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Investigating the Adoption of Blockchain Technology in Agri-Food Supply Chains: Analysis of an Extended UTAUT Model

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Abstract: Against a backdrop of globalization, dynamic shifts in consumer demand, and climate change impact, the intricacies of agri-food supply chains have become increasingly convoluted, necessitating innovative measures to guarantee agri-food security and authenticity. Blockchain technology emerges as a promising solution, offering transparency, immutability, traceability, and efficiency in the overall supply chain. This study aims to investigate determinants impacting both the intention to use and the actual usage of blockchain-driven agri-food supply chain platforms. To achieve this, an expanded and adapted conceptual model rooted in the Unified Theory of Acceptance and Use of Technology (UTAUT) was formulated and empirically examined through Partial Least Squares Structural Equation Modeling using data from 175 respondents from agri-food companies across eight European countries. Agri-Food Supply Chain Partner Preparedness (FSCPP) emerged as the pivotal factor with the highest degree of influence on the intention to use blockchain-driven supply chain platforms. Additionally, the results from this study offer support for the significant influence of Performance Expectancy (PE), Effort Expectancy (EE), and Perceived Trust (PT) on usage intention, while also revealing the positive impact of Organizational Blockchain Readiness (OBR) on expected Usage Behavior (UB). This study provides significant insights into blockchain adoption within agri-food supply chains, contributing to the existing literature through an extended UTAUT framework.

Keywords: agri-food supply chain; agri-food security; blockchain; technology adoption

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1. Introduction

In recent years, the agricultural industry has faced significant challenges due to heightened demand for safe and high-quality agri-food products, leading to intricate supply chain dynamics. The globalization of food networks has introduced diverse stakeholders, complicating traceability processes, while geographical distances between producers and consumers pose additional hurdles in maintaining food standards. Moreover, transformative changes across political, social, economic, technical, and environmental domains have reshaped traditional supply chain models, prompting a need for novel approaches for performance improvement within the agri-food sector [1–4]. Numerous research endeavors have underscored the role and significance of these drivers in the novel configuration of business systems in this sector [5–7].

Concurrently, global agri-food markets are undergoing adjustments to meet emerging requirements aimed at addressing efficiency, effectiveness, resilience, and sustainability within the agri-food sector [8,9]. Furthermore, consumers prioritize the safety and quality of agri-food products and are increasingly seeking a prompt and reliable means to access critical information related to sourcing, cultivation, processing, and environmental considerations [10,11].

The integration of sustainability, traceability, and transparency into agri-food supply chains is crucial to meet consumer expectations and ensure product authenticity and security, thereby preventing potential global health crises [12]. To achieve this, collaborative efforts among stakeholders are needed to facilitate transparent information dissemination throughout complex supply chains [13]. Also, customized monitoring and tracking systems for agri-food products have the potential to enhance supply chain resilience and sustainability by providing precise real-time information [14,15]. Nevertheless, current supply chain management often relies on centralized structures lacking transparency and facing capacity limitations, posing risks to food safety and undermining consumer trust [16–18].

In this context, the application of blockchain technology emerges as a promising solution for ensuring secure and transparent record keeping throughout the entire agri-food value chain [19–21]. Blockchain's features, including transparency, immutability, and decentralized consensus, ensure data reliability and credibility, facilitating swift detection of unauthorized changes. Moreover, its distributed nature eliminates reliance on a single entity for traceability purposes, thus addressing scalability and vulnerabilities associated with a single point of failure [22].

Blockchain solutions for agri-food supply chains offer a comprehensive approach to addressing consumer demands, encompassing food safety, quality monitoring, traceability, waste reduction, and reliable data transfer, thereby enhancing the integrity and management of these supply chains [23]. Blockchain technology empowers producers to foster transparent connections with consumers, improving their reputation and market competitiveness, while also deterring fraudulent activities and enhancing quality benchmarks. Additionally, blockchain systems can facilitate consumer access to accurate and updated information regarding food production and associated transactions, addressing potential concerns regarding food safety and quality. Moreover, regulatory agencies can leverage the reliable data provided by blockchain to implement informed and efficient regulations throughout the supply chain [24].

Although blockchain technology offers promising solutions to numerous challenges in modern agri-food systems, it also faces limitations in addressing specific issues. It cannot directly address inherent production challenges such as water scarcity or the environmental impact of farming practices, nor can it guarantee the intrinsic quality attributes of food products. Additionally, it does not inherently resolve issues related to equitable access to food resources or regulatory compliance in the agri-food supply chains. Moreover, the high costs associated with obtaining data for network upload and the complexity of integrating blockchain with existing systems present significant adoption challenges [24].

Therefore, the mechanism of acceptance and adoption of blockchain technology within the agri-food industry constitutes a topic of utmost interest for both researchers and practitioners. The assessment of the critical factors ensuring the successful blockchain adoption in agri-food supply chains provides valuable insights into enhancing performance and competitiveness in agri-business. While most studies focus on monitoring the performance improvement of agri-food supply chains [25,26], few explore the perspectives of beneficiaries on innovative products and technologies [27,28]. Despite technology adoption models aiming for theoretically and practically acceptable frameworks, factual evidence supporting blockchain benefits remains inconclusive, with limited industry-specific validations.

The objective of this research is to analyze the factors exerting a positive effect on blockchain adoption within agri-food supply chains. Recent research conducted by the authors has led to the formulation of a conceptual model specific to blockchain adoption across various sectors. In the current study, the authors refine this model by selecting factors relevant to enhancing supply chain performance in the agri-food industry. The Unified Theory of Acceptance and Use of Technology (UTAUT) serves as the foundation for the proposed model, empirically tested using Partial Least Squares Structural Equation Modeling (PLS-SEM). The model serves as a valuable instrument for capturing beneficiary feedback and facilitating timely adjustments in blockchain technology implementation within agri-food supply chain dynamics.

This paper is structured as follows: The introduction delineates the contextual background and research relevance, encompassing the identification of the research problem and expected results. The second section presents a literature review with a synthesis of the opportunities and challenges in agri-food supply chains and the benefits and adoption challenges of blockchain technology, relying on theoretical concepts from the existing literature with the aim of establishing an analytical framework for the research model. Subsequently, a dedicated section focuses on the empirical study, employing Partial Least Squares Structural Equation Modeling (PLS-SEM) as the chosen research method. The research progression unfolds through a section of pertinent discussions, emphasizing the added value of this study through both the theoretical and practical implications of the proposed research approaches. Finally, the conclusions highlight the contribution that this study has made to this field of knowledge.

2. Literature Review

2.1. Challenges and Opportunities in Agri-Food Supply Chains

The food supply chain is defined as a complex network that interconnects the agricultural system with end consumers and is characterized by processes such as production, packaging, storage, and distribution [29]. Moreover, the food supply chain is increasingly susceptible to natural disasters, primarily attributed to climate change, and anthropogenic and crisis-related events (such as accidents, ecological disasters, pandemics, armed conflicts, etc.), population growth, competition for key resources, shifts in demand and consumer values, and ethical considerations [30–32].

Given the imperative for maintaining an uninterrupted flow of products, the food supply chain requires the ability to swiftly adapt to unforeseen circumstances that may cause disruptions in the supply chain. The implementation of innovations for monitoring efficiency and proper risk management ensures such adaptability. To effectively reduce risks and mitigate threats, concrete solutions need to be applied, involving the identification, analysis, and continuous improvement of means to strengthen the supply chain [33].

In this context, the effective management of any unforeseen internal or external events necessitates the real-time dissemination of information contained within the value stream of the chain to suppliers, intermediaries, and consumers [34]. This approach is crucial for enhancing overall resilience and responsiveness in the face of challenges within the complex and dynamic food supply chain.

Within the realm of food supply chains, the intricacy of informational flows is notably high, primarily due to their direct correlation with quality concerns. Nakandala et al. state that the operations are closely interconnected, and any disruption in one process may result in unintended cascading effects, potentially affecting the entire supply chain [35].

The intricacies surrounding the challenges inherent in the processes of the agri-food supply chain have generated considerable debate among scholars. Various factors contributing to localized constraints have become topics of discussion, encompassing market dynamics, geographical distances, weak associations with retailers, and consumer behavior impeding producers from attaining a critical mass of clients or penetrating broader markets [36–38]. Recent researches [39,40] associate vulnerabilities with weak supply contacts, supplier absence, or reliance on multiple suppliers. However, the myriad of challenges confronting supply chains underscore the necessity for a systematic approach as opposed to a random enumeration that may introduce confusion [41].

Iakovou et al. [42] systematically categorize challenges within the operational agri-food supply chain into three principal categories of factors. These factors encompass dependence on suppliers and contracts, variability, and the visibility and traceability of suppliers, including potential production interruptions. This classification enables a systematic approach to addressing dysfunctions in the agri-food supply chain, organizing them according to their specific impact. Consequently, it can be asserted that improving the sustainability of supply chains requires addressing multiple stages to achieve meaningful enhancements.

2.2. Critical Challenges in the Agri-Food Supply Chains

The contemporary agri-food supply chains depend heavily on the centralized control of information by central authorities, which poses potential transparency risks, information imbalances, and trust issues. Companies can selectively share information to shape their brand image, but they can also withhold details, limiting consumer access to relevant information. The centralization of supply chains increases susceptibility to bribery, leading to potential network disruptions from a single failure [43]. Consequently, consumer concerns intensify, demanding more information prior to a purchase.

The global expansion of the agri-food industry has led to intricate collaborative networks known as agri-food supply chains, which facilitate the movement and distribution of goods across diverse markets. The supply chain networks involve various stakeholders, including farmers, distributors, processors, wholesalers, retailers, and end consumers, all of whom seek high-quality and safe products that also offer comprehensive information. Nowadays, agri-food production operates within complex value chains, requiring increased focus on handling procedures, including production and storage [44,45].

In this context, it is essential to acknowledge that critical issues such as agri-food safety, agri-food authenticity, agri-food fraud, agri-food waste, and agri-food loss, along with inefficient processes, warrant increased attention to address the enduring lack of consumer trust in the agri-food industry, notwithstanding the presence of legislated regulations and policies [46].

2.2.1. Agri-Food Safety

Increased consumer awareness has heightened the importance of agri-food safety in the traditional supply chains. Current challenges arise from quality variations, external factors, and complex processing, leading to failures encompassing foodborne illnesses, subpar quality, mislabeling, and undisclosed ingredients [46]. To address these concerns, traceability has emerged as a pivotal solution, albeit with considerable complexities, necessitating a comprehensive supply chain reassessment [41]. Therefore, ensuring agri-food safety requires rigorous oversight at each product life cycle stage, involving robust agri-food control systems and standardized practices at governmental and operational levels to uphold stringent standards.

2.2.2. Agri-Food Authenticity and Agri-Food Fraud

Agri-food fraud presents multifaceted challenges, impacting consumer trust, fair business competition, and brand reputation, and might result in long-term economic repercussions. Instances of agri-food fraud entail activities such as substituting ingredients, incorporating substances to mimic higher quality, disseminating incorrect information about origin or composition, and deviating from declared prior distribution processes. In this context, the establishment of precise and unequivocal product specifications plays a pivotal role in the verification of agri-food authenticity. Nevertheless, achieving consensus on these specifications among different countries is a challenging endeavor, given that authenticity standards arise from different sources, such as national and international legislation and governmental and non-governmental bodies [44].

2.2.3. Agri-Food Loss and Agri-Food Waste

Agri-food loss and agri-food waste constitute additional critical challenges within the realm of food security, which contribute to unjustified environmental stress and the misallocation of resources for agri-food production, transportation, and preservation.

Agri-food loss denotes a reduction in the quantity or quality of agri-food items, resulting from decisions and interventions made by participants in the supply chain, commencing at the production stage. The issue of agri-food loss presents a multifaceted challenge, attributed to a variety of factors, including suboptimal farm management, processing-related issues, surplus production, and the instability of markets. These complexities become particularly pronounced in instances where unsustainable farming practices contribute to the depletion of natural resources [47,48].

Similarly, agri-food waste refers to the reduction in either the quantity or quality of agri-food products, specifically arising from choices and activities undertaken by retailers, agri-food service providers, and end consumers [47]. Taking into account the world's struggles with global hunger and resource wastage, agri-food waste results in an economic loss of USD 940 billion annually, amounting to 158 and 298 kg per capita waste in Europe alone. The lack of infrastructure, inefficiencies in handling, and missing storage capacities further contribute to overall agri-food waste [41].

Agri-food loss and agri-food waste contribute to unjustified environmental stress and the misallocation of resources designated for agri-food production, transportation, and preservation. Statistics indicate that approximately 14% of global agri-food production is lost, with an additional 17% being wasted [47]. These losses and wastages span the entirety of the agri-food supply chain, originating from agricultural production, continuing through industrial processing and distribution, and culminating in household consumption [46]. Moreover, loss patterns vary according to the development stage of each country, with developing nations experiencing pre-consumer losses and developed regions grappling with post-consumer waste [41].

2.2.4. Inefficient Processes

Trading, auditing, and regulatory enforcement are among the various supply chain activities plagued by inefficiencies in conventional practices. The partial digitalization of these processes, which consistently require manual handling and paperwork, is the primary reason for faltering efficiencies. Additionally, local databases create inaccessibility and redundancy issues. These operational complexities and financial burdens result from the lack of a single reliable data source and a convoluted data retrieval process. Relying on paper-based settlement methods, a larger number of intermediaries, and traditional databases heightens the risk of information loss and the oversight of illicit activities [44].

The examination of challenges inherent in supply chains establishes the foundation for exploring opportunities to augment the effectiveness, efficiency, resilience, and sustainability of agricultural markets and agri-food supply chains. Policymakers, industry leaders, and all stakeholders must work collaboratively towards integrated approaches that address market limitations, alleviate supply chain disruptions, and enhance sustainable outcomes. Technological innovations, infrastructure improvements, policy reforms, and investment in research are crucial components of the strategic development of these systems. Strengthening supply chains serves as a pivotal means to construct a more food-secure and sustainable future, ultimately fostering global nourishment through equitable and responsible practices.

2.3. Blockchain Technology as an Opportunity for Enhancing Agri-Food Supply Chains

Blockchain technology, known for its decentralized and widely distributed ledger, offers a secure and transparent method for recording transactions. It operates through individual blocks that contain specific sets of transactions connected via cryptographic hashes to ensure chronological consistency. Key blockchain principles, including decentralization, immutability, consensus mechanisms, and transparency, create a strong foundation for enhancing data integrity and instilling trust [49].

Due to their centralized structure, traditional supply chains are susceptible to data security breaches and fraudulent activity. By contrast, blockchain-driven supply chains provide a higher level of security through consensus mechanisms and encryption. This subsequently diminishes the probability of unauthorized access and tampering. In terms of data transmission, traditional supply chains tend to display opacity and fragmentation, whereas blockchain-driven supply chains offer transparency through real-time updates. Lastly, traditional supply chains can fail at a single point in the network. This is less likely to happen in blockchain-based systems because they have built-in fault tolerance mechanisms. This approach renders the blockchain network capable of sustaining its operation, rejecting flawed or deceitful transactions, and thereby ensuring data integrity [50].

Table 1 presents a comparison between traditional supply chains and blockchain-driven supply chains.

Table 1. Comparison between traditional and blockchain-based supply chains (*source: adapted from [50]*).

Item	Traditional Supply Chain	Blockchain-Based Supply Chain
Data integrity	Data can be altered	Immutable, tamper-proof
Information flow	Opaque, fragmented	Transparent, real-time updates
Trust establishment	Contractual agreements, intermediaries are involved	Cryptographic techniques, trust through technology
Authority	Centralized	Decentralized consensus mechanism
Fault tolerance	Risk of a single point of failure	Fault tolerance mechanisms

Given the prevailing challenges in agri-food supply chains, the emergence of blockchain technology presents a promising avenue for establishing a secure framework for supply chain traceability [51]. The capabilities of blockchain technology extend to addressing issues of confidentiality, integrity, and data availability, thereby overcoming current challenges in the supply chain realm [52].

In the context of customer demands, blockchain-driven agri-food supply chain platforms offer the potential to fulfill a wide array of requirements, including ensuring agri-food safety, conducting quality monitoring, enforcing regulatory control, enabling traceability for waste minimization, and providing analytical insights [45]. By facilitating visibility and ensuring reliable data transfers within fully digitized supply chains, blockchain technology not only offers provenance but also safeguards against counterfeit products. Nonetheless, establishing consumer acceptance and fostering confidence in the technology requires coordinated endeavors from organizations, considering past instances of credibility-related assertions [53].

In blockchain-based agri-food supply chains, three layers—the physical layer, the digital layer, and the blockchain network layer—collaborate to facilitate the seamless movement of agri-food products. The physical layer encompasses various processes, including sourcing, manufacturing, product identification, quality verification, and distribution, ensuring that end consumers can trace the product origins and safety information. The digital layer utilizes technologies such as QR codes, RFID tags, and IoT sensors designed to measure temperature and humidity within an interconnected framework facilitated by the Internet. The blockchain network layer plays a central role in securely recording and storing transactions and data related to agri-food products using blockchain technology. Each operational activity involving digital technologies is meticulously documented within the blockchain network, ensuring immutability and chronological sequence. Moreover, transaction data validation is achieved through a consensus mechanism among stakeholders, with each verified block adding a permanent record to signal transaction completion [54,55].

Figure 1 depicts a graphical representation of the layers.

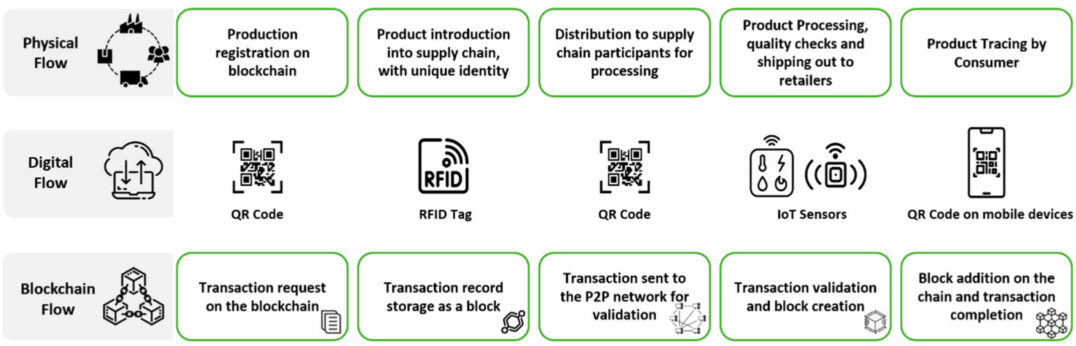

Figure 1. The three layers in a blockchain-based agri-food supply chain (*source: adapted from [54]*).

2.3.1. Benefits of Blockchain for Agri-Food Supply Chains

Blockchain technology has gained considerable attention for its capacity to modernize agri-food traceability across the supply chain, enabling meticulous tracking and recording of each stage from production to consumption. This not only fosters consumer trust but also enhances the efficiency of agri-food safety and control [56].

With its fundamental attributes, blockchain holds the potential to bring about a revolutionary transformation in the agri-food industry by addressing prevailing inefficiencies and challenges. This technology exhibits the potential to significantly amplify the transparency and security of the agri-food supply chain, thereby reinforcing consumer confidence in the system, streamlining the intricacies of supply chain dynamics, and elevating overall supply chain performance [46,57].

The concept of traceability in the context of the agri-food supply chain encompasses a comprehensive array of activities, spanning from the initial recording of relevant information to the ongoing tracking and verification of the movement of products. The achievement of precise traceability through blockchain solutions confers benefits encompassing enhanced decision making, quality assurance, and the expedited conduct of product recall procedures. Alongside its function in authentication, traceability operates as a strategic marketing instrument, fostering customer loyalty and bolstering their trust [46].

The immutability feature ensures the integrity of data records by preventing unauthorized alterations, particularly during agri-food recalls, to prevent tampering and evade responsibility. This attribute also provides assistance during inquiries in cases of potential agri-food crises, facilitating the acceleration of product recalls and reinforcing claims regarding the authenticity of products [46]. Furthermore, the immutability inherent to blockchain-based solutions ensures the confidentiality and reliability of data, preventing any individual actor from independently altering recorded information. This stipulation mandates a consensus-based decision-making process, necessitating agreement among all participants before any modifications are incorporated into the network [57].

Enhancing transparency stands as another advantage derived from the integration of blockchain technology in agri-food supply chain management. This pertains to the establishment of transparent documentation, which facilitates improved traceability. Beyond its potential to expedite responses to failures, transparency holds the promise of simplifying routine business operations through the establishment of an authentication and confirmation network [44].

The inherent decentralization characteristic of blockchain-based systems, as opposed to conventional transaction systems, eliminates the need for central authorities in transactions, fostering direct interactions among supply chain participants. Authorized users collectively validate transactions, monitor records, and access data. This is crucial for agri-food supply chains, as it facilitates the transparent and credible recording of product information. Decentralization also prevents network vulnerabilities, reducing susceptibility to hacking threats by requiring user majority control [46].

Lastly, smart contracts, a distinctive feature embedded within blockchain technology, provide automated mechanisms that streamline processes according to predefined agreements. Consequently, the integration of blockchain technology serves to mitigate the potential risks associated with transactions conducted in environments characterized by limited trust, while concurrently enhancing the visibility and transparency of supply chain operations, heightening operational efficiency, and ensuring the protection of stakeholder interests [46,58].

2.3.2. Challenges of Implementing Blockchain in Agri-Food Supply Chains

Blockchain technology holds the potential to revolutionize agri-food supply chains; however, despite its promising benefits, several challenges have been identified, including storage capacity, scalability, privacy concerns, regulatory obstacles, elevated costs, integration issues with existing systems, and a shortage of blockchain expertise. Of particular concern are the challenges related to storage capacity and scalability, impacting the decentralization of the agri-food value chain and leading to notable repercussions on different facets of the blockchain, such as data size, transaction processing speed, and data transmission latency. The increasing transaction volume within agri-food value chains exacerbates these challenges, resulting in resource-intensive processes, reduced system capacity, and prolonged synchronization periods for new users [59,60].

Blockchain technology's potential for transparency and trust enhancement is countered by privacy concerns, as traceable transactions can be linked to identifiable users through public keys or cryptographic hashes. Mitigating these concerns requires employing cryptographic techniques or obscuring transaction associations yet achieving complete anonymity remains challenging. The integration of blockchain into the agri-food supply chain underscores the need for comprehensive policies protecting user rights and proprietary information, given blockchain's transparent nature [58,59].

The high setup costs associated with blockchain adoption in food supply chains pose significant concerns, particularly in cost-sensitive sectors like groceries and commodities, potentially hindering widespread industry adoption unless competitors follow suit. However, the anticipated benefits of blockchain, such as streamlined operations, data transparency, traceability, and risk reduction, are expected to outweigh these initial costs [61]. Additionally, integrating blockchain into existing supply chain structures requires substantial resources and technical expertise, emphasizing the importance of smooth integration with established databases and legacy systems [24].

Lastly, the limited availability of blockchain experts presents another obstacle, as familiarity with the technology significantly influences adoption attitudes, underscoring the need for a comprehensive understanding of its advantages and limitations across different supply chain stages to identify optimal solutions [59].

2.3.3. Blockchain Applications in the Agri-Food Sector

To clarify and better understand the benefits associated with the integration of blockchain technology in agri-food supply chains, we provide a detailed illustration and characterization of the widely recognized TE-FOOD platform, which is employed in both Western and Eastern Europe. The motivation for choosing this platform as a model of good practice lies in the implications it has on the selection of the target group and acquiring the required information for accomplishing the objectives of our research.

TE-FOOD is a blockchain-based traceability solution for livestock and fresh products, with a particular emphasis on emerging markets [62]. This system meticulously monitors items throughout the entire agri-food supply chain, encompassing stages such as farming, slaughterhouses, wholesalers, and retailers. Furthermore, TE-FOOD offers tools to consumers, supply chain entities, and regulatory authorities, enabling them to access comprehensive insights into the history and quality of products. The primary objectives of this platform include enhancing transparency and accessibility within the agri-food industry. It also aims to mitigate the impact of epidemics and agri-food fraud in emerging nations, promote informed consumer behavior, and support competitiveness among farms [63].

The TE-FOOD platform is structured with three distinct tiers: a blockchain layer, an off-chain data layer, and a client application layer. Within the blockchain layer, there is an exchange market section, a unique ID management mechanism where products are given digital identities, and a ledger devoted to traceability and agri-food quality. Subsequently, the off-chain data layer encompasses notifications and reports originating from agri-food supply chain participants. Lastly, the client application layer serves as a platform for both TE-FOOD's proprietary applications and third-party applications [64].

TE-FOOD possesses the capacity to generate distinct process flows tailored to diverse product categories. QR codes serve to establish a connection between the physical and digital layers through the TE-FOOD mobile application, thus facilitating the uploading and monitoring of data records. The platform also utilizes ID tags, which function as identification tools to ensure the traceability of agri-food products across the supply chain.

Figure 2 presents the process flow from farm to consumer for meat products within TE-FOOD's framework.

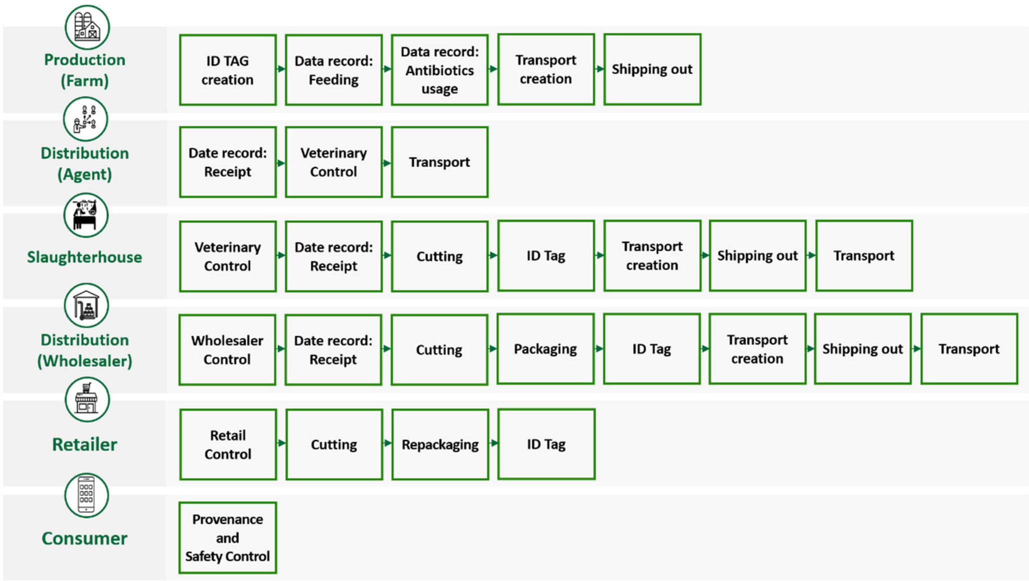

Figure 2. Process flow for meat products *(source: adapted from [63])*.

At the farm level, the application of ID tags is undertaken, concomitant with the inclusion of feeding and antibiotic utilization data in the blockchain ledger. This precedes the creation of transportation logs, ultimately leading to the shipping out of the consignment to the designated distributor (agent). This stage integrates preliminary veterinary oversight preceding the transportation to the slaughterhouse. The subsequent level of veterinary control falls under the purview of the slaughterhouse, which takes place prior to meat cutting and ID tag placement. Subsequently, the meat product is dispatched to the wholesaler, involving another layer of quality control. This stage is succeeded by a further phase of cutting, packaging, and tagging. Then, the transportation record is created and the product is shipped out to the retailer. During this stage, the product undergoes a meticulous inspection under the purview of the retailer, preceding subsequent activities such as cutting, repackaging, and the application of ID tags. Ultimately, customers possess the capability to trace the product's provenance, along with pertinent safety details within the mobile application.

Nowadays, over 6000 companies utilize the TE-FOOD platform to augment supply chain transparency, encompassing entities such as Auchan, Migros, and Grain Corp [58]. For example, Auchan, a multinational retail group, formed a partnership with TE-FOOD to integrate blockchain technology into its fresh agri-food supply chain, aiming to enhance transparency and quality assurance. After successful trials in Vietnam, this innovative approach has been implemented in France for the organic carrot supply chain, and in Italy, Spain, and Portugal for other specific products [65]. TE-FOOD provides Auchan consumers with the ability to trace agri-food products through QR code scanning using smartphones. This access provides authenticated information pertaining to agri-food quality, logistics, and every stage of the supply chain journey from farm to table [64].

3. Research Methodology

In the realm of the nascent research topic investigating the integration of blockchain technology into agri-food supply chains, various gaps in research become evident and warrant acknowledgment. Firstly, we acknowledge the lack of a universally applicable technology adoption model that companies and stakeholders can utilize to expedite the implementation of blockchain-driven innovation more effectively. Furthermore, our examination of the pertinent literature underscores the scarcity of studies grounded in empirical research that specifically address the adoption of blockchain technology within agri-food supply chains. Additionally, to the best of our knowledge, there is a lack of research that has systematically examined the determinants influencing the adoption of blockchain-based agri-food supply chain platforms, particularly among agri-food companies in Europe.

3.1. Research Approach and Research Objectives

Research exhibits an interdisciplinary nature as it delves into a topic of paramount importance within the context of intense market competition, namely digital innovation. By putting forth a fresh theoretical angle, this research seeks to add to the current fervent discussion around the adoption of blockchain technology. The uniqueness of this research resides in the development of a novel conceptual framework encompassing highly pertinent factors within the domain of agri-food supply chains. Research management is conducted throughout all stages of research through a gradual succession of premises in which objectives are formulated. Thus, research comprises the following:

a. Theoretical research that lays the foundation for the development of the proposed conceptual model, including the constructs and measurement items examining the intention to use blockchain-based platforms and the actual Usage Behavior (UB).
b. Empirical research demonstrated by investigations conducted across the agri-food supply chain sector in Europe.

Research objectives are articulated with the intention of realizing the anticipated outcomes, specifically the construction of a conceptual model delineating the factors that contribute to the adoption of blockchain technology.

In light of the distinctive attributes inherent to this research inquiry and the factors discerned therein, the subsequent specific research objectives have been proposed as follows:

O_1: identification of factors and their mutual influences that determine the adoption and utilization of blockchain technology, drawn from the specialized literature.
O_2: proposal of an extended and adapted conceptual model based on the UTAUT framework to suit the unique features of blockchain technology and the specific needs of the agri-food supply chain sector.
O_3: investigation of the relationship between organizational blockchain readiness and the expected Usage Behavior (UB) of blockchain-based agri-food supply chain platforms.
O_4: assessment of the distinct impact of various determinants on decision-making processes and identifying the factor with the strongest association with the intention to use blockchain-based agri-food supply chain platforms.
O_5: formulation of recommendations for theory and practice regarding the adoption of blockchain technology in agri-food supply chains.

3.2. Conceptual Model and Research Hypotheses

This study introduces an innovative conceptual framework that adapts and extends the Unified Theory of Acceptance and Use of Technology Model (UTAUT) to explore and assess the determinants of blockchain technology adoption within the domain of agri-food supply chains.

The UTAUT model, originating from the work of Venkatesh et al. [66], delineates the following three key factors influencing the behavioral intention to adopt a new technology: performance expectancy, which assesses how well the technology aligns with user expectations and improves their performance; effort expectancy, which delves into users' perceptions of the ease of using the technology; and social influence, which examines external factors impacting the technology acceptance. Additionally, the model encompasses the following two primary drivers of Usage Behavior (UB): behavioral intention to utilize the new technology and facilitating conditions, incorporating organizational and technical support. In order to improve the predictive capability, moderating variables such as gender, age, voluntariness of use, and previous experience have also been introduced to the model [67].

The UTAUT model serves as a comprehensive framework for understanding the adoption of emerging technologies, with the capacity to explain as much as 70% of the variance in behavioral intention and around 50% in actual Usage Behavior (UB) [66]. However, despite its robust explanatory power, subsequent research identifies limitations, including the marginal impact of moderating factors such as age, experience, gender, and voluntariness of use. Studies often selectively employ subsets of the model, underscoring the necessity of considering specific research objectives and contextual elements in its application [67].

The proposed conceptual model, developed by the authors in their recent research, provides a novel theoretical framework, modifying and extending the foundational UTAUT model, while also addressing previous constraints. As such, the new model incorporates factors derived from the extant literature on technology adoption, which have been tailored to suit the specific context of agri-food supply chain management. Moreover, this model takes into account the particular expectations and characteristics of its target group, consisting of experts and specialists from agri-food companies operating in Europe. Therefore, the initial UTAUT model has been enhanced through the incorporation of three novel constructs: agri-food supply chain partner preparedness, perceived trust, and organizational blockchain readiness. The incorporation of these variables aims to augment the capacity of the model to comprehensively capture the complexities inherent in the agri-food value chain, thus enhancing its practical relevance.

Figure 3 provides a visual representation of the proposed conceptual framework, elucidating the hypothesized relations among the various constructs.

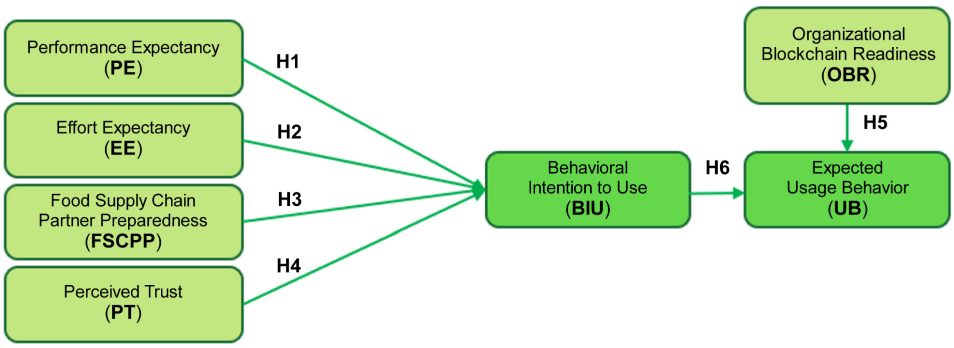

Figure 3. Proposed conceptual model (*source: by author*).

The selected constructs in this study, in combination with the established connections derived from the previous literature on technology adoption, establish the foundation for the hypotheses outlined in the subsequent section.

3.2.1. Performance Expectancy (PE)

Performance expectancy encompasses an individual's assurance that a specific technology will effectively address challenges and facilitate the attainment of desired job performance objectives, particularly in conjunction with benefits that facilitate the adoption of the service [68]. For this research, performance expectancy specifically pertains to the managers' confidence in deploying blockchain technology within agri-food supply chains to enhance their companies' performance. Prior empirical inquiries have consistently corroborated the substantial impact of performance expectancy on the intention to adopt blockchain technology [68,69]. Hence, we posit the following hypothesis:

H1. *Performance Expectancy (PE) positively impacts the Behavioral Intention to Use (BIU) blockchain-based agri-food supply chain platforms.*

3.2.2. Effort Expectancy (EE)

Effort Expectancy (EE) pertains to the assessment of the level of ease associated with the utilization of a specific technology. When users perceive a technology as less intricate and demanding less effort than the current system, their inclination to embrace this technology improves [70]. In this research context, assessing the user-friendliness of blockchain technology involves scrutinizing both the time investment and the effort required from participants in the agri-food supply chain. Consequently, one can argue that, if supply chain participants perceive the utilization of blockchain-based agri-food supply chain platforms as involving minimal effort and being easily navigable, they will be satisfied with their experience in using such novel technology. This relationship between effort expectancy and the intention to adopt blockchain aligns with prior research findings [69,70]. Drawing upon the insights from prior investigations, we posit the following hypothesis:

H2. *Effort Expectancy (EE) has a positive impact on the Behavioral Intention to Use (BIU) blockchain-based agri-food supply chain platforms.*

3.2.3. Agri-Food Supply Chain Partner Preparedness (FSCPP)

Agri-Food Supply Chain Partner Preparedness (FSCPP) has been derived from the initial UTAUT model's social influence construct to specifically address the pivotal function of supply chain partners in facilitating the seamless implementation of blockchain technology within agri-food supply chains. Partner preparedness refers to the level of readiness exhibited by business partners when embracing an innovative technology. The readiness level encompasses both the inclination to embrace blockchain technology and the capability to assimilate it into operational processes, exerting a substantial impact on the overall effectiveness of blockchain implementation [71].

The effective implementation of blockchain technology in agri-food supply chains requires strong collaboration among supply chain partners [72]. When partners lack technical and financial resources, unilateral adoption decisions become challenging [73]. Also, external resistance from supply chain partners, stemming from reluctance to integrate technology or lack of top management support, can significantly delay adoption [74].

Prior empirical investigations underscore the significance of partner preparedness in enabling the smooth implementation and successful assimilation of blockchain technology. For instance, Clohessy and Acton [66] identified partner preparedness as the most influential factor influencing the adoption of blockchain technology. Additionally, studies conducted by Malik et al. [73], Kamble et al. [75], and AL-Ashmori et al. [76] unveiled a significant association between partner preparedness and the inclination to embrace blockchain technology. In consideration of these research findings, we formulate the subsequent hypothesis:

H3. *Agri-Food Supply Chain Partner Preparedness (FSCPP) has a positive impact on the Behavioral Intention to Use (BIU) blockchain-based agri-food supply chain platforms.*

3.2.4. Perceived Trust (PT)

The notion of trust is characterized as the propensity to embrace novel and possibly ambiguous concepts. In the context of adopting blockchain technology, Perceived Trust (PT) can be interpreted as consumers' reliance on accepting a nascent technology. Trust constitutes a fundamental component fostering confidence and alleviating uncertainty for individuals deliberating the adoption of emerging technologies [77]. The absence of trust in technology is a significant determinant in the process of technology adoption [68].

Previous research studies have explored the relationship between trust and the willingness to adopt blockchain technology, consistently revealing trust as a significant factor influencing the individuals' intentions to embrace blockchain. Within the context of agri-food supply chains, Saurabh and Dey [78] discovered that trust can have a significant impact on the decision-making processes of supply chain actors concerning their blockchain adoption intentions. Other empirical studies conducted by Queiroz et al. [79], Liu and Ye [80], and Ullah et al. [81] have demonstrated the significant influence of individuals' trust (both in the technology and the diverse stakeholders) on their preparedness and eagerness to adopt and interact with blockchain technology. This is especially pertinent for users who are unfamiliar or less experienced with blockchain, as their initial level of confidence significantly shapes their decision to embrace this pioneering technology. Therefore, we posit the following hypothesis:

H4. *Perceived Trust (PT) positively affects the Behavioral Intention to Use (BIU) blockchain-based agri-food supply chain platforms.*

3.2.5. Organizational Blockchain Readiness (OBR)

The Organizational Blockchain Readiness (OBR) construct, derived from the facilitating conditions factor of the original UTAUT model, relates to the level of preparedness exhibited by an organization concerning the adoption of a novel technology. It encompasses the organizational ability to adapt its culture, structures, and operations to align with the requirements of the impending change. Organizational readiness also encompasses the effective allocation of resources, ensuring the required IT knowledge and expertise to facilitate the successful implementation of blockchain technology. Within this framework, vital organizational resources such as technological infrastructure, skilled personnel, and adequate funding play a pivotal role in the technology adoption [82].

Additionally, there exists an additional facet of organizational readiness, namely absorptive capacity, which refers to the ability to efficiently leverage innovations and existing knowledge [83]. In this context, companies demonstrating higher levels of readiness in both organizational and information communication technology domains are more inclined to adopt novel technologies within their supply chains compared with those with lower readiness levels [74].

In prior empirical investigations by Clohessy and Acton [71], Li et al. [84], and Lu et al. [85], organizational readiness has been identified as a critical determinant influencing the adoption of blockchain technology. Furthermore, Sternberg et al. [74] ascertained that organizational readiness positively affects the intentions of supply chain participants to adopt blockchain-based solutions. Drawing from earlier research, we propose the following hypothesis:

H5. *Organizational Blockchain Readiness (OBR) positively influences the expected Usage Behavior (UB) of blockchain-based agri-food supply chain platforms.*

3.2.6. Behavioral Intention to Use (BIU)

In the realm of social psychology, there has been extensive research into behavioral intentions, focusing on a user's deliberate inclination to engage in future behaviors. In the context of adopting innovative technologies, behavioral intention encompasses an individual's subjective perception and personal conviction regarding the likelihood of employing or acquiring a particular technology in the future [16,86].

Previous research studies have consistently underlined the importance of behavioral intention as a predictor of actual Usage Behavior (UB). Studies conducted by Venkatesh et al. [66] and Khan and Abideen [87] provided compelling findings highlighting the significant impact of behavioral intention on actual Usage Behavior (UB). Considering the benefits offered by blockchain-based platforms in agri-food supply chain management, the association between intention to use and subsequent Usage Behavior (UB) assumes particular significance within the envisaged conceptual framework. Based on the previous research findings, the subsequent hypothesis has been developed:

H6. *Behavioral Intention to Use (BIU) blockchain platforms for agri-food supply chains is positively correlated with expected Usage Behavior (UB).*

3.3. Model Validation

In order to validate the proposed model, the PLS-SEM (Partial Least Squares Structural Equation Modeling) approach was applied, utilizing version 4 of the SmartPLS software [88]. The utilization of PLS-SEM has gained prominence as a favored approach for estimating path models with latent variables and their interrelations. A commonly pursued objective of PLS-SEM analysis is the identification of pivotal determinants for essential constructs, including but not limited to behavioral intentions and user behavior. A key methodological rationale for the appeal of PLS-SEM lies in its alignment with a causal-predictive framework, wherein the primary objective is to assess the predictive efficacy of a conceptual model grounded in theoretical and logical foundations. Furthermore, PLS-SEM facilitates the assessment of intricate models containing numerous constructs and indicator variables while requiring significantly reduced sample sizes in comparison with factor-based SEM approaches [89].

In contrast with linear regression, which may have limitations in addressing measurement inaccuracies, SEM adopts a confirmatory perspective in evaluating the structure grounded in the phenomenon, yielding more reliable insights into the patterns of numerous indicator variables. The selection of PLS-SEM for this research was motivated by its capacity to model causal relationships grounded in theory, positioning it as a modern approach within the realm of multivariate analysis. Moreover, it appears that PLS-SEM is more suitable for examining the variance relationships between dependent and independent variables, demonstrating advantages over covariance-based methods in structural equation modeling [90].

Partial Least Squares Structural Equation Modeling has gained widespread popularity across various disciplines, including social sciences, for developing and estimating complex models. Beyond social sciences, PLS-SEM has found relevance in domains like agriculture, engineering, environmental sciences, geography, and medicine. Notably, this analytical approach has been effectively employed in recent research on technology adoption within the supply chain management field [77,91].

3.4. Measurement Items

Regarding the research tool utilized, a questionnaire comprising 22 measurement items was deployed to evaluate the constructs integrated into the envisaged conceptual framework. Participants in the study assessed these items utilizing a Likert scale with seven points, where a rating of one represented "strongly disagree", and a rating of seven denoted "strongly agree". Respondents were encouraged to furnish their responses grounded in personal comprehension and individual experiences. Emphasis was placed on the absence of right or wrong answers, and their inputs were exclusively intended for academic research purposes.

Table 2 provides an aggregation of these constructs and their associated measurement items, along with the scholarly references from which they were sourced.

Table 2. Constructs and measurement items.

Construct	Measurement Item	Sources
PE	***PE1:*** *The incorporation of blockchain technology within the agri-food supply chain has the potential to improve my company's efficiency.* ***PE2:*** *Integrating blockchain technology in agri-food supply chains offers the opportunity for my company to attain cost efficiencies.* ***PE3:*** *The utilization of blockchain technology holds promise in optimizing various aspects of our supply chain processes.*	[66,92]

Table 2. *Cont.*

Construct	Measurement Item	Sources
EE	***EE1:*** *My organization would find it easy to acquire the expertise in operating blockchain-based solutions for agri-food supply chains.* ***EE2:*** *The utilization of blockchain platforms would be clear and comprehensible.* ***EE3:*** *I anticipate that blockchain-based platforms for agri-food supply chains would be easy to use.*	[92,93]
FSCPP	***FSCPP1:*** *The successful integration of blockchain technology within our organization necessitates support from our supply chain partners.* ***FSCPP2:*** *The key supply chain partners exhibit both technological readiness and financial preparedness for blockchain adoption.* ***FSCPP3:*** *The agri-food supply chain partners acknowledge the significance of blockchain innovation and its potential value.*	[67,76,94]
PT	***PT1:*** *From my perspective, blockchain platforms for agri-food supply chains are deemed to be trustworthy.* ***PT2:*** *I have confidence in the reliability of blockchain solutions for agri-food supply chains.* ***PT3:*** *I place trust in blockchain's ability to perform effectively even without constant monitoring.*	[67,69,95,96]
OBR	***OBR1:*** *My company needs to ensure it has access to personnel with the necessary expertise to support blockchain adoption.* ***OBR2:*** *My company possesses the financial resources required for the implementation of blockchain-based agri-food supply chain platforms.* ***OBR3:*** *My company possesses the suitable technological infrastructure required for the incorporation of blockchain technology.* ***OBR4:*** *My company needs to facilitate the availability of service providers to support the adoption of blockchain technology.*	[67,74,83,94]
BIU	***BIU1:*** *I anticipate that the integration of blockchain technology into my company will occur in the imminent future.* ***BIU2:*** *My company is inclined towards the adoption of blockchain-based platforms for agri-food supply chains.* ***BIU3:*** *There is an intention within my company to utilize solutions based on blockchain technology.*	[93,97,98]
UB	***UB1:*** *I foresee a propensity within my company to adopt blockchain technology for agri-food supply chains in the foreseeable future.* ***UB2:*** *I project that my company will regularly utilize platforms based on blockchain technology for agri-food supply chains in the future.* ***UB3:*** *I anticipate a preference within my company for the use of blockchain-driven platforms in agri-food supply chains over traditional systems.*	[67,97]

4. Analysis of the Structural Model

Analysis of the conceptual model was systematically conducted through a sequence of prescribed steps. These encompassed the delimitation of the target group, application of the questionnaire, data collection and processing, testing and evaluation of correlations between the analyzed structures, assessment of the reliability and validity of the model, analysis of causal relationships within the structural equation model, and hypothesis testing culminating in model validation.

4.1. Sample and Data Collection

The method employed for the selection of the target group involved expert sampling. The participants were selected to encompass individuals with a comprehensive understanding of the complexities associated with food supply chain operations and a good understanding of innovative technologies, specifically focusing on blockchain technology. The expert sampling method proves advantageous by yielding high-quality data, given that experts contribute more precise and reliable information owing to their extensive knowledge and experience within their respective domains [99].

Given this study's focus and objectives, participants were carefully selected from experts and specialists directly involved in implementing blockchain technology in agri-food supply chains within the countries under study. These individuals were chosen to embody a comprehensive understanding of the intricacies of food supply chain operations and possess significant knowledge of innovative technologies, particularly blockchain. Many held decision-making or specialized roles in agri-business organizations. Additionally, the selection of the eight countries (Czech Republic, France, Germany, Italy, Poland, Romania, Spain, and Switzerland) from which the specialists were drawn was guided by the availability of experts who are knowledgeable and proficient in blockchain adoption. The aim was also to capture relevant insights from countries where blockchain technology is well established and from those where its adoption is still emerging. A common characteristic among all eight countries was the prior adoption of traditional advanced technologies in the food industry. Consequently, a total of 175 experts engaged in blockchain technology projects across these nations participated in this study.

This research adopted a cross-sectional survey approach and the questionnaire was generated using the Qualtrics platform and subsequently disseminated between July and September 2023. After filtering out incomplete submissions, a sum of 175 comprehensive and valid responses were gathered. The majority of respondents were from Switzerland (22.86%) and Germany (17.14%), with subsequent representation from Italy (14.29%), France (13.14%), Spain (10.86%), Romania (10.29%), Poland (6.29%), and Czech Republic (5.14%).

The professional profile of this study's participants can be found in Table 3.

Table 3. Professional profile of study participants.

Professional Characteristic	Response Variants	Proportion of Answers
Supply chain area	Input supplier	6.86%
	Farming	26.29%
	Processing/packaging	32.00%
	Logistics	20.00%
	Retailers	14.86%
Professional domain	Technical	58.86%
	Economic	36.00%
	Other	5.14%
Management level or decision-making level	Junior level	24.00%
	Middle level	57.71%
	Senior level	18.29%
Industry expertise	0–10 years	17.14%
	10–25 years	52.00%
	>25 years	30.86%

The data indicate that the individuals chosen for participation in the study possessed qualifications suitable for the expert sampling method, meeting the requisite profile criteria for this survey methodology.

Subsequently, a comprehensive collinearity assessment was conducted to evaluate the potential occurrence of Common Method Bias (CMB) in the data collection process via online surveys. CMB has the potential to artificially inflate or distort the associations between internal and external variables with a single respondent. Kock [100] introduced a pragmatic approach for the identification of common method bias, involving the examination of Variance Inflation Factors (VIFs). When a VIF surpasses the threshold of 3.3, it indicates the presence of problematic collinearity, suggesting that the model may be susceptible to the influence of Common Method Bias (CMB).

Table 4 indicates that the inner model's Variance Inflation Factors (VIFs), acquired through a thorough assessment of collinearity, consistently registered below the established threshold of 3.3. Hence, we can assert that there were no observable indications of Common Method Bias (CMB) in the model.

Table 4. Inner model's variance inflation factors.

	VIF
BIU ⇒ UB	2.373
OBR ⇒ UB	2.373
EE ⇒ BIU	1.206
FSCPP ⇒ BIU	1.985
PE ⇒ BIU	1.805
PT ⇒ BIU	2.249

4.2. Validity and Reliability Tests and Assessment of Discriminant Validity

For the determination of the composite reliability of all constructs, both the Composite Reliability (CR) and Dijkstra–Henseler's rho (rhoA) were computed and assessed [101]. In the case of all constructs included in the conceptual model, the CR values exceeded 0.7, signifying that the items employed to gauge each construct consistently and reliably capture the fundamental nature of the respective construct [93].

Furthermore, the internal consistency and reliability were affirmed, as both Cronbach's alpha and Dijkstra–Henseler's rho measurements surpassed the 0.7 benchmark [99]. The reliability of the measurement items was also evaluated following the criterion mentioned by Rădulescu et al. [102], which stipulates that the factor loading should exceed 0.60. For all measurement items, the loadings exceeded the recommended threshold, ranging from 0.788 to 0.936.

The construct's convergent validity was evaluated through the utilization of the Average Variance Extracted (AVE). According to Fornell and Larcker's criterion [103], AVE values should surpass 0.5. Our findings demonstrated that all constructs achieved noteworthy AVE scores, ranging from 0.714 to 0.863. This suggests that a minimum of 71.4% of the variance in the indicators can be attributed to the latent construct, indicating a strong level of convergent validity. In the subsequent evaluation of reliability and validity, we conducted an analysis that included an examination of the Variance Inflation Factor (VIF) to detect any collinearity between the constructs. To ensure the absence of collinearity, the VIF value should not exceed 5.00, as recommended by [90]. Our findings demonstrated that all VIF values remained below 5.00, providing strong evidence that there was no collinearity among the variables under investigation.

The validity and reliability indicators are depicted in Table 5.

Discriminant validity concerns the degree to which a particular construct is truly distinguishable from other constructs in the structural model. Initially, the discriminant validity of the proposed constructs was evaluated using Fornell and Larcker's criterion.

This criterion posits that the extent of shared variance between a construct and its indicators should surpass the shared variance among the constructs themselves. The results demonstrated that the square root of the Average Variance Extracted (AVE) surpassed the respective correlation values among the constructs, thereby validating the discriminant validity of the proposed constructs. Table 6 presents detailed results regarding the discriminant validity in accordance with Fornell and Larcker's criterion [103].

To further assess the discriminant validity of the latent variables within the model, the Heterotrait–Monotrait (HTMT) ratio of correlations was utilized. The results indicated that the HTMT ratio was below the specified limit of 0.90, aligning with the criteria recommended by Henseler et al. [104] and Hair et al. [90]. These results provided evidence that the reflective variables exhibited clear distinctions from each other.

Table 7 provides a detailed assessment of the discriminant validity of the constructs, assessed through the HTMT ratio criterion.

Table 5. Validity and reliability indicators.

Construct/Item	Factor Loading	VIF	Cronbach's Alpha	rhoA	CR	AVE
BIU			0.877	0.881	0.924	0.804
BIU1	0.932	3.782				
BIU2	0.919	3.429				
BIU3	0.835	1.806				
OBR			0.947	0.948	0.962	0.863
OBR1	0.917	3.587				
OBR2	0.936	4.808				
OBR3	0.928	4.370				
OBR4	0.934	4.469				
EE			0.865	0.874	0.917	0.786
EE1	0.893	2.207				
EE2	0.873	2.265				
EE3	0.894	2.217				
PE			0.800	0.800	0.882	0.714
PE1	0.795	1.344				
PE2	0.864	2.487				
PE3	0.874	2.548				
PT			0.853	0.879	0.911	0.774
PT1	0.907	2.679				
PT2	0.926	2.896				
PT3	0.800	1.684				
FSCPP			0.878	0.889	0.924	0.802
FSCPP1	0.894	2.182				
FSCPP2	0.874	2.434				
FSCPP3	0.919	3.101				
UB			0.831	0.829	0.900	0.750
UB1	0.886	3.776				
UB2	0.918	4.181				
UB3	0.788	1.413				

Table 6. Assessment of discriminant validity: Fornell and Larcker's criterion.

	BIU	OBR	EE	FSCPP	PE	PT	UB
BIU	**0.896**						
OBR	0.761	**0.929**					
EE	0.444	0.404	**0.887**				
FSCPP	0.693	0.665	0.311	**0.896**			
PE	0.680	0.683	0.384	0.527	**0.845**		
PT	0.696	0.622	0.234	0.680	0.612	**0.880**	
UB	0.625	0.603	0.440	0.606	0.657	0.505	**0.866**

Note: diagonals (bold) are the square root of the AVE, while the off-diagonals are correlations.

Table 7. Assessment of discriminant validity: Heterotrait–Monotrait (HTMT) ratio matrix.

	BIU	OBR	EE	FSCPP	PE	PT	UB
BIU							
OBR	0.836						
EE	0.501	0.442					
FSCPP	0.782	0.724	0.350				
PE	0.804	0.772	0.458	0.607			
PT	0.796	0.688	0.259	0.766	0.731		
UB	0.729	0.675	0.523	0.708	0.800	0.600	

4.3. Results of the Structural Equation Modeling

For the analysis of the structural model, a standard bootstrapping technique was employed to examine the statistical significance of the path coefficients, using 5000 resampling iterations. Furthermore, an assessment of the structural model's explanatory power was carried out using the coefficient of determination (R^2).

In evaluating the research hypotheses, a significance test was conducted on the path coefficients. In accordance with the criteria outlined by Chin et al. [105], the path coefficients should exceed a critical "t-value" of 1.645 at a significance level of 0.05 or exceed 2 at a significance level of 0.01. The results obtained from the analysis of the structural model suggested the presence of a statistically significant causal link between Performance Expectancy (PE) and Behavioral Intention to Use (BIU) at a significance level of 1% (PE → BIU, β = 0.286, t-value = 4.665, $p < 0.01$). Therefore, hypothesis H1 receives empirical support.

Moreover, the hypothesized positive association between Effort Expectancy (EE) and Behavioral Intention to Use (BIU), as stated in hypothesis H2, was observed to be statistically significant (EE → BIU, β = 0.176, t-value = 3.167, $p < 0.01$). Likewise, Perceived Trust (PT) was determined to exert a positive effect on Behavioral Intention to Use (BIU) (PT → BIU, β = 0.275, t-value = 4.049, $p < 0.01$). Consequently, hypothesis H4 is likewise substantiated by the empirical evidence.

Furthermore, it was determined that Agri-Food Supply Chain Partner Preparedness (FSCPP) holds the strongest positive association with Behavioral Intention to Use (BIU) agri-food supply chain platforms leveraging blockchain technology (FSCPP → BIU, β = 0.301, t-value = 4.790, $p < 0.01$), confirming the hypothesized effect in H3. Additionally, Organizational Blockchain Readiness (OBR) was established as a substantial factor influencing the expected Usage Behavior (UB) (OBR → UB, β = 0.305, t-value = 3.527, $p < 0.01$).

Lastly, it was also proved that Behavioral Intention to Use (BIU) plays a pivotal role in predicting the expected Usage Behavior (UB) (BIU → UB, β = 0.393, t-value = 4.294, $p < 0.01$). These observed results are consistent with the effects articulated in hypotheses H5 and H6, thereby substantiating their statistical significance.

Figure 4 offers a graphical depiction of the causal connections within the proposed structural equation model.

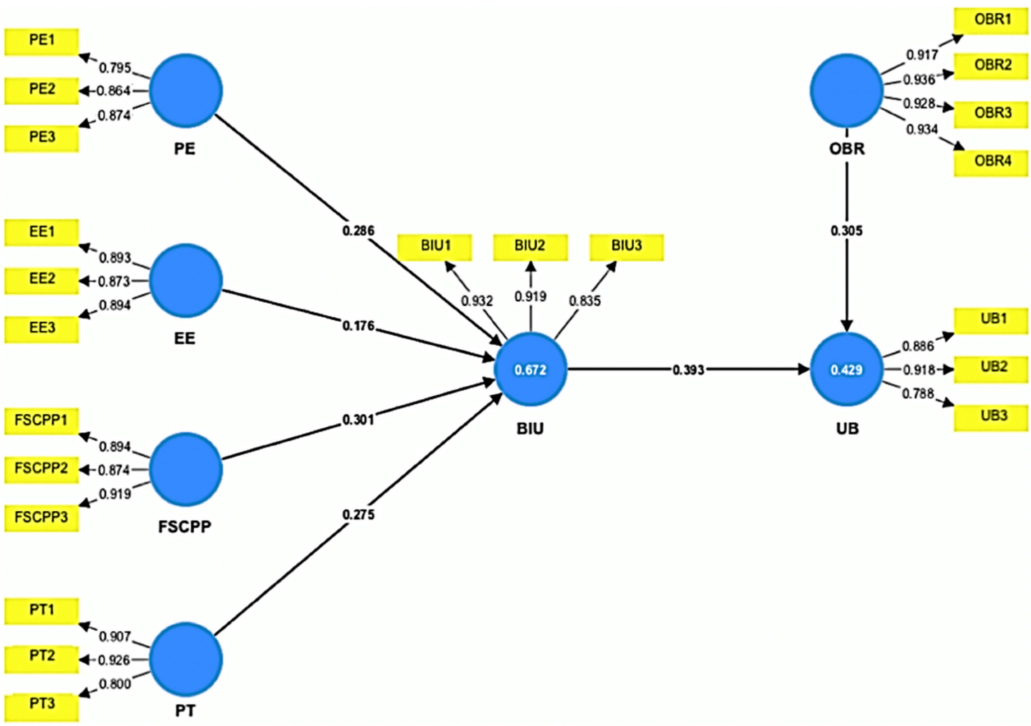

Figure 4. SmartPLS results of the proposed model *(source: by author)*.

Table 8 presents the results of the significance tests for the path coefficients, serving as the basis for either accepting or rejecting the hypotheses.

Table 8. Testing the hypotheses and validation of the model.

Hypothesis	β Coefficient	Standard Deviation	T Statistics	*p* Values	Decision
H1: PE → BIU	0.286	0.061	4.665	0.000	Supported
H2: EE → BIU	0.176	0.055	3.167	0.002	Supported
H3: FSCPP → BIU	0.301	0.063	4.790	0.000	Supported
H4: PT → BIU	0.275	0.068	4.049	0.000	Supported
H5: OBR → UB	0.305	0.086	3.527	0.000	Supported
H6: BIU → UB	0.393	0.091	4.294	0.000	Supported

The predictive power of the envisaged structural model was further examined by employing the coefficient of determination (R2). The results indicate that the combined influence of Performance Expectancy (PE), Effort Expectancy (EE), Agri-Food Supply Chain Partner Preparedness (FSCPP), and Perceived Trust (PT) accounted for 67.2% of the variability observed in the Behavioral Intention to Use (BIU) blockchain-based agri-food supply chain solutions. Furthermore, Behavioral Intention to Use (BIU) elucidated 42.9% of the observed variance in Usage Behavior (UB).

5. Discussion

5.1. General Discussion

This study has methodically identified and examined the main factors exerting a positive influence on both the intention to use and the anticipated Usage Behavior (UB) of blockchain-based platforms within agri-food supply chains. To address the research question pertaining to the identification of key determinants that positively influence blockchain adoption, the authors built upon recent research and developed a conceptual model tailored specifically to blockchain adoption within the agri-food industry. The Unified Theory of Acceptance and Use of Technology (UTAUT) provided the theoretical foundation for this model, which was subsequently empirically tested using Partial Least Squares Structural Equation Modeling (PLS-SEM). The proposed model functions as a valuable tool for capturing beneficiary feedback and facilitating timely adjustments in the implementation of blockchain technology within agri-food supply chain dynamics. The positive relationships derived from these observations establish a solid groundwork for advancing the integration of blockchain technology within the agri-food supply chain domain.

Drawing upon survey data gathered from 175 specialists from agri-food companies across eight European nations, this investigation underscored the existing variations between the intention to use blockchain-driven platforms within agri-food supply chains and the actual usage patterns. The outcomes of the Partial Least Squares Structural Equation Modeling (PLS-SEM) technique unveiled several insights. First, this research substantiated the theoretical and statistical validity of augmenting the Unified Theory of Acceptance and Use of Technology (UTAUT) model with three new constructs encompassing Agri-Food Supply Chain Partner Preparedness (FSCPP), Perceived Trust (PT), and Organizational Blockchain Readiness (OBR). The selection of the four independent variables resulted in a model characterized by a good explanatory power, as Agri-Food Supply Partner Preparedness (FSCPP), Perceived Trust (PT), Performance Expectancy (PE), and Effort Expectancy (EE) collectively represented 67.2% of the observed variability in the Behavioral Intention to Use (BIU).

Supply chain partner preparedness emerged as the pivotal factor with the strongest association with people's intention to use agri-food supply chain platforms powered by blockchain technology, as measured by the Behavioral Intention to Use (BIU) construct. This outcome highlights the crucial role of supply chain partners in shaping the adoption of blockchain-based platforms for agri-food supply chains. In particular, this finding underscores the importance of supply chain partners' technological competencies and their willingness to allocate financial resources, as these factors guide the dynamics of the adoption endeavor. Ultimately, fostering robust partnerships with innovative and technologically astute agri-food supply chain partners becomes essential for facilitating the seamless integration of blockchain technology within the agri-food supply chain ecosystem. This result is congruent with the findings obtained by Clohessy and Acton [71], who affirmed that partner readiness emerged as the key driver of blockchain technology adoption. Additionally, corroborating evidence is found in the studies conducted by Malik et al. [73], Kamble et al. [75], and AL-Ashmori et al. [76], all of which underscored the significant positive relationship between partner preparedness and the inclination to embrace blockchain technology.

Next, this study's results also offer support for the positive association between Performance Expectancy (PE) and the Behavioral Intention to Use (BIU) blockchain technology, in line with previous empirical investigations conducted by Khazaei [86] and Chang et al. [69]. This finding underscores the importance of performance expectancy perceptions, wherein managers believe that blockchain can lead to efficient processes, cost reductions, and optimized supply chain operations. This is identified as a crucial element in the decision-making process regarding blockchain adoption.

Furthermore, the demonstrated positive association between Effort Expectancy (EE) and Behavioral Intention to Use (BIU) blockchain resonates with previous findings reported by Zhang et al. [68]. Additionally, this study's results show that Perceived Trust (PT) has a noteworthy positive effect on Behavioral Intention to Use (BIU) blockchain-enabled solutions within agri-food supply chains, aligning with previous empirical investigations [52,78].

Lastly, the outcomes of this research demonstrate a positive relationship between Organizational Blockchain Readiness (ORB) and expected Usage Behavior (UB), aligning with prior investigations conducted by Clohessy and Acton [71], Li et al. [84], and Lu et al. [85]. This finding suggests that organizations with elevated levels of readiness, encompassing technical infrastructure, skilled personnel, service provider accessibility, and financial resources, demonstrate a higher propensity for effective implementation and incorporation of blockchain solutions within their operational framework.

5.2. Theoretical Implications

Given the nascent stage of research into the adoption of blockchain technology, encompassing both theoretical exploration and empirical investigation, this article delivers noteworthy contributions that enrich the current body of knowledge in the agri-food supply chain domain. In a context where achieving a thorough understanding of the complexities inherent in blockchain technology adoption remains an emerging endeavor, this study gains prominence through its provision of relevant insights and viewpoints that contribute to the ongoing scholarly dialogue concerning blockchain technology and its implementation.

While numerous qualitative and quantitative research endeavors have explored the adoption of blockchain in the broader field of supply chain management, a noticeable research gap persists in the literature, particularly regarding investigations focused specifically on the agri-food supply chain. This gap is especially apparent when considering agri-food companies across European countries. Leveraging the conceptual model that adapts and extends the Unified Theory of Acceptance and Use of Technology (UTAUT) model, coupled with the empirical dataset collected from a cohort of agri-food companies spanning eight European countries, the results offer notable insights that hold relevance for academic scholars, professionals, and policymakers in equal measure. The current research delves into the key determinants that shape individuals' propensity to adopt blockchain-based applications within the context of agri-food supply chains, followed by a subsequent investigation of the expected Usage Behavior (UB).

In the realm of theoretical advancements, this study stands as pioneering in its endeavor to augment the foundational structure of the UTAUT model by integrating the following three novel constructs: Agri-Food Supply Chain Partner Preparedness (FSCPP), Perceived Trust (PT), and Organizational Blockchain Readiness (OBR). Furthermore, it represents the first empirical inquiry that distinctly focuses on blockchain adoption for agri-food supply chain platforms within the European context.

Through an extensive analysis using the Partial Least Squares Structural Equation Modeling (PLS-SEM) analytical framework, this study enhances our understanding of individual behavioral intentions related to the adoption of agri-food supply chain platforms based on blockchain technology, while also elucidating the expected Usage Behavior (UB) associated with these platforms. The results underscore the favorable influence exerted by factors such as Performance Expectancy (PE), Effort Expectancy (EE), Agri-Food Supply Chain Partner Preparedness (FSCPP), and Perceived Trust (PT) on individuals' inclination to engage with blockchain-driven supply chain platforms. Notably, Agri-Food Supply Chain Partner Preparedness (FSCPP) stands out as the main driver impacting the Behavioral Intention to Use (BIU) these platforms.

Regarding the expected Usage Behavior (UB), Organizational Blockchain Readiness (OBR) emerged as a statistically significant factor. This construct encompassed the assessment of various items, such as the presence of technologically skilled personnel, monetary resources, pertinent technical infrastructure, and accessibility to service providers, all of which are essential for a seamless adoption of this disruptive technology.

5.3. Practical Implications

The current investigation provides practical insights and offers guidance to European agri-food enterprises aiming to leverage the functionalities of blockchain-based platforms to optimize their agri-food supply chain processes. This research elucidates the determinants influencing the adoption of blockchain technology, offering organizations an enhanced understanding of strategies to amplify their transformative potential and harness blockchain advantages. These benefits include improved transparency and security within agri-food supply chains, streamlined supply chain processes, reduced agri-food waste, and enhanced consumer trust.

Furthermore, this study provides significant insights into the primary determinants shaping the Behavioral Intention to Use (BIU)and actual usage of innovative technologies such as blockchain, allowing companies to uphold a competitive advantage within a dynamic business environment. The practical aim of this study is to equip companies with the means to judiciously discern, devise proper strategies, and adeptly navigate the intricate challenges intertwined with the integration of blockchain-driven agri-food supply chain platforms.

The results show that Agri-Food Supply Chain Partner Preparedness (FSCPP) emerged as the most influential construct impacting the behavioral intention to use blockchain-based agri-food supply chain platforms. This underscores the imperative for organizations to place significant emphasis on evaluating the preparedness and willingness of their supply chain partners to embrace blockchain technology. The potential advantages arising from the application of blockchain technology within agri-food supply chains are primarily rooted in its collaborative and inter-organizational nature. Notably, the attainment of comprehensive transparency, especially concerning elements such as provenance, tracking, and tracing, is contingent upon the participation of all stakeholders engaged in the agri-food supply chain. Through acknowledging the central significance of these partners and their available assets, organizations can effectively plan and allocate the required technological and financial resources to streamline the integration of agri-food supply chain platforms based on blockchain technology.

Performance Expectancy (PE) stands out as the second most significant determinant influencing the Behavioral Intention to Use (BIU) blockchain-driven agri-food supply chain platforms. Therefore, it is imperative for companies to attain a comprehensive understanding of the advantages associated with the integration of blockchain technology into their agri-food supply chains. These benefits encompass enhanced operational efficiency, heightened transparency, improved traceability, and improved consumer trust. Collectively, these advantages contribute to the overall efficiency, cost reductions, and process optimizations within agri-food supply chains.

Two additional variables, namely Perceived Trust (PT) and Effort Expectancy (EE), have demonstrated significant influence on the Behavioral Intention to Use (BIU) blockchain-driven agri-food supply chain platforms. Trust serves as a catalyst in reducing uncertainty and instilling confidence in the potential benefits of blockchain. In the realm of agri-food supply chains, this highlights the importance of strategies focused on enhancing the understanding of blockchain functionalities. Simultaneously, it emphasizes the need for ensuring data integrity and reliability through the implementation of resilient safeguards for data protection and ensuring transparency in governance structures. Moreover, it is imperative for organizations to pay attention to optimizing the user-friendliness of these blockchain-based agri-food supply chain platforms. It is essential to recognize that these platforms do not only serve the network of supply chain partners but also extend their impact to the ultimate end user—the customer. Through the acknowledgment and proper communication of these benefits, companies can effectively promote and ensure the adoption and utilization of blockchain-driven agri-food supply chain platforms.

Additionally, Organizational Blockchain Readiness (OBR) holds a pivotal role in shaping the actual utilization behaviors of blockchain-based agri-food supply chain platforms. Consequently, the seamless integration of blockchain hinges upon robust organizational support, encompassing elements such as reliable technical infrastructure, proficient personnel, adequate financial resources, and accessibility to relevant service providers. The findings derived from this study offer significant utility to companies as they devise strategies to foster the digitization of the agri-food supply chains. Embracing this paradigm can empower agri-food enterprises to harness a more streamlined and transparent agri-food supply chain, yielding benefits not only to their individual operations but also extending to their supply chain partners and, ultimately, to the final consumers.

5.4. Limitations and Future Research

In recognizing the theoretical advancements and practical implications, it becomes imperative to also acknowledge the inherent constraints within this study, as they simultaneously present avenues for future research endeavors.

While this study establishes a foundational framework for future researchers exploring the factors influencing the adoption of this innovative technology, it is essential to acknowledge that the empirical validation was confined to a restricted pool of 175 respondents. Expanding the sample size to include a larger and more diverse set of respondents could provide additional perspectives on the factors influencing the intention to use and expected Usage Behavior (UB) of blockchain-based platforms, creating opportunities for further investigation and implementation of the proposed model across various settings. Additionally, it is important to recognize the limitations of generalizing these findings to other regions. Diverse contextual factors such as cultural norms, economic conditions, political stability, regulatory frameworks, and technology infrastructure disparities may significantly influence the implementation of blockchain-based solutions in agri-food supply chains outside of Europe. Moreover, the variability in transport networks, logistics, and distribution channels across regions implies that blockchain solutions tailored for European agri-food supply networks may lack direct applicability in other regions. Tailored approaches are needed to address region-specific challenges, requiring collaboration with stakeholders and understanding local contexts. Future research could expand the geographical scope to achieve a more comprehensive understanding of blockchain adoption in other regions.

Furthermore, the adoption of a cross-sectional design resulted in the evaluation of Behavioral Intention to Use (BIU) and anticipated Usage Behavior (UB) concerning blockchain-based agri-food supply chain platforms at a singular time point. However, this survey approach may introduce uncertainty regarding directionality, as delineating the temporal sequence of events proves challenging. The current study employed PLS-SEM analysis to estimate path coefficients (β) elucidating proposed associations or correlations between variables. Additionally, the selection of constructs was guided by a robust theoretical framework rooted in the Unified Theory of Acceptance and Use of Technology (UTAUT). Mitigating this limitation may necessitate the adoption of a research design characterized by repeated observations of these constructs over extended durations. However, longitudinal studies pose challenges in determining the appropriate time lag for observing effects, particularly considering factors such as the varied timelines for blockchain adoption across organizations and countries. Moreover, conducting longitudinal studies entails resource-intensive efforts, rendering them a commendable yet challenging endeavor.

This study relied on self-reported data, which may introduce biases such as social desirability, sampling, confirmation bias, cultural bias, misinterpretation, and response variability. To mitigate these biases, an expert sampling method was utilized, ensuring representation from diverse subgroups and anonymizing responses. Additionally, clear survey guidelines were provided, and questions were formulated with neutral language using pre-validated measurement items to minimize ambiguity and cultural misinterpretation. However, it is crucial to acknowledge that experts themselves may hold preconceptions that could influence their responses.

Finally, it is important to emphasize that the factors proposed within the extended UTAUT model should not be regarded as exhaustive. A complex interplay of organizational, economic, technical, legal and regulatory market-related factors, and social influences extends beyond the boundaries of the proposed model and intricately shapes the decision-making processes surrounding blockchain technology adoption for agri-food supply chains. Consequently, researchers are encouraged to consider the inclusion of supplementary factors that could further enhance the explanatory power of the model.

6. Conclusions

Traditional supply chain practices often lack digitization and transparency, leading to delays and inaccuracies in essential certificates and authentication documents. The intricate agri-food supply chains face increasing vulnerability from natural disasters, climate change, and various crises. Adaptability to disruptions is crucial, necessitating innovations for efficient monitoring and risk management. Through traceability, transparency, and data integrity, blockchain emerges as a potential solution that can restore consumer trust and enhance agri-food supply chain efficiency.

Despite its anticipated transformative impact, the widespread integration of blockchain technology within the European agri-food supply chain has yet to achieve widespread adoption. Consequently, this study aims to address this gap by seeking to determine the factors influencing both the behavioral intention to adopt and the actual usage of blockchain-driven agri-food supply chain platforms. The current study proposes and analyzes an adapted and extended version of the Unified Theory of Acceptance and Use of Technology (UTAUT) framework. Diverging from both the foundational UTAUT model and previous investigations on blockchain technology adoption, this research introduces an innovative conceptual model by incorporating the following three new variables: Agri-Food Supply Chain Partner Preparedness (FSCPP), Perceived Trust (PT), and Organizational Blockchain Readiness (OBR).

The results provide noteworthy insights and enrich the current understanding within the realm of agri-food supply chain management. Their implications extend widely to diverse stakeholders, encompassing decision makers in agri-food corporations, participants within agri-food value chains like producers and distributors, policymakers, technology experts, and scholarly researchers.

In summary, the adoption of blockchain-driven agri-food supply chain platforms emerges as a promising avenue with the capacity to revolutionize the dynamics of the European agri-food supply chain landscape. The strategic incorporation of this innovative technology within agri-food companies promises multifaceted advantages, including improved traceability mechanisms, transparent supply chain data, agri-food authenticity, and streamlined operational efficiencies. In this context, blockchain can foster an environment where consumer trust is improved and agri-food waste is minimized. Nonetheless, it is imperative to recognize that the effective integration of blockchain demands significant investments in both technological infrastructure and skilled personnel. Furthermore, the preparedness of supply chain partners and the organizational state of blockchain readiness play pivotal roles, demanding careful consideration. By meticulously addressing these elements, agri-food enterprises can effectively capitalize on the advantages presented by blockchain-based agri-food supply chain platforms.

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