT adoption. Supporting this, Premkumar (2003) and Wang et al. (2016) find that compatibility of new technologies with existing IT infrastructures is pivotal for the adoption process of organizations. In contrast, Ramdani et al. (2009) found no importance of compatibility in their study of new technology adoption in SMEs. Ramdani et al. (2009, p.20) proposed as an explanation that SMEs have fewer processes in place and, therefore, "do not worry about integrating their applications". On the contrary, this study found that interviewees were somewhat concerned about SMEs and small organizations' ability to integrate BCT to adopt it. It follows that the compatibility of BCT plays a role for the internal IT infrastructure, the internal accounting department and cross-organizational IT infrastructures.

In literature, the prevailing view is that the lack of standardization and regulatory of a technology impedes its adoption in an organization (Baker, 2011; Cheng et al., 2021; Clohessy and Acton, 2019; Malik et al., 2021; Suwanposri et al., 2021). Likewise, all interviewees noted that reaching an agreement on which standard to use for certain BCT processes could significantly advance BCT in the automotive industry. Without a common standard, cross-organizational applications of blockchain in particular are limited. In addition, regulation is closely linked to standardization. In line with this, this study revealed that as long as regulations are not clear or supporting, the automotive industry will be reluctant to further implement BCT on a bigger scale. In particular, regulations like the GDPR (General Data Protection Regulation) require that data can also be deleted again, which in turn contradicts the immutability of BCT and thus, hampers adoption. Additionally, global differences in regulation are a concern for the internationally operating automotive industry. These results allow for generalization within the TOE framework literature, suggesting that both factors are one of the most impactful factors from the automotive industry perspective.

The medium impact cluster consisting of competitive pressure, maturity, relative advantage, and transparency, represent the context factors perceived as important to BCT adoption but not as strongly highlighted as the high impact context factors. Although prior literature suggests BCT maturity is an influential factor (Kouhizadeh et al., 2021), this study shows perceptions to be more mixed. Equally, the relative advantage is important for the question of BCT adoption (Baker, 2011; Kouhizadeh et al., 2021; O'Dair et al., 2016). Still, this study revealed that this factor is also related to the calculation of a business case, which is currently difficult for BCT, and thus only a medium impact was associated with the relative advantage. Further, many scholars acknowledge the strategic necessity of transparency (Cheng et al., 2021; De Castro et al., 2020; Kouhizadeh et al., 2021; Malik et al., 2021; Suwanposri et al., 2021) for BCT adoption. However, interviewees were reluctant to acknowledge the high importance of transparency in the automotive industry. On the one hand, it can be an essential advantage, especially in the supply chain. On the other hand, increased transparency can also expose data to stakeholders that is confidential or relevant for negotiations. Montecchi et al. (2019) already identified that a fully transparent supply chain could be unwanted by some stakeholders. If the somewhat hesitant impact from the present study is taken together with the previous literature results, a medium impact on BCT adoption can be identified. Surprisingly, competitive pressure was clustered in the medium impact group and was perceived as currently less relevant in the automotive industry. This is an important revelation that thereby contradicts previous research of Wong et al. (2020, p.15), Malik et al. (2021) who found that competitive pressure acts as "catalytic force" for blockchain adoption. The reasons for the differing findings can be twofold: On the one hand, BCT can work successfully in contexts where it enables connections between stakeholders, thereby creating a more collaborative than competitive tone (Suwanposri et al., 2021). On the other hand, it also became clear that the hype of 2019 has flattened out and pilot projects have unfortunately shown that blockchain is not the one solution and therefore the impact of competitor activities is lower. Nevertheless, the automotive industry is highly competitive and should a competitor launch an interesting BCT application, the other competitors will definitely consider this as well.

Factors within the low impact cluster have a limited influence on blockchain adoption. The low impact cluster includes disintermediation, size, and top management knowledge. Extending the findings of O'Dair et al. (2016), the results suggest that while a basic knowledge of BCT of top managers is beneficial, a high level of knowledge is not required for successful adoption. One explanation for this is that the complex implementation is typically carried out by skilled employees and not by top management. Further, the TOE framework has been extended to fit the BCT context by incorporating specific BCT related factors like disintermediation (Malik et al., 2021). Yet, disintermediation, as part of the low impact cluster, has been perceived as less relevant for blockchain adoption. While Malik et al. (2021) and O'Dair and Beaven (2017) identified perceived disintermediation as an important driver for BCT adoption, this study's findings suggest that it plays a smaller role in the automotive industry. One possible explanation is that private or consortium blockchains are not decentralized, and thus disintermediation does not occur. Correspondingly, this study's findings discovered that all interviewed organizations applied a private blockchain in their BCT projects. The highly regulated and privacy-oriented environment in the automotive industry requires access control and control of data, which precludes the use of a public blockchain in which anyone can participate. This finding is consistent with Cohessy and Acton (2019), who discovered that all organizations they explored in their study about organizational factors influencing blockchain adoption had applied private blockchains. However, in the context of advanced standardization, blockchain-to-blockchain communication could emerge, enabling a combination of public and private blockchains, which would then also increase the relevance of disintermediation. With respect to size, the study provided empirical evidence that a distinction is necessary in the context of adoption: Interviewees differentiated between pilot projects and overall implementation in terms of the influence of size. While large companies have advantages in setting up pilot projects due to larger resources, the already existing internal, sometimes rigid networks and regulatory requirements make it difficult for them to implement BCT on a large scale. Meanwhile, small companies benefit from their flexibility and loose structures. Therefore, our quantitative study revealed that size rather plays a subordinate role with respect to BCT adoption.

The second research question revolved around the emerging opportunities that arise from blockchain adoption in the automotive industry. While Upadhyay et al. (2020) was the first to explore opportunities and challenges in the UK automotive industry, they applied a more general approach suggesting opportunities like security or immutability; this study provides concrete use cases based on current industry expert knowledge. This study revealed that among the discovered opportunities, the most emphasized were autonomous driving, a decentralized network, digital identity management and traceability of the supply chain. While previous literature often considered the inclusion of BCT in the automotive industry in the context of financial contexts such as payment in ridesharing (Vazquez and Landa-Silva, 2021) or vehicle financing (Gösele and Sandner, 2019; Zivic, 2020), in this study's findings especially autonomous driving and digital identity management were highlighted. Particularly for mobility-as-a-service solutions, digital identity management and a decentralized network can serve as secure way to authenticate users across providers, and in addition, smart contracts limit the potential for errors at this point. These findings fit with Dorri et al. (2017), demonstrating that BCT enabled applications can protect user privacy in high-connectivity situations, such as linking the vehicle to mobile devices, charging stations or smart-home applications. Therefore, the security and immutability through blockchain can be seen as a key element for digital identity management and autonomous driving. Nevertheless, it was evident that these opportunities are yet to be implemented on a large scale. The reasons for this were evaluated in the first research question and include the already very distinctive process landscape in the automotive industry, the lack of a positive business case, limited employee education and skills, regulation uncertainty, and lack of standards, all of which make blockchain implementation difficult.

Contributions to Blockchain in Theory

The original TOE framework, which provides a guideline for adoption factors for new technologies in general, is applied in this study to build a new model that can specifically explain the factors of blockchain adoption in the automotive industry. The model includes factors rooted in earlier research and newly developed factors. This study contributes novel insights into factors influencing blockchain adoption and opportunities that arise from it in the German automotive industry. This is the first study to provide empirical evidence about the context factors and opportunities that impact BCT adoption in the automotive industry based on the TOE framework through a qualitative approach combined with a quantitative verification. Past research has focused predominantly on the financial industry (Suwanposri et al., 2021), logistics (Orji et al., 2020) or the health industry (Yoon, 2019), whereas a limited body of literature on the automotive industry can be found. In addition, previous literature on BCT in the automotive industry has taken a more technological perspective (Chen et al., 2020; Vazquez and Landa-Silva, 2021; Zivic, 2020) while neglecting the factors that lead to blockchain being adopted in the first place, a gap that this study sought to fill. Further, this study expands Upadhyay et al.'s (2020) study, which analyzed adoption factors of BCT in the UK automotive industry through a systematic literature review, by identifying new factors that influence blockchain adoption. In particular, the theme of sustainability and education & skills represent entirely new context factors embedded in the TOE framework. Further, although sustainability and education & skills are at least to some degree related to existing research, this is the first time their importance to BCT adoption has been identified. Additionally, this is the first study to employ a qualitative approach to provide a deeper understanding of the relevant contextual factors and opportunities for the adoption of BCT in the automotive industry. The results support existing literature that explored opportunities emerging through BCT adoption (Fraga-Lamas and Fernandez-Carames, 2016; Kamble et al., 2021; Upadhyay et al., 2020) by providing concrete activities such as digital identity management and autonomous driving that go beyond more general opportunities like improved transparency and disintermediation. This work further contributes to the growing literature around the TOE framework and reveals that the automotive industry has specific characteristics that lead to differences compared to the existing literature on emerging technologies in other industries. For example, competitive pressure, disintermediation, and transparency, that have played a significant role in previous BCT literature (Cheng et al., 2021; Malik et al., 2021; O'Dair and Beaven, 2017; Wang et al., 2016) are currently not perceived as critical BCT adoption drivers in the automotive industry. In contrast, according to the results of our quantitative study, education & skills, complexity, IT compatibility, regulatory, security, standardization, sustainability, and top management support were the most critical factors driving the adoption of BCT in the automotive industry. In addition, the findings are consistent with Malik et al. (2021) that resolving standard uncertainty can accelerate blockchain adoption. Interestingly, like in this study, Sternberg et al. (2021) found that full transparency along the supply chain was viewed critical by involved organizations and did not accelerate adoption.

Implications for Blockchain in Practice

The findings offer strategic insights into how organizations, consultants and managers should organize the structural and cultural environment to increase the likelihood of adopting BCT. This study reveals that the government plays a pivotal role in promoting blockchain adoption in the automotive industry. For the future, the government must provide clear regulatory that defines blockchain elements and the legal standings of, for example, blockchain transactions and smart contracts. Regulations go hand in hand with standardization; BCT standardization must be promoted to create a common basis and interoperability in the automotive industry. Especially in inter-organizational contexts, seamless blockchain-to-blockchain communication must be enabled (Holotiuk et al., 2018). Besides, organizations are reluctant to invest in a technology for which standards do not yet exist, fearing investing in the wrong technology. Therefore, it is essential that the government, technology experts, and organizations together develop industry-wide standards to overcome the uncertainties that hinder the widespread adoption of BCT. Again, the government can enforce this by subsidizing the activities of organizations and allowing them to collaborate without fear of cartel issues. Managers who want to implement blockchain applications in inter- and intra-organizational contexts must consider their own IT infrastructure and the ones of their suppliers, which increases the work and cost effort considerably. In line with this, consulting firms and blockchain-as-a-service providers need to be mindful that offering BCT services only makes sense if suppliers and organizations have the ability and resources to adapt their IT infrastructure to fit BCT. Most importantly, managers must demonstrate a positive business case for the specific blockchain application to justify the extensive changes to existing systems. This finding leads to the recommendation for automotive managers to consider BCT especially for new systems for which there are no existing or comparable processes in the automotive industry yet. While the complexity of BCT is not as critical to the likelihood of adoption as expected, BCT still requires highly skilled BCT experts. Hence, managers should provide further training and education to selected employees to build strong in-house technology competence in German automotive organizations. Consequently, costs for BCT projects would be lower because no external experts would need to be hired. In addition, outside the automotive industry, universities should expand their courses to build essential BCT skills beyond basic knowledge. Finally, the findings imply that digital identity management is currently the most promising BCT opportunity in the automotive industry. The unique and tamper-proof storage of identity-related data through BCT will be essential in the future automotive world, from autonomous driving to in-car shopping. Thus, automotive managers should consider identity related BCT applications when deciding which BCT project to support.

Conclusion

The present work shed light upon the emerging technology blockchain and its application in the automotive industry. In particular, it explored the slow uptake of BCT-based projects through the lens of the TOE framework. By applying an exploratory qualitative and a subsequent quantitative empirical study with blockchain experts from the German automotive industry, this study demonstrated that the three TOE framework contexts, technology, organization and environment, are suitable for a deeper understanding of BCT adoption. In addition, a revised TOE framework was proposed, confirming previous findings while also incorporating the newly discovered contextual factors of education & skills and sustainability. The findings and revised TOE framework serve as a first empirical step in understanding how blockchain opportunities emerge from an industry perspective and how and which context factors influence the adoption of this new technology. Additionally, the findings of the study highlighted that while all factors do impact BCT adoption, not all of the context factors have an equally strong impact on it. The high impact cluster included complexity, education and skills, IT compatibility, regulatory, security, standardization, sustainability, and top management support. While competitive pressure, maturity, relative advantage, and transparency were clustered in the medium impact cluster, the factors top management knowledge, size, and disintermediation were placed in the low impact clusters. Also, the most emphasized emerging BCT opportunities were autonomous driving, decentralized network, digital identity management and traceability of the supply chain. Particularly, digital identity management and autonomous driving were perceived as the most promising BCT based applications in the future for the automotive industry. Overall, BCT will be an important element for targeted applications in the future, but it is not a one-size-fits-all solution, contrary to the hype and expectations. Especially in a traditional industry such as the automotive industry, factors such as IT compatibility, lack of standardization, regulatory uncertainty, and limited education and skills are currently impeding a widespread adoption. Opportunities to exploit the advantages of blockchain, such as security and immutability, arise especially in new applications for which processes are not yet established. The findings of this study provide guidance to organizations, politicians, consultants and managers for defining strategies that aid in the successful adoption and value creation of BCT applications. Future research should build on these findings to enhance its validity and generalizability. BCT adoption is still at an early stage and further quantitative and longitudinal studies are necessary to help interpret the results and provide further explanations.

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