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Blockchain and Its Impacts on Agri-Food Supply Chain Network Management

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Abstract: Blockchain is an emerging meta-technology and considered a new institutional technology with the potential to change the governance of vertically integrated food supply chains. This paper investigates the effects on coordination mechanisms in vertically cooperating agri-food networks that result from the implementation of different blockchain technology platform types (BCTPT). The research is based on an extensive literature overview and exploratory use cases of BCTPT implementations in the agri-food industry which are presented to illustrate the applicability of the findings. Our analysis shows that BCTPT predominantly differentiate through the coordination mechanisms exerting of power, information sharing, decision-making, and collective learning benefits. We also reveal that blockchain use cases with high success rates typically operate in a vertical ecosystem where a focal firm assumes the responsibility for coordinating the activities in the supply chain network. These use cases are typically operationalized in tracking and tracing applications as well as in provenance-based information provision, which either operate in vertically coordinated private blockchain or consortium-type blockchain platforms. We conclude that the choice of a specific BCTPT with its respective coordination mechanisms is a key determinant of the economic success of the intended use case, the efficient management of the supply chain network, and eventually for the chosen digital business model. This paper will close a research gap, as the potential impacts of different blockchain technology platform types on digital agri-food business models and its supply chain management have scarcely been researched.

Keywords: vertical coordination; sustainability; blockchain; supply chain; food industry

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1. Introduction

Food supply networks are organized centrally with a focal firm standing in with its brand to ensure high product standards and product safety. The focal firm therefore assumes responsibility for the coordination of the network [1]. Despite their centralized structure, these networks are increasingly supported by the implementation of blockchain technology (BCT), predominantly for food tracking and tracing as well as providing provenance information [2]. BCT and its applications have already been adopted by several industries, including, but not limited to, agriculture, finance, healthcare, manufacturing, and logistics. BCT, with its decentralized architecture, has the potential to significantly change the supply chain management (SCM) [3]. However, its potential implications for the management of agri-food supply chain networks (SCN) are still under-researched. Although it is obvious that BCT has the potential to impact coordination mechanisms in supply networks, there is only limited research on the effects of BCTs on cooperation and coordination and their potential impact of reducing bounded rationality, opportunism, and information asymmetries, which would increase the efficiency of the supply network.

When building a business case for a BCT implementation, both the economic effects from efficiency gains in the supply chain as well as the total cost of ownership (TCO), which includes, besides the capital expenditures (CAPEX), the operational expenditures

(OPEX), need to be taken into account. While our research focusses on the analysis of the economic effects of BCT in the agri-food supply chain network and draws on use cases of operationalized platforms, we also paid attention to the environmental sustainability of BCTPT. Recent discussions on the increasing energy consumption of BCT need to be taken into account when analyzing the economic effects in the supply chain efficiencies [4]. The cause of the increasing energy consumption is the inefficient proof-of-work (POW) consensus algorithm resulting from the processor-intense Bitcoin mining process which is taking place in the blockchain network. A single transaction in the Bitcoin blockchain currently accounts for nearly 668 kWh, the energy that an average US household consumes in appr. 23 days [5]. There are ongoing discussions about the environmental sustainability of blockchain technology resulting from the POW algorithm [6–8]. Operating a BCTPT can result in significant OPEX when bound to an inefficient consensus algorithm. Besides the economic effects, we also address the sustainability effect of several other blockchain consensus algorithms which can be utilized alternatively to POW.

Despite the lack of research on the effective application of the technology to solve the specific business problem, blockchain projects across all industries are flourishing [9]. However, only a fraction reach operational status [10].

There are ongoing discussions and arguments in the scientific literature as to view BCT as a disruptive, a foundational, a general-purpose, or an institutional technology when conducting research in order to properly analyze its potential economic impacts. BCT in the agri-food supply chain network has the potential to eliminate the intermediaries because of the implementation of the trusted peer-to-peer exchange of food products and the respective transactions. It also has the potential to impact transaction costs in the supply chain by reducing bounded rationality, opportunism, and information asymmetries. For the purpose of our research, it will be viewed as an institutional technology and approached from a transaction cost economics (TCE) point of view [11]. Eventually, BCT will have an impact on the governance of organizations and firms.

Typically, the application of BCT in supply chain economics has been researched with an understanding of blockchain representing a single platform solution, although distinguishing between the different platform types could have a profound effect on the efficiency of the supply chain management and the supply chain network. We consider it as mandatory to distinguish between the three types of blockchain platforms, which are public, private, and consortium.

Following an extensive literature overview, we will outline the key requirements of agri-food supply chains and SCM. Subsequently, we provide an overview of the characteristics of blockchain technology that are relevant to the agri-food SCM. We then analyze the three different BCTPT in respect to the applicability of coordination mechanisms in the respective platform and underline our findings with BCT use cases from the agri-food industry. The aim of this paper is to analyze the effects of how supply chain management control mechanisms are supported by the different BCTPT attributes to provide guidance on how the choice of a particular platform impacts the governance of digital business models.

2. Materials and Methods

The research undertaken for this article was conducted through an extensive literature overview concerning BCT in vertically coordinated agri-food supply chains, combined with ongoing discussions with operators of BCT with practical experiences in using BCT for tracking and tracing as well as for provenance information in agri-food supply chain networks.

We combined secondary and primary research to find evidence that the choice of a specific BCTPT has an impact on the economic success of a digital business model and, more precisely, on the efficient management of the supply chain network. The research strategy that we selected supports the research objectives of providing academic guidance in the management of agri-food firms which are confronted with the obvious contradiction of a centralized agri-food supply chain process benefiting from a decentralized BCT solution by demonstrating the potential impacts of this novel institutional technology on how the choice of a particular platform impacts the governance of digital business models operating in the complex vertically coordinated agri-food ecosystem. With this approach, we provide a theoretical foundation for managerial decision-making in the realm of strategic IT decisions as to what specific BCTPT should be chosen to support a digital agri-food business model. Two use cases in the European agri-food industry were identified and analyzed. Two further use cases were identified within the US American agri-food sector.

2.1. Literature Overview

As for the secondary research and due to the novelty of the research topic, an in-depth literature overview has been performed to describe the impacts of coordination mechanisms on different BCTPT on practical examples of BCT-enabled tracking, tracing, and provenance use cases in the agri-food supply chain network. We conducted the literature overview with a systematic search of this topic by using the terms "blockchain", "blockchain platform", "blockchain platform types" in combination with the terms "agri-food", "Food industry", "supply chain", "supply chain network", "netchain", "supply chain management", "coordination mechanism", and any combination of the mentioned keywords in relevant dissertations, books, the University library, the website of the German Blockchain Center Frankfurt, scientific journals, and newspaper and magazine articles. The Internet-based search was done by using the above listed keywords and applying a nesting technique, a combination of search terms (e.g., "blockchain"+"agri-food"), by using double quote marks, and also truncation. We also conducted domain-specific research with the above-mentioned terms on key journal websites such as www.mdpi.com. For example, the search command "site: www.mdpi.com blockchain+agri-food" lists all articles of the MDPI domain which include the terms blockchain and agri-food. We also utilized bibliographic mining on the agri-food blockchain journal articles and books to further identify resources. Articles that did not provide research results on how the different BCTPT impact supply chain management and coordination mechanisms were not further included in our literature overview. Journals that we reviewed during the extensive literature overview phase include, but are not limited to, the International Journal of Production Research, Computers in Industry, and Trends in Food Science & Technology. We are aware that this is not a stringent methodological approach with classical quantitative and qualitative research. The in-depth literature overview provides the theoretical groundwork to apply the findings to the practical examples.

2.2. Ongoing Discussions with Industry Experts

The primary data that we use include the results of the ongoing expert discussions with the management of a leading European agri-food firm and its BCT solution provider. The reason for engaging with these experts is that they are operating a blockchain solution in the agri-food industry to track and trace as well as to provide provenance information to consumers. They operate one of the very few BCT networks and they have also operated their agri-food BCT solution for several years now to support their business processes, thus having gained multifaceted practical experiences. Following the initial meeting that took place at the beginning of March 2020, we engaged in a series of discussions during which the BCT solution provider joined. The discussions were of an explorative nature due to the novelty of the research topic. Due to the impacts of the COVID-19 pandemic on personal meetings, the sessions took place by utilizing video conferencing application software as well as traditional telephone connections. The meetings were prepared with an outline of the topics of discussion, which acted as guidance. The exchanges lasted, in general, 30 to 60 min and notes were taken for further synthesis. The ongoing discussions provide practical insights into the impacts of the BCTPT and its impacts on coordination mechanisms in the SCM as, due to the novelty of the BCT, there are only limited practical knowledge and operationalized projects in the European agri-food industry.

3. Results

3.1. Vertical Coordination in Agri-Food Supply Chain Networks

For the past few years, hierarchies and centralization have been efficient methods to coordinate decision-making in organizations, to efficiently allocate resources, perform coordination activities, and build relationships. Due to the centralization of the decision-making process in hierarchies, managers have always been challenged to effectively improve the economic performance of a firm [12]. This is a result of the hierarchic architecture, as the centralization of decision-making power leads to inefficiencies and a lack of flexibility [13]. In the agri-food business, due to the increasing number of stakeholders in the food supply chain (FSC), which includes, amongst others, suppliers, intermediaries, and a coordinating authority, FSC have developed into complex, centralized, and vertically cooperating supply chain networks [14]. Food supply chains consist of several consecutive stages, and at each stage of one or more independent firms, so that goods and information flows have to be coordinated as to timing, quantity, quality, and other factors.

The food scares in the early 2000s resulted in a demand for transparency in the food chain. Maintaining constant product quality and ensuring product safety requires the effective coordination of all stakeholders. As a result, the agri-food business transformed from vertically integrated to vertically cooperated supply chain networks which are coordinated by a focal firm [1], where coordination can be understood as the alignment of actions to mutually achieve goals between intentionally chosen partners [15]. The focal firm is, in general, identified by the consumers as “responsible” for the specific food item. This can be the producer in the case of a producer brand, and the retail firm in the pyramidal–hierarchical case of a private brand. The focal firm can act as an information broker (e.g., a retailer possesses knowledge of the final consumer, etc.) or the focal firm is engaged in production (e.g., processors, brand owners, etc.). Other network actors are dependent on the focal company because of (long-lasting) explicit or implicit contracts. The level of dependency for vertical ties is usually higher than for horizontal ones [16]. In the event that the focal organization itself depends on the critical inputs of its suppliers, mutual dependencies exist so that the supplying organizations restore some power to the focal company [17]. Consumers are increasingly demanding a high level of product quality and safety and expect transparency about their food products, including information about provenance, suppliers, production, and transport conditions. The increased demand in FSC transparency initiated a redesign of the food chain which is driven by trust attributes such as product quality and food safety [18]. Trust attributes can be differentiated by transparency, credence, as well as risk-related characteristics [18]. Trust has become a significant element of product quality and safety for which the focal firm is standing in with its brand to ensure constantly high standards. A key challenge is to signal and transfer trust to the market and to be able to react immediately in case of food faults and necessary recalls. The current agri-food supply chain systems are lacking in transparency and are highly inefficient and it is estimated that two thirds of the final cost of the agricultural goods are needed to operate the supply chain [19]. Processes in the supply chain are also being impacted by numerous intermediaries. SCM of agri-food chains is predominantly used as a quality assurance tool, followed closely by the consideration of business management and logistical aspects. As a result, amongst the key challenges of the supply chain today is how to ensure traceability, transparency, and efficiency across the network from farmer to consumer.

Information demand on food products in the FSC varies between consumers and producers. Where consumers are predominantly interested in metaphysical attributes such as origin and production process details, producers benefit from traceability information relating to their products, including information on potential replenishments. Traceability is becoming an increasingly urgent requirement and a fundamental differentiator in many supply chain industries, including the agri-food sector [20]. In order to assess blockchain opportunities, Carson et al. performed an analysis of the use cases for several industries, including agriculture. The impact of blockchains proved to be very high in the agricultural supply chain, with food safety and origin even surpassing the high impact level [21]. A distinct requirement of agri-food supply chains is the transparency of the food products in the supply chain to enable tracking and tracing and rapid product recalls, which is an enterprise-driven requirement. Consumers expect transparency and provenance information about the origin of the products, which will, in turn, increase the trust with the brand. The requirement for supply chain transparency can be met by implementing BCT- and DLT-based solutions [22].

Food networks have been classified as strategic networks [18], which are characterized as pyramidal–hierarchical collaborations [23]. Attributes of strategic networks are the hierarchical coordination through a focal firm, the intensity of relations, and the coordination mechanisms. A self-evident reason for the formation of vertical networks instead of single-line chains is the differing sizes of firms along the food chain. Striving for economic independence, protection against market power, and economies of scope constitute other reasons to collaborate. Due to the changes, producers and firms need to be part and be embedded in networks to sustain high-quality products, to satisfy the customer needs, and to be competitive in the long run [24]. There is still no unified definition for the term networks, and we borrow the term "network" from the network topologies section as it also applies to economic networks such as supply networks. A network can be seen as a group of two or more entities which are linked through means of physical or intangible connections permitting the connected entities to share information and resources. In this context, networks address all questions on inter-organizational relationships of more than two firms [25]. Thorelli characterized networks as long-term relationships of power and trust through which organizations exchange influence and resources between at least two or more actors in the network [26]. Furthermore, networks are seen as inter-organizational links which have strategic significance for the participating actors [27]. On account of this, they possess a focal firm coordinating the network in a hierarchical style. Additionally, the intensity of relations within strategic networks is rather high, and recurrent interactions are inherent in them [28]. Nevertheless, because the focal company is the core element of the SCN, it has the power to align the actions of the network partners. Thus, it coordinates the network to realize its strategic objectives.

3.2. Coordination Mechanisms of Food Supply Chain Management

Supply chain management comprises the effective coordination of supply chain activities between internal and external stakeholders, including the coordination and collaboration of channel partners [29]. The efficient flow of goods through supply chain networks is being coordinated through SCM measures. As such, coordination and cooperation between SCN stakeholders who are maintaining closer relationships have become common as the increase in the efficiency of the supply chain leads to an increase in higher levels of economic success for the whole chain. Successful management of these SCN requires a strong SCM which engages in customer value creation and coordination of business processes across the stakeholders [3]. Coordination and cooperation represent major attributes of inter-firm relationships and are of significant value for the efficiency of the management of vertically cooperated food supply networks, where the key objective of the participating supply chain stakeholders is to provide the end customer with the products and services that are being demanded. Hence, the objective of the supply network is to maximize its value by improving the overall efficiency of the network. Secure transactions, tracking and tracing, including monitoring of transport and storage conditions relevant to food safety, as well as provenance information could lead to an increase in the value of the supply chain network, where data and information sharing is key to improving the efficiency of the supply chain. As stakeholders hold different levels of information, the efficiency of the supply chain benefits from information transparently being shared and synchronized between the various participants. Although the benefits of information sharing are obvious, such as reducing or even eliminating the bullwhip effect and transaction cost reduction, there is still reluctance to share information, which results in coordinating inefficiencies, although the sharing of data could lead to a competitive advantage [30]. Coordination inefficiencies and problems arise if actors are not aware that their actions are interdependent or if there is uncertainty about others' rationality, so that one does not know how others will act. Thus, problems of coordination are the result of the lack of shared and accurate knowledge about the decision rules that others are likely to use, and how one's actions are interdependent on those of others [15]. There are three types of interdependencies: (i) pooled interdependencies between firms competing in the same market, (ii) vertical interdependencies between firms operating in different markets but linked by sequential work flows, where the output of one is the input of the other, and (iii) reciprocal interdependencies between firms that complement each other or have reciprocal product and/or information flows [31]. Lazzarini et al. advocate for exerting managerial discretion for sequential (vertical) interdependencies, achieving process standardization for pooled interdependencies, and maintaining coordination through mutual adjustments for reciprocal interdependencies [31]. Coordination mechanisms in food supply chain management can be broadly divided into six groups: power, contractual relationships, information sharing, joint decision-making, collective learning, and building routines [32,33]. In addition, Pietrwicz examined consensus building in blockchain technology (BCT) as well as coding and executing smart contracts as coordination mechanisms for online transactions [34].

3.3. From Hierarchies to Decentralization

Transaction cost economics in hierarchically operating firms assume three behavioral assumptions of human beings, which are bounded rationality, opportunism, and risk neutrality [35]. The current centralization of supply chain networks through the focal firm, which takes responsibility for the quality of the food product, still lacks transparency regarding the transactions in the network, which is needed by the participating entities as a trust attribute. Data and transactions, as well as their history, would need to be made transparently available to every participant, which could be achieved by a secure, distributed, and constantly synchronized and data storage solution. Verification is to be done by each member of the network, without the need to include a trusted intermediary. Transactions and communication between participants are being performed directly in a peer-to-peer setting instead of routing through a central authority. A key requirement is the immutability of transaction data that cannot be altered or deleted as soon as it has been stored in the ledger. Blockchain, a software protocol that enables the secure transfer of assets over the Internet, is one of the key enablers of decentralization. It provides both transparency and privacy to stakeholders and has the potential to improve the visibility of data and transactions while, at the same time, protecting the interests of the individual enterprises [22]. As SCM in agri-food chains is being used to ensure the quality of the food product but also to decrease the cost of transactions and to improve the flow of products within the network, a solution that provides trust and transparency is needed. BCT enables constant transparency through decentralization and it has an impact on transaction costs by reducing bounded rationality, opportunism, and information asymmetry in supply chains [36].

3.4. Distributed Ledger Technology

BCT is amongst the Gartner Top 10 Strategic Technology Trends for 2020 [37]. The Federal Government of Germany emphasized the importance of this technology to the future economic development by approving a strategy paper on 18 September 2019 containing measures to promote the blockchain technology [38].

Distributed Ledger Technology (DLT) can be viewed as a meta-technology as it comprises various existing technologies that are intelligently combined, creating a new technology [39]. DLT and BCT are oftentimes used interchangeably. A clear distinction between the two terms is vital to further analyze the impact of the technologies on coordination processes in the supply chain network. Various and mostly overlapping definitions of the BCT exist today, most of them having their roots in the technology space. Even the renowned

Merriam-Webster dictionary focusses on the technical aspects, declaring blockchain as being "a digital database containing information (such as records of financial transactions) that can be simultaneously used and shared within a large decentralized, publicly accessible network." [40]. Obviously, due to the nascent state of this technology, there has not yet been agreed upon a general definition of blockchain. DLT has its roots back in 1982, when a solution to the so-called Byzantine Generals problem was developed in order to ensure reliable computer processing despite the existence of malicious behavior or faults [41]. While DLT is a distributed ledger, DLT is not a database since data records can neither be modified nor deleted once they are stored in the distributed ledger. Attributes of databases are reading, writing, modifying, and deleting data, whereas DLT permits only the reading and writing of stored data. DLT enables the real-time transfer of assets, whereas the Internet enables only the transfer of information. The self-organizing peer-to-peer data-sharing technology operates without a central authority or intermediaries such as banks or brokers authorizing or coordinating transactions. DLT provides transparency to all participating entities and is immutable against potential fraud as the data cannot be changed or deleted.

BCT is a distributed ledger system and a specific type of DLT with additional features and capabilities. What differentiates blockchain from DLT in general is its capability to chain transaction blocks and secure it with hashes. As the name implies, its data are recorded as blocks, with each new block connected to the previous block, thus building a chain. These blocks are sealed by hashes, a cryptographic signature that enables a tamper-proof set of transaction data. By design, a blockchain is resistant to modification of the data. The foundation of blockchain dates back to 1991, when Haber and Stonetta proposed a method for a distributed system to certify the actual bits of digital media in order to prove their creation date and, in a further step, their authenticity [42]. In 2002, Mazieres and Shasha presented a method to verify the integrity of data stored on an untrusted disk [43]. Finally, Satoshi Nakamoto built on both methods and published his proposal for a blockchain-based cryptocurrency, "Bitcoin: A Peer-to-Peer Electronic Cash System", and on November 1, 2008, this was developed as the most popular application of blockchain [44]. BCT enables software-coded smart contracts that autonomously perform transactions, accelerating and automating processes.

BCT enables the implementation of smart contracts to enter into and execute contractual commitments. Smart contracts are software programs that are based on BCT, with fixed rules for automatically executed transactions based on a set of predefined conditions that have to be met [45]. Smart contracts enable the tracking of products along the supply chain, manage ownerships, and authorize automatic payments. They replace the trust that has been established by intermediaries so that parties that have not met and performed trades before can rely on the integrity of the transaction. Key benefits of smart contracts are the increased transparency and trust in a decentralized system with no single ruling authority [46] and the reduction of ex-ante and ex-post transaction costs [47]. Smart contracts in BCT can be seen as coordination mechanisms applying an institutional perspective over coordination [48]. Tokens, the digital, alphanumerical representation of a physical asset, are the simplest form of a smart contract.

Environmental Sustainability of Consensus Algorithms

From an environmental perspective, Bitcoin mining is resource- and energy-intense as huge computing power is necessary to compete in the solution of the complex mathematical equations as part of the POW consensus process to receive new Bitcoins as gratitude. Energy consumption for solving the POW-related increasingly complex mathematical tasks is massive [49]. However, it has been found that, from an energy consumption per transaction point of view, the environmental effect of POW can be neglected since the energy consumption does not increase substantially when additional transactions are processed [49]. Moreover, 39% of POW-related total energy consumption is being drawn from renewable energies, which have little impact on the environment [50]. On the other hand, the POW consensus algorithm is still predominantly powered through traditional energy sources, and in the year 2020, the Cambridge Center for Alternative Finance estimated a total of nearly 93-terawatt consumption, equal to one sixth of the annual German consumption [50]. However, also in this sphere, detailed studies on the environmental impacts of blockchain usage are rare.

With Bitcoin and its peer-to-peer transactions in a decentralized infrastructure, BCT began to convince firms of the disruptive potential of this meta-technology. Although it is a very new technology, it is still inefficient and several BCTs are in trial or pilot state to test business processes and digital business models. Key issues to overcome can be found in the realms of scalability and in the increase in transaction speed and cost to own and operate. Especially for the latter, consortium blockchain platforms offer the opportunity to test the novel business process based on a proven BCT solution and benefit from the experience of the participants. Ethereum as a consortium BCT platform enables smart contracts and dApps, which make the solutions more adaptable and flexible. The POW consensus mechanism that is being used in public blockchain networks slows down the transaction processes in addition to the high-energy consumptions created by the miners. To mitigate these effects Hedera, a proof-of-stake public DLT, introduced the Hashgraph consensus mechanism for their network, which enables secure and fast transactions. It increases the transactions per second from beyond 12 in Ethereum to more than 10,000, thus reducing the average fee per transaction from USD 0.20 to USD 0.0001 [51].

Where private blockchains have been operationalized today, they can, in the future, be combined and consolidated by a coordination blockchain which is capable of coordinating the processes of several independent private blockchains. With this private blockchain, platforms could be transformed also into consortium blockchains by utilizing Ethereum MainNet or SideChain technology. Further research is needed to analyze the impact of these platforms on agri-food supply chain networks.

3.5. Blockchain as an Institutional Technology

Despite the increasing attention that blockchain is receiving, there is still limited scientific research about its economic effects on firms and supply chains. Some scientific literature categorizes blockchain as a disruptive technology [52], others as institutional technology [11], or it is being declared as foundational or even as general-purpose technology (GPT) that has the potential to fundamentally change economies and societies, creating a new type of economy [34,53,54]. Being viewed as a GPT, it is proposed that its effects on the economy's facilitating structure could be compared to those resulting from the invention of the steam machine, electricity, and information and communication technology (ICT), all of them having, over the past 200 years, driven the first three waves of the industrial revolution. These GPTs significantly transformed production processes and led to large-scale changes in economies and societies in the past [55,56]. Only a few true GPTs have been identified, such as the steam engine, electricity, and ICT, which have caused significant structural changes to the way a firm is managed and organized, to its governance, or even to the geographical location and concentration of industries [57]. Lipsey et al. conclude that a new GPT does not start with a single invention at a specific date but rather evolves continuously and that it not necessarily would be accompanied by an expected productivity gain. According to them, a GPT can be identified by meeting six specific characteristics [58]. Although BCT in its current evolution phase meets many of these characteristics, it cannot yet be viewed as a GPT since it still has close substitutes in certain applications, such as tracking and tracing in consortium-type BCTPT, which can be provided by cloud-based solutions. However, it does not have substitutes when acting as an enabler of asset transfer over the Internet, enabling smart contracts and Decentralized Autonomous Organizations (DAO). We therefor conclude that it is a potential GPT.

There is also an approach which positions BCT as a foundational rather than a disruptive technology, as one of the most important digital trends [59,60]. A common definition of what constitutes a foundational technology (FT) does not exist yet and even research on BCT as an FT addressing economic and business aspects is scarce [61]. Some broader definitions exist, such as FT being an important tool, a new product or service, the building block of technological development that provides new foundations for the economy and society, or a technology that enables progress [60,62]. Examples of foundational technologies are ICT, synthetic biology, and neuroscience [62]. As BCT potentially builds the foundation for a new crypto-based economy, it could be categorized as an FT. A further indicator is that the invention has been made by an individual, as with many innovations in the ICT age. However, BCT is a meta-technology which is built by combing various technologies and, as such, we conclude that it does not fall into the FT category as described above.

Finally, there is the argument to declare it as an institutional technology [11]. In their research, Davidson et al. conclude that DLT can be approached via two economic theories: through Schumpeter's Neoclassical Economics or through Williamson's New Institutional Economics. Following the traditional theory of Schumpeter's creative disruption through innovation, BCT could potentially be a disruptive innovation which calls, in the case of BCT, for a technology that replaces something existing with something better. BCT could be considered a new technology which increases productivity, exerting a destructive effect on firms, economy, and society. Schumpeter examines disruptive technologies as technologies which increase total factor productivity in existing economic operations, which has "creative destruction" effects on firms and markets. It is obvious that BCT has the potential to replace existing business processes, but we value the effect as being far more severe as to view it simply as a technology that creatively disrupts existing business models. BCT has the potential to transform markets, governance, and society, creating new use cases and, eventually, innovative digital business models and should therefore not be viewed as a single disruptive technology.

Following Williamson's NIE theory, BCT and DLT are viewed as an institutional technology, revolutionizing governance and competing with the traditional economy [63]. Davidson et al. elevate blockchain beyond just being a disruptive technology but rather as being "a new institutional technology of governance that competes with other economic institutions of capitalism, namely firms, markets, networks, and even governments" [11]. Since BCT enables P2P transactions and since it has the potential to eliminate intermediaries from transactions and, as such, substitute banks, notaries, lawyers, etc.), the standard institutional point of view is that blockchain is a substitute for traditional intermediaries (banks, exchanges, notaries, lawyers, insurers, etc.), reducing transaction costs. This view results in the application of the transaction costs economy theory. However, not only the minimization of cost should be taken into account but also the quality and value of transactions [64]. We conclude that BCT should therefore be viewed as an institutional technology and approached from a transaction cost economics (TCE) point of view [11]. Eventually, BCT will have an impact on the governance of organizations and firms and a decentralization of governance could be achieved with this new technology. As the impact on governance is key to our research, we will follow the institutional view of Davidson and Frolov and view BCT as an institutional technology utilizing aspects of the transaction cost theory.

3.6. Trust in a Central Authority against Trust in a Shared Technology

The exchange of goods and services in today's economy, which has been hierarchically organized for centuries, relies on trusted authorities. How radical the impact of BCT can be for the management of supply chain networks and, in particular, on agri-food SCN can be demonstrated through a comparison of the key characteristics of traditional and BCT-enabled SCNs, which will be discussed in this section.

3.6.1. Centralization against Decentralization

The traditional agri-food SCN is a centralized system consisting of suppliers, intermediaries, and a focal firm, where the focal firm's power rises asymmetrically and dominates the coordination activities in the network. According to Ketchen and Hult, intermediaries in supply networks increase the potential for abusing power and are intentionally taking advantage [65]. The actors in the network show opportunistic behavior by applying power to increase the dependency of the suppliers on them. However, power could also be applied to the advantage of the network by fostering trust between partners, which reduces the potential for opportunistic behavior [1] and to solve issues and problems in supply networks [32]. Intermediaries reduce the cost of transactions in supply chain networks as they reduce bounded rationality, opportunistic behavior, and information asymmetry [66].

The decentralization nature of a blockchain system refers to the level of control. Every single node in a decentralized network makes its own decision and the summary of the decisions results in the behavior of the total system. There is no central authority coordinating the network. In a centralized network, a central entity, such as a server, handles the major processing based on requests that come from connected clients such as terminals or printers. In a decentralized network architecture, the major processing and decision-making is distributed across several processing entities, where each entity again performs tasks for clients connected to those entities. Where a single authority in a centralized system is vulnerable to centralized manipulations, decentralized systems, due to their network architecture, do not have a single point of failure.

In a decentralized network, the lack of a centrally coordinating entity can reduce transaction costs and create network effects [67]. In addition, the application of BCT to the management of a supply network can increase trust by generating closer relationships between the firms [66]. Blockchain induces trust in the network, replacing the intermediaries and focal firms that had taken this role in the past.

3.6.2. Hierarchic against Peer-to-Peer Organization

The traditional agri-food SCN is pyramidal–hierarchic, organized and coordinated by a focal firm that sets the strategy and aligns the actions in the network. Collaboration in such a pyramidal–hierarchic SCN requires building trust and commitment between trading entities [1]. In a blockchain-enabled SCN, the hierarchic structure is replaced by a decentralized network. Decentralization enables peer-to-peer value exchange without the need of an intermediary and shifts power away from the central authority as BCT enables the elimination of intermediaries from transactions [68]. Transactions are now conducted by the participating entities non-hierarchically in a peer-to-peer format. In this decentralized network, trust is now established between the entities rather than by the single authority, as in a hierarchic environment. Decisions are made between participants directly, where each participating entity has equal rights to access the transaction data. As a result, BCT, with its decentralized network architecture and peer-to-peer trading, enables disintermediation [69]. Generating transactions without intermediaries, BCT has the potential to significantly change the structure and organization of supply chains and, hence, the supply chain management [3,70].

3.6.3. Information Asymmetry against Transparency of Transactions

Transaction cost economics is based upon three behavioral assumptions of human beings, which are bounded rationality, opportunism, and risk neutrality [35]. Williamson created the concept of "information impactedness," as "a characteristic of transactions in which the parties to a contract are inclined to operate opportunistically in the presence of uncertainty and complexity surrounding the contract". As per NIE, bounded rationality of trading partners exists, which is a consequence of incomplete knowledge and limited information processing capacities [71]. Agri-food supply chain networks are complex in structure and network members operate under bounded rationality and suffer from anonymity and a lack of transparency about the activities in the supply chain as information is predominately held by the single authority. The focal firm holds information critical to transactions in the supply chain to increase its power and the dependency of its suppliers on it. Access to this information is restricted and controlled by the focal firm.

Blockchain technology enables real-time and historic transaction data access and evidence has been provided that blockchain in the supply chain increases transparency [72].

Blockchain limits the effects of bounded rationality, confirming the theory of Transaction Cost Economics [36]. If transparency between trading partners can be established, trust can be created, which reduces the suspicion of opportunistic behavior and increases the probability of effective communication and information sharing [1]. The application of disruptive technologies such as BCT to SCM can increase trust by generating closer relationships between the firms [66]. Every single transaction can be monitored by the participating entities, which increases trust in the process. With ubiquitously available information, which each of the transaction partners can access, information asymmetries in transactions between business partners might be reduced. In order to maximize the value of the chain, decisions should be made free from errors and based on all available information. However, human beings are not capable of making perfectly rational and logical decisions, according to Herbert A. Simon's theory of bounded rationality [73], although this has been implicitly presumed in previous works [74]. Humans' decisions are limited by their cognitive abilities, including, but not limited to, processing large amounts of data, their emotions, and the limited amount of time they have for making decisions, without exploring all available alternatives or obtaining all relevant information, which results in decision-making based on incomplete information. In a BCT-enabled SCN, the participating entities are interconnected through a data network, which allows ubiquitous information exchange, enabling efficient communication in the supply chain to ensure transparency and effective coordination between the parties.

3.6.4. Single against Mass Consensus

In a pyramidal–hierarchic organization, decisions are made by the focal firm, which is responsible for the strategic direction of the SCN. According to Ketchen and Hult, intermediaries and agencies in supply networks increase the potential for abusing power and intentionally take advantage of the SCN, which is the result of a single decision authority [65]. However, power could also be applied to the advantage of the network in order to solve issues and problems in supply networks [32]. The level of decision-making power applied to the supply network is critical for its efficiency, with a higher degree of control resulting in an increase in supply network value. It has also been proven to impact the management of highly interconnected networks, where the supply network performance suffers less with higher control applied [74].

The decentralization nature of a blockchain system impacts the level of control as well as the decision-making. In a decentralized network, decisions are made by the joint consensus of the participating entities. A trust attribute of BCT is that blockchain is consensus-safe as transactions can only be executed when the majority of participants approve them. Participants can reliably and efficiently verify transaction attributes [67]. Based on the BCT platform, different mass consensus algorithms apply, which are summarized in Table 1. Another aspect of coordination with BCT is achieving consensus about the contents and validity of transactions.

Table 1. Comparison of key characteristics of traditional and BCT-induced food supply chain networks.

Traditional FSCN	Blockchain FSCN
Centralization	Decentralization
Hierarchic organization	Peer-to-peer organization
Information asymmetry	Transparency of transactions
Single consensus	Mass consensus
Written contracts	Smart contracts

3.6.5. Written Contracts against Smart Contracts

The combination of encrypted transaction data, anonymity of the trading partners on one hand, and decentralization and immutability of data on the other hand enables further confidence-building and enhances trust [39]. This is a prerequisite for the operationalization of smart contracts, where software-coded contracts are set to replace reciprocal trust of trading entities. While traditional contracts are written in a document and where its stipulations can be interpreted to a certain extent, smart contracts do not have a severability clause in it that allows the execution of the contract despite unintended defaults. Traditional contracts typically have mechanisms such as amendments or modifications deployed, which can be used to mitigate in case of unclear wording or unforeseeable events, without compromising the whole contract. These mechanisms cannot be coded in smart contracts [75]. Software-coded smart contracts have fixed programmed go/no-go conditions that do not permit any interpretation. The respective transaction can only be performed when all conditions have been met according to the conditions programmed in the smart contract code. BCT therefore provides coordination mechanisms through its smart contracts which can autonomously execute contracts, without the need of a centrally coordinating authority, through the definition and coding of the contracts and through consensus-driven validation.

The key characteristics of traditional food supply chain networks (FSCN) and blockchain-enabled food supply chain networks are summarized in Table 1.

3.7. Key Characteristics of Blockchain Platforms Impacting the Management of Traditional Food Supply Chains

In this section, we will describe the three different blockchain platform types that exist today: the public, private, and consortium blockchain. These blockchain platform types are differentiated through the access rights and the rights to read and write in the ledger, which is described in the following. What all blockchain platforms have in common is the distributed ledger technology, peer-to-peer transactions, as well as a consensus mechanism.

Public blockchain consensus is achieved through the majority of the participating entities utilizing the POW algorithm. The public blockchain network is open for participation to everyone and everyone can access the transaction data, validate them, and participate in the consensus process. This type of blockchain platform is called permissionless, as no permission from a central authority is needed to participate in the network. Transaction data, once validated, are secure and immutable. Bitcoin and Ethereum are examples of public blockchain applications.

In the private blockchain platform, only approved and authorized members can participate in the network. A single ruling authority coordinates the permissioned access and validation of transactions. Private blockchain platforms are mainly used in enterprise environments. As the decisions are made by a central authority network, consensus remains in one hand and is, as a consequence, much faster compared to those in public blockchain platforms. As a result, transaction throughput can be much higher.

A consortium blockchain is also a permissioned technology, such as the private one, as only authorized participants are granted access to the network. In contrast to the private platform, the network is controlled by a group of entities, such as several firms having equal rights and maintaining the network and system technology. The system is decentralized, permissioned, and only authorized users are granted access. Its aim is rather collaboration than competition between the participating firms. Consortium blockchains can be further differentiated by their individual focus being technology, business, or technology and business, the latter being a hybrid form. The top benefits that organizations expect from a certain consortium are cost savings, accelerated learning, and sharing of risks, according to recent research conducted by Deloitte [76]. Other benefits include the fact that participation is only by authorized entities, the predetermined rules and processes in a regulated environment, easier integration into corporate IT environments, and avoidance of malicious access as all nodes are authenticated.

The criteria by which organizations join consortia do not have a clear focus. Aligning objectives with other firms joining the consortium blockchain platform is the key reason for joining. The expectations are distributed nearly uniformly across the attributes. Obviously, the benefits of public and private blockchains seem to be easier to comprehend than those of consortium blockchains [76].

Traditional information technology architectures that are used to share information require certain types of centralized governance to ensure the integrity of the network. With Bitcoin cryptocurrency and the underlying blockchain architecture, a publicly shared platform for securely transferring assets without any intermediaries or central authority has been introduced [44]. Trust in the transactions is established through the consensus mechanism that governs transactions. Consensus mechanisms are not suitable for all BCTPT universally and different protocols are implemented with the platforms. Table 2 provides an overview of the consensus mechanisms in different BCTPT.

Table 2. Key characteristics of blockchain technologies—technical aspects.

Technical Aspects	Public	Private	Consortium
Consensus algorithm	mass (PoW)	single authority (e.g., PoA, PoET, Raft, IBFT)	limited (PoS, PoA)
Transaction throughput (TPS, transaction per second)	low	high	high
Scaling	limited	flexible	flexible
Decentralized	yes	no	yes
Immutable data	yes	yes	yes
Identical ledgers in the nodes	yes	yes	yes

IBTF = Istanbul Byzantine Fault Tolerance; PoA = proof of authority; PoET = proof of elapsed time; PoS = proof of stake; PoW = proof of work.

These mechanisms vary depending on the BCTPT and can be broadly split into proof-based consensus algorithms and voting consensus algorithms. It is very well known that the environmental effect of Bitcoin is immense due to the POW consensus algorithm deployed for validating new transaction blocks and mining Bitcoins in return as reward [4]. This specific consensus algorithm requires huge processing power, which consumes energy to solve the complex mathematical puzzles. For ease of comprehension, we will continue using the publicly used term "energy consumption", although energy in a closed system can neither be created nor consumed but only be transferred and change its form. The POW consensus algorithm used in public networks is effectively used in networks where assets are being exchanged between users that are unknown to each other and where trust has to be provided through the consensus algorithm. Miners benefit in the short term from additional processing power to more quickly solve the cryptographic problem to earn more Bitcoins. However, the long-term environmental and societal effects should be taken into consideration as natural resources such as fresh air, clean water, and the environment within society might be impacted by the huge energy consumption. POW consensus can therefore be seen as an economic problem which is known as the tragedy of the commons, where there is a conflict between the rationality of the individual and the public.

Voting consensus algorithms are mainly found in private BCTPT, where the central authority manages the nodes, grants access, and validates blocks. As a result, this process of consensus building is very energy-efficient.

Consortium-type platforms use both proof-based as well as voting-based consensus algorithms. Predominantly implemented are proof of stake (POS) and proof of authority (POA) methods, which are more energy-efficient than POW. However, a single POS-based transaction performed with the consortium-type Ethereum platform consumes 35.04 kWh, in comparison to 668 kWh with Bitcoin [5]. More recently, Directed Acyclic Graph (DAG), an innovative DLT, has been introduced, which utilizes Tangle, which is an energy-efficient consensus mechanism where each transaction attempts to validate the two previous transactions, eliminating the need for miners and, at the same time, reducing energy consumption drastically. Tables 2 and 3 summarize the key technical as well as organizational characteristics of the three different BCTs.

Table 3. Key characteristics of blockchain technologies—organizational aspects.

Organizational Aspects	Public	Private	Consortium
Access	permissionless	permissioned	permissioned
Hierarchy/focal firm	no	yes	few
Coordination	public	single firm	several firms
Topology	distributed	centralized	decentralized
Control	none	one	few
Ownership	none	one	few
Collaborative	yes	no	yes
Participation	open to everybody	closed	closed user group
Participants known	no	yes	yes
Census	resistant	yes	limited
# of serving enterprises	many	one	few

3.8. Coordination of Centralized Agri-Food Supply Chains with Decentralized Blockchain Solutions—The Role of Supply Chain Management Coordination Mechanisms

As described in the coordination mechanisms of food supply chain management section, coordination mechanisms in supply chains include power, contractual relationships, information sharing, joint decision-making, collective learning, and building routines. We discuss the coordination mechanisms while, at the same time, differentiating between the three existing BCTPT to obtain insights into the impact of BCTPT on agri-food supply chain management.

3.8.1. Exerting Power

In public BCTPT, the coordination mechanism exerting power is implemented decentralized as no ruling central entity exists. Power is exerted through a mode of network governance which distributes tasks fluidly, dependent on the current role [77]. Power moves to the participants of the network and roles change depending on the tasks and the relationships. In private BCTPT, power is centralized as the private blockchain network is operated by a single enterprise for their own purposes. The central authority decides on participation in the network. In consortium-type platforms, power is distributed to a few coordinating entities as these share the network coordination and act as a common central authority of network coordination.

3.8.2. Contractual Relationships

Smart contracts are coordination mechanisms for online transactions [34]. They replace the trust that has been established by intermediaries and central authorities and enable the tracking of products within the supply chain network, execute contracts, and authorize payments. Contractual relationships as coordination mechanisms are executed through smart contracts in all three BCTPT and, hence, there is no difference in this specific coordination mechanism on the impact on the BCTPT.

3.8.3. Information Sharing

Information sharing and transparency are two of the key trust attributes of BCT and the implementation differs between the BCTPT. In public BCT, every participant has access to the transaction data and their history, which provides trust in the asset that is being transferred. Due to its nature, transactions in the private BCTPT can only be accessed and shared by the centrally governing entity, whereas in consortium-type platforms, transaction data can be accessed by all participating and authorized entities.

3.8.4. Decision-Making

Decision-making in DLT occurs typically through mass consensus as implemented in the public BCTPT. In the centralized BCTPT, a single ruling entity performs the decisions alone; in consortium platform types, authorized participants perform the decisions.

3.8.5. Collective Learning

One of the key benefits of supply chain management is the collective learning experience of all participating stakeholders in private and consortium platforms. Participating stakeholders benefit from the experience of others. This is the sole responsibility of the individual in public blockchains, because every individual acts on its own. As one of the key reasons for joining the consortium platform, 55% of the respondents stated their expectations of a consortium platform in terms of the benefit of accelerated learning [76]. In private platforms, the focal firm can demand participation in joint learning activities from its members.

3.8.6. Building Routines

Building routines in supply chain transactions can be achieved by implementing smart contracts to automatically perform contractual activities associated with transactions. Building routines as coordination mechanisms are executed through smart contracts in all three BCTPT and, hence, there is no difference in this specific coordination mechanism on the impact on the BCTPT.

The findings relating to how the coordination mechanisms are impacted by the three different BCTPT are summarized in Table 4.

Table 4. Impact of BCTPT on coordination mechanisms.

Coordination Mechanism	Public	Private	Consortium
Exerting power	decentralized	centralized, enterprise solution	distributed, no single ruling entity
Contractual relationships	smart contracts	smart contracts	smart contracts
Information sharing	transparency of transaction data to everyone	transaction data controlled by single firm	transparency of transaction data for authorized participants
Decision-making	public consensus	single firm consensus	consensus through authorized participants
Collective learning	individual responsibility	focal firm demands participation	yes, cost savings as a driver
Building routines	smart contracts	smart contracts	smart contracts

As coordination mechanisms show varying characteristics depending on the chosen BCTPT, we presume that the choice of a specific BCTPT has an impact on the economic success of the planned use case and the efficient management of the supply chain network.

We also assume as part of our research that, despite the decentralization character of BCT, agri-food supply chain networks continue to be dominated by vertical coordination.

3.9. Use Cases

BCT is still in its infancy phase, which is characterized by the exploration of the technology, and a complete blockchain solution has not yet entered the market [52]. According to their definition, complete BCT solutions mean that the solution is distributed and encrypted, data are immutable, tokenization is possible, and the solution is truly decentralized. Use cases and solutions based on the first three characteristics can currently be found with tracking and tracing as well as in provenance information. The capability to track and trace goods as well as to gather provenance information are key requirements in the agri-food business. In order to assess the blockchain opportunities, a comparison of several industries has been performed. The impact of BCT proved to be very high in the agricultural SCN, where food safety and provenance use cases even surpassed the high impact level as shown in the research. However, both received an average grade in terms of feasibility [21].

Solino Coffee Products is a partnership under German law. Solino provides consumers with access to provenance information about the origin of the coffee. The business challenge was to provide trusted information about the coffee products in the supply chain in their quest to further increase customer loyalty as consumers are increasingly asking producers to make the supply chain processes more transparent to them; at present, this applies especially to the provenance information about the products sold. Several years ago, Solino Coffee from Hamburg implemented the first blockchain application to transparently present the activities in the supply chain to provide information for its customers and for the company. Consumers can now obtain information on the origin of the product from the QR code on the back of the coffee packaging, using a smartphone. As a result, information from the supply chain, from harvesting to roasting and shipping to Hamburg, is presented in a visible and transparent way, increasing trust and customer loyalty.

FRoSTA AG is one of the largest manufacturers of frozen food products in Europe. They offer various frozen food products, including fish, meals, vegetables, and others, which are distributed throughout Europe. Their business requirement is to further increase trust in their frozen fish products and, as a result, increase customer loyalty by providing reliable provenance data about the place where the fish was captured. With a BCT-based solution, provenance data are printed on their frozen fresh fish packages, enabling consumers to obtain provenance information on the frozen fish products in the supply chain.

IBM started Food Trust back in 2017. Food Trust is based on Hyperledger Fabric BCT and connects participating firms in the food supply chain to share food system data on their products. The driving force to develop Food Trust was to provide a platform that would be able to rapidly activate food recalls if needed and to keep the lot of recalled products as small as possible in order to eliminate unneeded and excessive waste. Currently, more than 80 members, such as Walmart, Albertsons, and Carrefour, are using IBM's Food Trust consortium blockchain, which has predominantly offered traceability and provenance features for the food supply chain ecosystem since 2017. The blockchain-based system was built, and proof-of-concept (POC) tested for food traceability based on Hyperledger Fabric. Walmart, the America-based multinational retail enterprise, joined the Hyperledger Fabric consortium in the USA in 2020. Their requirement was to enable the traceability of food items in case of food-originated disease outbreak. Today, they receive provenance information and are able to track and trace food products from various suppliers, including Nestle and Unilever. The progress is fastest in those cases where adoption is pushed on others. Walmart, for example, obliges in its Food Traceability Initiative, which is based on IBM's Food Trust network, its suppliers of fresh leafy greens, such as salad and spinach, participating in their blockchain to enable transparency and provenance in their quest to increase food safety by radically reducing the time to recall products. Walmart has proven with this project that they can track food products from their store back to their origin within seconds, rather than days or weeks, as was previously the case [78].

All four use cases have in common that they are permissioned systems, such as private or consortium BCTPT, that are centrally coordinated, with access that is granted only to participating entities. This is in contrast to the original blockchain idea, where participating entities trade peer-to-peer with each other, without any central authority coordinating the SCN.

Our research shows that use cases with high success rates follow a certain pattern. First and foremost, the use case operates in a vertical ecosystem, such as the traditional vertically coordinated agri-food supply chain represents. Second, a focal firm takes responsibility for the management of the supply chain network. Third, participation in the BCT-equipped supply chain network is required by the focal firm from its suppliers. More aspects include that the transactions revolve around an asset and the use case has to provide network effects so that the value grows with a growing network.

Our research shows also that these use cases were found in ecosystems with predominantly consortium-type BCTs. The fastest-growing BCT use cases in 2019 were provenance in wholesale trade and asset tracking in transportation, manufacturing, and wholesale trade [10].

4. Discussion

There are still many factors that are delaying the wider adoption of BCT across all industries. First and foremost, blockchain is still in its evolution phase and firms are moving along the trajectory of the learning curve to gain a better understanding of its economic effects on their digital business models. The application of blockchain technology in the agri-food value chain has been predominantly researched from a technical point of view and a differentiation between the different BCTPT has not been considered. When planning, designing, and operating blockchain networks, both economic and environmental aspects should be considered. We conclude that BCT should be viewed through the lens of new institutional economics and treated as institutional technology [11]. Therefore, we analyze its impact on decentralized network governance and consequently on transaction costs. We draw upon the theory of transaction cost economics to demonstrate how BCTPT impact SCM control mechanisms [32,34]. The analysis of the different BCTPT reveals that the proper choice of BCTPT for a specific digital business model can mitigate coordination problems, leading to a more efficient application of the technology in supporting innovative digital business models [79]. Our research shows that the choice of the BCT platform has an impact on coordination and cooperation in agri-food SCN. We identified six coordination mechanisms in the agri-food supply chain and applied them to the three BCT platforms [32,34]. The comparison shows that each platform addresses the way in which power is exerted, the way in which information is shared, joint decision-making, and collective learning differently. Solely the mechanisms by which contractual relationships are managed and how building routines are addressed can be viewed as being similar for all platforms. These findings are supported by the analyzed use cases, which show that use cases in a vertical coordinated supply chain network have been increasingly operationalized. These use cases operate either on a private or a consortium type of blockchain, which supports the coordination mechanisms of power, information sharing, decision-making, and collective learning benefits. We also reveal that blockchain use cases with high success rates typically address a novel business need and operate in a vertical ecosystem, where a focal firm takes the responsibility for coordinating the activities in the supply chain network. These use cases are typically operationalized in tracking and tracing applications as well as in provenance-based information provision, where a closed user group is sharing information, providing transparency to the supply chain. We conclude that the choice of a specific BCTPT with its respective coordination mechanisms is a key determinant of the economic success of the intended use case, the efficient management of the supply chain network, and eventually for the chosen digital business model.

In answering the first research assumption on how the different BCTPT impact the control mechanisms in agri-food supply chain networks, we proved that the control mechanisms of supply chain management in strategic networks are not uniformly supported and vary depending on the selected BCTPT.

Elaborating on the second assumption leads to the result that control mechanisms in BCT-enabled strategic networks, which are operationalized through private or consortium BCTPT, do currently not lead to a decentralization but rather strengthen the implementation of the existing vertical-coordinated ecosystem by providing trusted track, trace, and provenance information to the focal firm and the consumer. For the food supply chain, our research shows that the use of the consortium blockchain seems to increase the success rate of these solutions. It has also been demonstrated that use cases with a high success rate have a working business case, especially when an urgent business problem is being addressed.

In agri-food tracking and tracing as well as provenance information, use cases are being addressed with private and consortium blockchain solutions. These solutions do not yet require a tokenization of assets. However, to offer a complete BCT solution, also tokenization of assets needs to be implemented, which has not yet been introduced widely, especially not in the agri-food sector.

As of today, three different BCT platform types exist and choosing the wrong platform for a specific digital business model might result in performance impacts. Development of automated transactions and smart contracts is slow, although the technology is evolving rapidly, but a lack of understanding the technology and its potential applications, coupled with many blockchain projects not reaching the operational implementation phase, might lead to slower adoption. Research on its economic impact is still limited and should take into account the different BCTPT.

The aspects of how the different BCTPT reflect FSCN characteristics have been summarized in Table 5, where "−" means no effect, "+" means a moderate effect, and "++" a strong effect.

Table 5. The impact of FSCN characteristics on different BCTPT.

Characteristics	Public BCTPT	Private BCTPT	Consortium BCTPT
Centralization	−	++	+
Hierarchic Organization	−	++	+
Information Asymmetry	−	++	-
Single consensus	−	++	+
Written contracts	−	−	−

Research on blockchain's governance aspects is still scarce and the synthesis provided by the authors should not substitute a thorough review of the existing literature but rather provide a preliminary insight into this research area. As part of the digital network governance, relationships are being entertained between the individual participants in the network, which might influence the previously discussed attributes, such as manipulation and influence, which results in inefficient operation and impacts flexibility [13].

5. Conclusions

Research on BCT and the impacts of its various platform types on economic and environmental sustainability is still scarce. We are aware that our paper provides the first results in an area that is still under-researched, rather than a comprehensive analysis. Further research is needed which employs advanced methodologies such as agent-based modelling and simulation (ABMS). Simulation of complex socioeconomic systems with ABM is being utilized as a substitute for experiments, especially in those cases where the process to be observed takes too long, a large number of participating stakeholders over a longer timeframe needs to be analyzed, or too many iterations with changing variables need to be run. Agent-Based Computational Economics (ACE), the application of ABM to economics combined with computer simulation, is a relatively new approach for modelling complex systems and tracking economic activities through time based on independent agents interacting with their environment [80]. Although the use of ABM for analyzing agri-food supply chains has increased in recent years, there is a lack of research and simulation in the realms of cooperation and coordination, as well as in the realms of coordination mechanisms in agri-food supply chains [79]. Researching blockchain platforms in the supply chain with ABMS will provide additional insights into potential developments within the chain.

Based on an extensive literature overview, we first analyzed the differences between traditional and BCT-induced food supply chain networks in the agri-food sector and identified the key coordination mechanisms that are supported differently depending on the selected blockchain platform types. We then compared the findings with use cases from the agri-food industry.

A key driver of blockchain adoption in the agri-food industry is food safety concerns. Contamination or food fraud that can be detected in the supply chain and the potential of rapid product recalls are spurring the implementation of blockchain projects in the agri-food industry. BCTPT projects at the technology's current level of maturity predominantly differentiate through the coordination mechanisms of power, information sharing, decision-making, and collective learning benefits. Blockchain agri-food use cases with high success rates typically operate in a vertical ecosystem, such as supply chain transparency and food safety, which are applications that also support sustainability initiatives, where a focal firm takes responsibility for coordinating the activities in the supply chain network. These use cases are typically operationalized in tracking and tracing applications as well as in provenance-based information provision, which either operate in vertically coordinated private blockchain or consortium-type blockchain platforms. These use cases have shown a higher proportion of operationalization compared to use cases from other industries. The use cases that we researched have in common that they operate in permissioned systems that are centrally coordinated. We show that BCT is offering solutions tackling these agri-food business-related problems. We conclude that successful implementations need a vertically coordinated ecosystem and revolve around providing provenance as well as tracking and tracing information, both needed as credence attributes in the agri-food industry. The current BCT use cases are predominantly successful when the participation of firms is mandated by a centrally acting entity. We further conclude that the choice of a specific BCTPT—for the agri-food-based use cases, the permissioned BCT—with its respective coordination mechanisms is a key determinant of the economic success of the intended use case, the efficient management of the supply chain network, and eventually for the chosen digital business model.

The impact of BCT on agri-food supply chain network management and its control mechanisms, which are operationalized through private or consortium BCTPT, do currently not lead to a decentralization of the agri-food supply chain network and SCM but rather strengthen the implementation of existing vertical-coordinated ecosystems by providing trusted track, trace, and provenance information to the focal firm and the consumer.

The results of this study provide a theoretical foundation for managerial decision-making in the realm of strategic IT decisions as to the specific BCTPT choice. This study proposes that SCM coordination mechanisms show varying characteristics depending on the chosen BCTPT and that the choice of a specific BCTPT has an impact on the economic success of the prospected business model. Despite the decentralization character of BCT, agri-food supply chain networks could, for the foreseeable future, continue to be dominated by vertical coordination and a responsible central authority. The consortium BCTPT has the strongest influence on agri-food SCM coordination mechanisms pertaining to provenance and tracking and tracing implementations. The cases that we reviewed all operate in vertical types of ecosystems, which are common to agri-food supply networks. With the introduction of smart contracts to BCTPTs, the coordination mechanisms, contractual relationships, and building routines will be addressed to enable reasonably full automation of business processes. Despite the initial expected benefits, such as an increase in consumer trust and a decrease in coordination problems through transparency and information sharing, it seems to be clear that BCT in the agri-food industry is predominantly in the phase of piloting, gaining more insights into its potential future application. There are many different technical solutions for BCT, and no single dominating technology has emerged. With this, a decision for a digital business model enabled by a specific BCT vendor needs to be calculated with a short ROI. With tokenization to be added to the agri-food supply chain, novel business models will emerge, likely to significantly impact the investment decisions of today.

Smart contracts and DAOs will introduce new types of governance which need to be the subject of future research. With the introduction of tokenization, smart contracts could not only further increase the transparency in the supply chain but also enable autonomous transactions based on electronic contracts, which has the potential to reduce ex-ante and ex-post transaction costs. As energy consumption of Bitcoin transactions is still growing and transaction speed is low, either alternative consensus mechanisms should be deployed, or transactions should be performed using energy-saving consensus mechanisms. Further research has to show how the introduction of smart contracts impacts the remaining two coordination mechanisms in supply chains, which are contractual relationships and building routines.

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