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Blockchain-powered agricultural production and insurance: A game-theoretic model for fraud prevention and smart compensation

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ABSTRACT

This paper presents a game theory model involving one insurance company (the insurer) and one agricultural producer (e.g., crop growers and agribusinesses). The latter uses blockchain oracles (e.g., Internet of Things) to gather information from the ecosystem and update smart contracts when disasters occur, thereby avoiding sales losses. In some cases, the agricultural producer may adopt fraudulent behaviors and falsify the extent of the damages to receive higher economic compensation since the insurer does not have full visibility over the agricultural producer's business. However, the insurer can decide to support the agricultural producer's blockchain investment to obtain accurate information about the real damages; hence, eliminating information asymmetry, mitigating false claims, and offering additional advantages to the agricultural producer, such as quick reimbursements for damages managed by smart contracts and no extra verification costs. Our findings show that collaboration on blockchain enhances investment strategies, reduces insurance fees, and yields a profit-Pareto-improving outcome. However, the joint investment can fail under some specific conditions, including equal price and reimbursement rates, high disaster avoidance capabilities, maximum coverage requirements, low verification costs, and delayed payments. Therefore, collaboration for blockchain technology requires a joint analysis of economic and operational implications.

1. Introduction

Climate change disasters and other crises, such as agricultural diseases and crop damage, cause significant economic losses to the agricultural industry and adversely affect food production. Consequently, insurance providers play a substantial role in insuring investments in the agricultural sector to mitigate the impact of risks for agricultural producers and other agricultural firms (Fang et al., 2021). Events such as devastating floods and destructive earthquakes severely impact the agricultural sector. At the same time, insurance companies face a high risk for reimbursement payments, which imposes revisions to insurance costs and plans (De Haen and Hemrich, 2007).

In the agricultural sector, despite notable advancements in achieving a resilient agricultural system through the transition to modern agriculture (Singh and Sharma, 2022), the developments of genetically modified crops (Kovak et al., 2022), and the implementation of sustainable practices and the extension of circular agri-food systems (Miranda et al., 2021; De Giovanni, 2026), companies face significant difficulties in managing all possible risks associated with agricultural businesses (Mol et al., 2020). Accordingly, comprehensive insurance programs are essential to address the production and financial risks posed by unpredictable natural hazards and severe weather issues in this sector (Chen et al., 2023).

Nowadays, insurance companies devise services aligned with the risk levels and production scales of agricultural producers. They collect monthly or yearly premiums to provide reimbursements for potential production damages up to a predetermined limit outlined in the contract (Kahan, 2008). However, the agricultural sector is facing challenges with immediate damage recognition and payment due to traceability and trust issues between agricultural producers and insurance firms. Several business issues remain unresolved: recognizing and estimating real damage, making timely payments, investing time and resources in a correct validation process, avoiding cheating and fraudulent behaviors while creating a transparent system, and determining and/or negotiating the proper amount to reimburse without incurring litigation procedures.

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Table 1
Real-world case of blockchain technology in agricultural insurance.

Real-world use cases	Blockhain role	Connection to this study
WaterTrack[a]	This project aims to utilize blockchain-based smart contracts to control the irrigation schedule using trustworthy real-time data. This leads to optimizing irrigation, which positively affects crop damage.	It indicates blockchain can mitigate the possibility of crop damages by controlling operations such as irrigation (see parameter σ in Table 2).
Lemonade Crypto Climate Coalition[b]	Protecting Kenyan farmers against drought and floods with parametric crop protection blockchain powered by Chainlink[c] on the Avalanche[d] platform. Moreover, using smart contracts enables fast payments without the need to file claims, which previously took months.	These are two examples of using parametric insurance program leading to eliminating verification and timely payment using blockchain (see parameters c_v and δ in Table 2). Moreover, as it is a parametric insurance, the assumption is that the smart contracts will be executed automatically according to the trusty collected data, which prevents fraudulent claims or at least the reimbursement is accepted by both parties (see parameters r and γ in Table 2).
Arbol[e]	Offering a transparent, automated, and fast reimbursement to producers by adopting blockchain technology, smart contracts, and parametric insurance for predefined scenarios related to disasters such as hurricanes, floods, crop damage, and freeze events.	
ZhongAn[f]	ZhongAn, as an Insurtech company, utilizes blockchain technology to track the life journey of chickens in organic farming. The real-time data includes information such as their chickens' whereabouts, their daily exercise (in the form of steps taken during daily walks), and the type of food they are eating.	This example indicates blockchain technology can increase trust among the insurer and the insured by using blockchain-based smart contracts that can be automatically executed according to the real-time data, eliminating the verification process and reducing the risk of document manipulation (see parameters c_v and γ in Table 2).

[a] https://blockchainusecases.com/supply-chain-management/blockchain-for-tracking-water-usage-and-conservation-in-agricultural-supply-chains/? (accessed October 06, 2025).
[b] https://blog.etherisc.com/etherisc-protects-another-7-000-kenyan-farmers-as-part-of-the-lemonade-crypto-climate-coalition-e169eca3d6bc (accessed March 31, 2025).
[c] https://chain.link/(accessed March 31, 2025).
[d] https://www.avax.network/(accessed March 31, 2025).
[e] https://www.arbol.io/post/parametric-insurance-what-it-is-and-how-it-can-enable-businesses-worldwide-to-achieve-financial-climate-resilience (accessed March 31, 2025).
[f] https://www.scmp.com/business/companies/article/2123567/blockchain-and-facial-recognition-zhongan-techs-recipe-changing? (accessed March 31, 2025).

According to the literature, these issues and obstacles can be addressed using blockchain technology (Ruzza et al., 2025), which has been applied to similar issues in various industries (Dutta et al., 2020). The blockchain records information from different sources and uses it to activate smart contracts. Smart contracts are programmed with triggers that automatically activate a series of actions when certain conditions are met. For example, data from advanced meteorological sources, such as military and other reliable weather forecast services, act as software oracles for a blockchain (De Giovanni, 2020). Without the intervention of humans, smart contracts integrate real-time weather data for agricultural planning, influencing the supply chain to obtain the cleanest water for the manufacturers and quick response planning to potential natural disasters, such as floods or droughts (Wang et al., 2021). Furthermore, blockchain can be a platform where the data obtained from the ground may be connected to smart devices, such as temperature and humidity sensors, through the communication protocol of other devices in the IoT (Internet of Things) network, which acts as hardware oracles (Maleki Vishkaei and De Giovanni, 2024). This granular weather data is then used to obtain better farming results by adjusting the irrigation system to the needs of the plants (Torky and Hassanein, 2020). So, for example, if the IoT sensors signal a spike in the underground moisture, the system's sensors can trigger the water systems to provide less water to the field, thus avoiding a possible overflow. This action can be recorded on the blockchain, as proof of sustainability.

Rather than just integrating data, the blockchain can capture traceability and transparency throughout the food production and distribution network. Information about natural disasters is recorded across the entire supply chain, and strategies are automatically adjusted by smart contracts and documented in the blockchain (Sunny et al., 2020). Surveillance drones monitoring crops and sensors embedded in the meteorological stations can track plant health and water needs. These systems allow agricultural producers to adjust their strategies to address disruptions while recording all modifications on a blockchain, thus providing a transparent record of the actions taken by the company during disruptive periods.

Agricultural and insurance companies both face the consequences of disasters and may be interested in implementing blockchain technology. The agricultural producer can adopt blockchain technology, aiming to prevent damage by accessing reliable real-time data to facilitate decision-making for different operations. The cases “WaterTrack” in Table (1) supports this idea. We also must take into consideration that reducing product damage can indirectly benefit the insurer as well as it may reduce the total reimbursement cost. Moreover, in the literature, there are several articles that provide frameworks for adopting blockchain by agricultural producers aiming to develop smart farming solutions by integrating blockchain technology with other technologies such as drones, IoT, and smart contracts (Hawashin et al., 2024; Sadiq et al., 2024). Moreover, blockchain technology can be beneficial for agricultural producers, as it enables automatic recognition and compensation of damages by the insurer without unreasonable delay in payments. The examples “Lemonade Crypto Climate Coalition”, and “Arbol” in Table (1) emphasize the efficiency of this technology in fast payment.

In addition, the insurer has several motivations to support agricultural producers’ blockchain investments to enjoy the automation of coverage verification, recognize fake damage claims, and reduce the time required for reimbursement services (Kim and Kang, 2017; Jha et al., 2021). This is further evidenced by reports provided by the United States Department of Agriculture. Accordingly, in 2023, they estimated overpayments equal to US$362 million, indicating an improper payment rate of about 2.58% of total expenditures (Risk Management Agency, 2024). In 2022, the overpayments were around US$289 million (Risk Management Agency, 2023). These reports are based on an annual sample review analysis.[1] The leading causes of overpayment include difficulties verifying policyholder certifications (such as acreage and production evidence), administrative and process errors in recognizing actual claims, failures to access necessary data, and missing documentation.[2] The examples of “Arbol” and “ZhongAn” in Table (1) discuss the importance of transparency in agricultural insurance to adopt parametric insurance solutions that ensure accuracy in analyzing the claims and increase consumer trust in organic products. In fact, blockchain technology facilitates robust traceability (Pun et al.,

[1] https://www.rma.usda.gov/policy-procedure/bulletins-memos/informational-memorandum/com-25-001-risk-management-agency (accessed December 26, 2025).
[2] https://www.gao.gov/assets/870/864365.pdf (accessed December 26, 2025).

2021; Biswas et al., 2023), ensures the authenticity of data sources, automatically validates the legitimacy of insurance claims, and reduces both the verification costs and possible litigation costs (Luo et al., 2022; Omar et al., 2023).

Overall, the examples in Table 1 highlight that blockchain adoption generates benefits for both agricultural producers and insurers, although these benefits are typically analyzed separately in practice. On the one hand, producers benefit from improved decision-making and reduced damage through better data and automation. On the other hand, insurers benefit from enhanced transparency, reduced fraud, lower verification costs, and faster claim settlement. These interdependent effects suggest that blockchain investment by producers can generate positive externalities for insurers. In this context, a joint investment arrangement—where the insurer partially supports the producer's blockchain adoption—can be interpreted as a mechanism to internalize these benefits and align incentives across parties. The present study builds on this intuition and provides a formal framework to analyze the optimal level of such collaboration.

Considering the trade-offs, insurers can propose collaborating with agricultural producers in this investment to obtain two primary advantages. Firstly, the insurance company mitigates the issue of information asymmetry, which leads to fraudulent claims due to the difficulty of verifying the reported incident accuracy and is potentially driven by the agricultural producers' opportunistic behavior (Dionne, 2013; Kao et al., 2022). Secondly, insurance companies must consider the costs associated with investing in blockchain technology, which may outweigh the potential losses due to inaccurate or fraudulent incident reports. Therefore, the insurer's participation decision reflects a trade-off between the costs of supporting blockchain adoption and the expected gains from reduced information asymmetry, lower fraud exposure, and improved operational efficiency. These incentives are consistent with observed applications of blockchain in agricultural and parametric insurance (see the cases in Table 1), where improved data transparency and automation directly affect insurers' cost structures. In this context, collaboration emerges as a rational and economically grounded strategic choice rather than an imposed arrangement. Accordingly, in this paper, we seek to answer the following questions:

RQ1) Given that the agricultural producer might face significant disruptions due to natural disasters, should blockchain be implemented to predict these disasters and adjust the smart contracts accordingly?

RQ2) Should an insurer support the agricultural producer's blockchain investment to prevent the agricultural producer from falsifying the extent of the damage?

RQ3) Under what conditions would both the agricultural producer and the insurer find it advantageous to collaborate on adopting blockchain?

To address our research questions, we use a Stackelberg game with two scenarios. For RQ1, we examine the independent investment scenario where the producer invests in blockchain solely, using oracles and smart contracts to mitigate disaster losses, while the insurer lacks access to blockchain data. This preserves information asymmetry and allows fraudulent claims to persist. For RQ2, we analyze the joint investment scenario where the insurer contributes to the blockchain investment, gains direct access to the information flow, and relies on smart contracts that eliminate verification costs and payment delays, thereby removing incentives for opportunistic behavior. For RQ3, we compare equilibrium outcomes across the two scenarios to identify when collaboration is advantageous for both parties.

Our findings reveal that, under specific conditions, increasing the effectiveness of blockchain in preventing damage reduces unit insurance costs and increases total investment in blockchain technology. Moreover, within the cooperative scenario, the relationship between unit reimbursement and unit revenue significantly influences optimal insurance, production, and investment decisions. Interestingly, cooperation is not always economically convenient. In particular, it may not arise when price and reimbursement are equal, coverage rates are high, verification costs are low, or delayed payments benefit the insurer. These results show that collaboration depends critically on the alignment between technological effectiveness and contractual parameters.

This study contributes to the literature by linking blockchain adoption to both operational and insurance decisions within a unified framework. In particular, it shows that blockchain simultaneously affects production outcomes—by reducing damage—and insurance processes—by improving the efficiency and reliability of reimbursements. This dual role is especially relevant in agricultural contexts, where production risks and financial compensation are tightly interconnected. A key contribution is to provide an economic rationale for joint investment in blockchain technology. While existing applications emphasize traceability and automation, the model demonstrates that these features generate direct benefits for insurers by reducing fraud, lowering verification costs, and improving payment efficiency. As a result, insurers may have incentives to support producers' blockchain adoption in order to internalize these benefits and align incentives.

The analysis also highlights the trade-offs associated with collaboration. For producers, blockchain improves operational control and enables more efficient investment, but reduces the scope for overstating damages. For insurers, it enhances transparency and reduces risk exposure, while requiring upfront investment. These opposing effects determine whether cooperation is advantageous. Although the analysis focuses on agricultural insurance, the framework applies more broadly to contexts where digital technologies generate shared benefits across supply chain actors. Examples include perishable goods, pharmaceuticals, and other sectors characterized by high uncertainty and information asymmetry. From a managerial and policy perspective, the results indicate when blockchain investments should be pursued collaboratively rather than independently. In particular, they emphasize the importance of aligning technological capabilities with contractual design and regulatory conditions, which may vary across industries and regions.

The remainder of the paper is structured as follows. Section 2 offers a review of the current literature concerning blockchain adoption in industries and value chains. Section 3 introduces and formulates the game theory model, whose equilibria are presented in Section 4. Section 5 compares the findings of the various scenarios and Section 6 extends the models by endogenizing some parameters. Section 7 provides the findings and Section 8 concludes, by highlighting the study's limitations and suggesting potential research extensions.

2. Literature review

Nowadays, catastrophes are related to global warming and other crises, such as pest outbreaks and diseases, jeopardizing food production by disrupting operations and threatening the agricultural sector's economy (Barrett, 2021). Forecasts show climate change will cause more frequent crises, such as floods and droughts, which negatively impact the productivity of the agricultural sector (Schoengold et al., 2015). For instance, in China, the average crop area affected by annual droughts has increased by approximately 120% since 1950 due to climate change issues. As a result, many more cultivation regions suffer from flood disruptions than they did in the past. These issues grab the attention of policymakers as they expect a growth rate of 44% in areas threatened by drought, already by the end of the 21st century (Huang et al., 2015). Consequently, the world is experiencing an accelerated pace in the frequency and severity of these events due to climate change, which underscores the need for devising effective strategies to mitigate the impact of the relevant risks and ensure resilience (Chen et al., 2023). Implementing these strategies requires the adoption of new initiatives and technologies along with collaboration among partners in the agricultural industry, such as agricultural producers and insurance companies (Rao, 2007). However, their conflicts of interest complicate the trade-offs and mutual profits, requiring more investigation to derive optimal strategies and successful decisions.

2.1. Agricultural producers investing in blockchain

In the agricultural sector, one possible way to mitigate the risks derived from ecosystem instability is the adoption of digital technologies to support the agricultural business (De Giovanni, 2026). The advent of new technologies, such as satellite imagery, remote sensing, and big data analytics, enables insurers to improve their risk assessment accuracy and tailor insurance offers according to the type of challenges, along with the probability and severity of damages in the agricultural sector (Kovak et al., 2022; Singh and Sharma, 2022). Many technologies have been analyzed, including the potential of adopting blockchain in agriculture. Studies have explored various aspects and dimensions of blockchain-based business models driving innovations in the farming marketplace (Leduc et al., 2021), data sharing between partners along the supply chain (Wang et al., 2021), ensuring food quality and safety (Dong, 2021; Yen-Ting et al., 2022), traceability, waste reduction, and operational efficiency (Hastig and Sodhi, 2020; Yadav et al., 2022), and building capabilities for sustainable competitive advantage (Behl et al., 2022). According to the Food and Agriculture Organization report (FAO, 2019), blockchain will play an important role in activating smart contracts, especially in agricultural insurance, improving traceability and food safety, and enhancing monitoring systems in the food value chain. Moreover, the agricultural sector can benefit from blockchain technology to mitigate and prevent product damage. For example, the adopting of blockchain in addition to other technologies such as computer imaging, drones, and the Internet of Things (IoT), can be useful to record information on the blockchain and facilitate the proof for undertaking prevention activities aiming to mitigate damages related to a lack of irrigation monitoring, quality control, and disease detection (Bodkhe et al., 2022). Blockchain allows for the creation of vehicular ad-hoc decision-supporting systems to monitor weather conditions, humidity, crop growth and soil conditions, fertilization, irrigation, and asset lifecycle (Sharma et al., 2022). In other words, blockchain records all these pieces of information and transfers all validated information to smart systems to provide proactive measures against damages and mitigate the risk of revenue loss as well as alleviate the economic consequences for both agricultural producers and insurers (Bodkhe et al., 2022).

Although there are several articles discussing the role of blockchain in the agricultural industry, the literature does not analyze the trade-offs and synergies among the insurers and agricultural producers in terms of the impact of adopting blockchain technology on their optimized strategies, such as production and insurance fees. For instance, Bai et al. (2021) develop a game theory model to manage an agricultural green supply chain concerning blockchain technology aiming to improve trust, traceability, and transparency in the system. They consider each greenhouse to manage a specific number of sensors and choose a set of players to receive certain agricultural information in which the blockchain ensures the trust value of each player. Yet, the proposed model focuses on environmental sustainability rather than insurance or compensation design. Most previous articles consider blockchain adoption for analyzing its capability in improving transparency in tradeoffs between partners in a supply chain, primarily between suppliers and retailers (De Giovanni, 2020; Dong et al., 2023; Biswas et al., 2023). However, they do not discuss the trade-offs related to its joint adoption in a network to address the challenges in the agricultural insurance field. In this study, we analyze contractual interactions between insurers and producers, integrating blockchain's operational role in traceability, fraudulent claims, and accelerating reimbursement.

2.2. Agricultural producers subscribing to insurance

In the agricultural sector, agricultural producers can subscribe to insurance plans to cover possible damages caused by either natural disasters or disruptive events. Market and financial insurance are well-known risk management tools in the agricultural industry. Other tools include adopting future price contracts, using fertilizers and pesticides, conducting crop rotation plans, and investing in genetically modified crops (Skevas et al., 2014). Risk aversion and other factors, such as contract items, purchasing experience, and competitor purchase ratios, play a significant role in agricultural producers adopting crop insurance schemes (Lyu and Barré, 2017). Insurance plans are popular for compensating for low yields due to agricultural risks. However, administration procedures and costs to verify the claims are challenging in this industry (Anderson and Monjardino, 2019).

Insurance programs share the risk consequences between the insured and the insurer and come in different types. Crop insurance focuses on issues related to harvest damages and low yields. Revenue insurance guarantees a minimum revenue for the insured company or producer (Assa et al., 2021). Moreover, there are different categories of insurance plans according to the prevalent damage types in a specific region. For instance, hail insurance is popular where crops suffer from hail damage. However, insurance adoption rates depend on the frequency of these types of events, user's education levels, and payment policies (Finger and Lehmann, 2012).

Nevertheless, adopting and benefiting from insurance programs includes several challenges for agricultural producers and insurers. The procedures regarding assessing and verifying the damage claims cause complexities to the insurance system due to a lack of accurate information and documentation, delays in sharing proper information, and the need for onsite evaluations (Glauber, 2004). Moreover, these procedures are time-consuming, possibly leading to delays in reimbursement payments, in addition to the occurrence of opportunist activities due to a lack of transparency (Walters et al., 2015).

Despite the literature studies various aspects of agricultural insurance in terms of challenges related to verification and reimbursement procedures, there is no article that focuses on independent and joint investment in blockchain technology, analyzing optimized strategies considering the trade-offs between both the insurer and the agricultural producer. For instance, some studies focus on insurance schemes in the agricultural sector using game theory models to analyze the trade-offs between partners in the supply chain. Assa et al. (2021) provides a theoretical framework for an insurance product on price indexes with the intention of stabilizing farm revenue. They investigate a game theory model to analyze the impact of the proposed insurance product in attracting investment in the agricultural sector and discuss how insurance can increase the benefit of the investment. However, the authors do not address fraud prevention or transparency issues. Li et al. (2023) study the role of agricultural insurance in a supply with three main players (i.e., a manufacturer, a bank, an insurer) under three scenarios: insurer-led Stackelberg, bank-led Stackelberg, and vertical Nash. Their outputs illustrate that the manufacturer purchases insurance in all scenarios if the bank is highly loss averse. However, despite the fact that agricultural insurance increases the profits of all players, it reduces supply chain efficiency in terms of production quantity. This study does not consider verification costs, information asymmetry, or the use of blockchain technologies to alter incentive structures. So, unlike Assa et al. (2021) and Li et al. (2023), we explicitly incorporate fraud prevention and verification costs into the modeling framework, showing how blockchain alters incentives for opportunistic reporting.

2.3. Agricultural producers and insurers collaborating through blockchain

In business-to-business relationships, such as the trade-offs between insurance firms and agricultural producers, blockchain mitigates paperwork processing and redundancies by storing. It verifies and shares accurate information using digital technologies as oracles to activate the information and verification flow (Vishkaei and De Giovanni, 2025). Blockchain facilitates the execution of various automated smart contracts according to accurate data between insurers and agricultural producers to eliminate delay in reimbursement (Leduc et al., 2021). Moreover, it improves traceability in finding the source of liability. This helps to trace issues and identify the primary causes of damage for evaluating and executing smart contract conditions between partners (Adalja et al., 2023; De Giovanni, 2026).

To develop a cost-efficient insurance program, it is essential to mitigate producer opportunism, which requires a transparent system with a high traceability performance (Walters et al., 2015). Blockchain technology decreases the risk of fraudulent claims by eliminating information asymmetry, improving traceability, and improving inherent immutability (Omar et al., 2023). Accordingly, financial and insurance institutions invest in blockchain technology to exchange information and ensure the elimination of information asymmetry through smooth channels of information to execute contracts properly and improve their credit systems (Zhang, 2020). Blockchain assists insurance companies in having fair financial audits by continuously storing and sharing verifiable and secure information, which partners can authenticate through online processing reports. Additionally, automatic auditing mitigates verification and assessment costs throughout the contract period (Sharma et al., 2022).

Consequently, both insurance companies and agricultural producers can benefit from the various characteristics of blockchain technology to mitigate verification costs, eliminate delays in reimbursement payments, and overcome fraudulent claims, in addition to applying blockchain's proactive measures to reduce crop damage. However, cooperation among partners to adopt blockchain hinges on whether the benefits and additional revenues from preventing damages, increasing transparency, and eliminating asymmetric information can outweigh the financial investment (De Giovanni, 2020; Cui et al., 2024). Hence, more investigation into the trade-offs between the insurer and the insured partners is necessary to analyze the optimal strategies and properly evaluate possible collaborations based on blockchain technology.

Furthermore, the collaboration and investment level in adopting blockchain technology depends on various factors, causing a conflict of interest between the insurance and farming companies. For instance, larger companies may find adopting blockchain technology more beneficial because of their economies of scale, high production capacity, and financial stability (Pan et al., 2020; Tseng et al., 2023). In other words, a sufficient production level can compensate for the implementation costs by increasing the profit margins (Pan et al., 2020). Another essential variable is the insurance cost, which impacts the adoption rate of insurance contracts for the target production capacity and the production level of the producer (Young et al., 2001; Sharma et al., 2022).

However, high insurance costs are usually the result of noticeable validation costs due to a lack of information transparency. In this case, implementing blockchain technology increases access to transparent information and mitigates costs for all partners, which consequently encourages companies to collaborate in blockchain investment (Sun et al., 2020). Accordingly, in this paper, we study the investment level in blockchain technology and each partner's share, including the production capacity and the insurance cost, with the ultimate goal of deriving the best players' strategies regarding their collaboration in adopting this technology.

Overall, this study stands out from literature for several reasons. Firstly, it provides new insights into joint investment for implementing blockchain technology to take maximum advantage of its capabilities, considering the trade-offs between partners in the agricultural industry. Secondly, this paper discusses the importance of collaboration among insurance companies in implementing new technologies, such as blockchain in the agricultural sector. It analyzes how insurers benefit from reducing fraud and, consequently, eliminating the issues of handling reimbursement and facing verification costs. Thirdly, this study analyzes the impact of traceability and preventive characteristics of blockchain, as well as the role of damage rate on optimal strategies. Finally, this paper explores how joint investment in adopting blockchain is profit-Pareto-improving for both parties by increasing their profit in addition to enhancing their investment strategies and operational costs. Moreover, we discuss various conditions that disrupt this collaboration. Accordingly, this study focuses on the role of joint investment between insurance and farming companies, aiming to foster technological advancements in the agricultural sector. The paper's output assist policymakers and business owners in the insurance and agricultural sectors in better understanding the potential of blockchain technology in improving profits and solving operational issues.

3. Models of blockchain in agriculture

This paper seeks a game theory model in the agricultural insurance sector. Our primary goal is to evaluate the operational and economic benefits, as well as the interest in implementing blockchain technology, among firms to mitigate crop damage, eliminate fraud, and facilitate reimbursement payments. Therefore, we investigate a game composed of two primary players: 1) a agricultural producer, A (he), and 2) an insurance company, Player I (she). In this model, we do not restrict ourselves to a specific agricultural good; rather, we keep the production facility and the farming activities broad to allow for generalized results. Table (2) summarizes the models' definitions, parameters, and variables.

3.1. An independent investment game for blockchain (T-game)

In the independent investment scenario (T-Game), the agricultural producer, A, is subject to a set of disasters due to climate change, which occur at the damage rate α. Considering the significant impact that climate changes has on agriculture, A identifies three levers to overcome the negative consequences of natural disasters.

Assumption 1. A invests in the blockchain technology, B, to face the negative impact of disasters through smart contracts, which implies an investment cost of $\frac{c_B B^2}{2}$, with $c_B > 0$ being the cost efficiency parameter.

Agricultural producer A invests in blockchain, B, to better estimate the adverse conditions of weather and the related possible disruptions. The existence of the blockchain allows A to manage the contractual relationships in the supply chain through smart contracts. This is a real advantage for A, since the blockchain constantly updates the clauses of the smart contracts when disasters occur. While traditional contracts must be respected completely even when catastrophic events disrupt

Table 2
Definitions of models, parameters, and variables.

Notation	Definition
T-game	The agricultural producer is the only Investing in blockchain technology.
C-Game	The agricultural producer and the insurance company collaborate in implementing blockchain technology.
α	The damage rate
σ	The damage alleviation rate per unit of investment in blockchain technology
p	The unit revenue of products for the agricultural producer
r	The reimbursement per unit of damaged products
γ	The claim fraud rate reported by the agricultural producer
δ	The financial impact of the delay in reimbursement payments and recognition of fraudulent claims
c_v	The unit verification cost
c_u	The coefficient related to the production investment/volume
c_B	The coefficient related to the blockchain investment
Φ	The insurer's investment share in blockchain technology (decision variable)
t	The unit insurance cost (decision variable)
u	The production volume (decision variable)
B	Investment in blockchain technology (decision variable)
Π_I	The insurance company's profit
Π_A	The agricultural producer's profit

firms, smart contracts automatically adjust using new information available from the blockchain, making them more adaptive and reactive to the new ecosystem conditions. The blockchain can use hardware oracles to capture information on disruptive events and adjust the smart contract clauses when disasters occur. The smart contracts also connect external data sources, register information on the blockchain, and update the contract clauses to avoid financial damages. According to Biswas et al. (2023), blockchain investment takes on a quadratic functional form, with c_B representing the penalties associated with blockchain technology investments.

Assumption 2. A faces damages from climate change, given $\alpha > 0$, *while the blockchain enables the damage reduction efficiency* σ. Therefore, $\alpha - \sigma B > 0$ *are the negative damages caused by climate change that A cannot detect by adopting blockchain technology.*

A study by the Food and Agriculture Organization (FAO, 2018) indicates that blockchain is a promising technology used to reduce human and operational errors and, consequently, mitigate product losses by recording, providing, and sharing accurate information from internal and external sources about weather changes, crop diseases, historical operational activities, and resource usage. Some real cases for using blockchain that can mitigate agricultural damages are the use of it for increasing irrigation transparency, specifically in areas where farmers are facing water scarcity. In that case blockchain can improve water conservation, reduce water waste, and provide a transparent water distribution plan for farmers[i]. As another example, the blockchain can make the use of drones in smart farming more trustworthy and efficient, and prevent damage by spraying pesticides with minimal errors, besides facilitating the transactions for renting drones between the agricultural producer and the renter (Lee and Shin, 2023).

Accordingly, in our model, adopting blockchain technology alleviates the damage rate, α, at a value of σB, depending on its detection efficiency and the total investment in this technology.

Assumption 3. A subscribes to an insurance contract at the price of t>0 per unit of food and receives compensation r>0, with $p \geq r$ illustrating that the unit reimbursement is less than the exogenous market price, p. I sets the insurance premium t endogenously and guarantees exogenous compensation r to A.

According to European Union regulations,[3] the public intervention price is a minimum price at which authorities must buy agricultural products. This ensures agricultural producers always receive at least this floor when market prices fall. Since it is set by regulation and not by the market, in our model, we treat product price as exogenous and based on this policy-defined minimum. Any price above it benefits the agricultural producers, while both the insurer and the producer calculate their risk, knowing that revenues cannot fall below it. So, we consider a fixed price (the minimum price) which the government guarantees, and the players can optimize their decision variables accordingly.

Moreover, a subscribes to an insurance contract with *I* against disastrous and catastrophic events that can heavily influence the entire food production process. This allows the agricultural producer to receive compensation *r* per unit of damaged product. *I* optimally sets the insurance premium to ensure an economically viable business model. The unit reimbursement is less than the unit revenue of the products ($p \geq r$), otherwise *A* prefers to have all products damaged to increase revenue. In many agricultural insurance systems, reimbursement levels are not fully flexible decision variables, but are often determined by institutional, regulatory, or contractual constraints (e.g., policy frameworks, predefined coverage schemes, or parametric insurance structures). For instance, in parametric insurance applications such as Arbol and Lemonade Crypto Climate Coalition, payouts are predefined based on objective triggers (e.g., rainfall levels or temperature thresholds), rather than negotiated ex post. Similarly, blockchain-enabled insurance solutions such as ZhongAn rely on standardized contracts where compensation rules are fixed in advance and automatically executed via smart contracts. In such contexts, insurers have greater flexibility in setting premiums than in adjusting reimbursement levels. Therefore, modeling *r* as exogenous is consistent with observed practices.

Assumption 4. A can cheat on the amplitude of the disaster at rate $\gamma > 0$.

A can adopt fraudulent behaviors and cheat on the real damages when writing the insurance reports to the insurance company; γ is the cheating rate and represents an additional fraction of fake damages reported by the agricultural producer that cannot be perfectly verified by the insurer, leading to inflated compensation claims. More generally, γ captures a broader class of overpayments arising from information asymmetries, including misreporting, incomplete documentation, and verification errors. Therefore, *A* obtains compensation for climate changes at the overall rate $\alpha - \sigma B + \gamma > 0$. The previous assumptions inform the three levers (blockchain, insurance, and cheating rate) that *A* adopts to face the challenges imposed by possible catastrophic events connected with the agricultural climate changes.

Assumption 5. A produces a quantity of food u>0, which implies investment and production costs $\frac{c_u u^2}{2}$, and sells it at an exogenous selling price p>0.

Firm *A* makes food quantity *u* and sells it at the given market price *p*. While this assumption is in line with previous agricultural studies (Golmohammadi and Hassini, 2019; Qian, 2021), it allows us to depart from the analysis of supply chain issues linked to vendor and buyer relationships. Instead, we focus on other aspects of the agricultural producer's business model linked to the financial flows associated with insurance payouts in the case of disastrous and catastrophic events. *A* spends $\frac{c_u u^2}{2}$ as the total production investment, with c_u representing the cost efficiency parameter associated with the production of volume *u*.

Assumption 6. I incurs verification cost, c_v, and reimburses A with a delay $\delta > 0$.

Since *I* cannot connect to the blockchain, she cannot gather information from the ecosystem, as *A* does. Therefore, she incurs verification cost c_v, which is related to analyzing the policyholders' evidence, conducting interviews, and determining the validity of the claims, along with a data analysis and background checks to detect and prevent possible fraudulent claims, as well as legal costs linked to the liability, the negotiations, and the defense against the lawsuits. All these activities are very complex and can take an exceptional amount of time, especially when the policyholder shows resistance to collaborating and does not provide all the required information (Ruzza et al., 2025). Hence, time is indicated by $\delta > 0$. Interestingly, *I* can also use δ as a means to delay the policyholder's payment as much as possible, with the objective of earning interest during the time period, and discouraging false claims.

Using the superscript *T* to indicate the *T*-Game, both firms play the game in an independent investment manner to maximize their profits in which their objective functions can be summarized as follows:

$$\Pi_I^T = \max_t \{u(t - (\alpha - B\sigma + \gamma)(c_v + (1 - \delta)r))\} \tag{1}$$

$$\Pi_A^T = \max_{u,B} \left\{ u(p - t) - pu(\alpha - B\sigma) + (1 - \delta)ru(\alpha - B\sigma + \gamma) - \frac{c_u u^2}{2} - \frac{c_B B^2}{2} \right\} \tag{2}$$

I maximizes Eq. (1) by optimizing the unit insurance fee, *t*, through which she generates revenues directly linked to the production volumes, *u*, which is covered by insurance. *I*'s total revenue is *ut*, and $u(\alpha - B\sigma + \gamma)(c_v + (1 - \delta)r)$ indicates the total cost. Hereby, $u(\alpha - B\sigma + \gamma)(1 - \delta)r$ represents the reimbursement that *I* transfers to *A*,

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013R1308 (accessed September 12, 2025).

where $(\alpha - B\sigma + \gamma)$ is the total production rate to be reimbursed, which consists of: the real damage rate, α, the rate of disasters avoided by the blockchain, $B\sigma$, and the rate of fake claims, γ. Instead, the term $c_v + (1-\delta)r$ represents the insurance marginal cost per unit of the product claimed to be damaged by A, including the marginal reimbursement, r, which is reimbursed by I with certain delay, δ, and the verification cost per unit of product, c_v.

A maximizes Eq. (2) with respect to production volume, u, and blockchain efforts, B. A's revenue depends on the production volumes and the marginal revenue, $p-t$. However, due to the real disaster that occurred, A loses αup, while she can avoid some of these losses through the implementation of blockchain at a rate of σB. In addition, $(1-\delta)ru(\alpha - B\sigma + \gamma)$ represents the reimbursement that Firm A receives from Firm I, delayed by time δ. Furthermore, $\frac{c_u u^2}{2}$ and $\frac{c_B B^2}{2}$ are quadratic and convex forms used to calculate the investments in producing u units of products and implementing the blockchain technology, respectively. We consider a quadratic form for both the blockchain and production investment, as it is a well-established function in game theory models in the literature. The reason is that it corresponds to real-world economic cases, where investments have high returns up to a point, and then there is a diminishing positive growth rate of their impact. In other words, investments have a greater impact on the efficiency and quality of operations and services initially. However, later, their efficiency decreases compared to the beginning, as improvement becomes more challenging beyond a certain point (Vessal et al., 2022).

3.2. A joint investment scenario for blockchain (C-game)

In this section, we present a joint investment scenario, namely, the C-Game, in which I supports the blockchain investments by paying the fraction $\Phi \in (0,1)$ to A to collaborate on blockchain investments and technology benefits.

Assumption 7. In this scenario, A cooperates in the blockchain investments at a rate $\Phi \in (0,1)$, and limits the chances to cheat ($\gamma = 0$). Since cheating is nil, I does not face a verification cost ($c_v = 0$); however, she cannot delay the reimbursement to A ($\delta = 0$) any more since the money transfers to A are managed automatically by the smart contracts.

By collaborating, I has full visibility of the blockchain system which eliminates the opportunity for A to cheat by fraction γ. By having transparency in A's system, I only grants reimbursements when A really experiences losses. In other words, there are no more fake claims and cheats ($\gamma = 0$). Moreover, as the blockchain technology precisely traces and records the events, there are no verification costs ($c_v = 0$) and no reason for payment delays ($\delta = 0$) since the smart contracts, using the oracles, make the payments to A immediately after validating the information through the blockchain (Ruzza et al., 2025). This assumption is aligned with the e-agricultural report published by FAO (2018 and 2019), which discusses the benefits of blockchain for crop insurance.

Using the superscript C to indicate the C-Game, both firms play the game jointly regarding the blockchain technology to maximize their profit functions as summarized below:

$$\Pi_I^C = \max_{t,\phi}\left\{u(t - r(\alpha - B\sigma)) - c_B\frac{B^2\Phi}{2}\right\} \tag{3}$$

$$\Pi_A^C = \max_{u,B}\left\{u(p-t) + u(r-p)(\alpha - \sigma B) - \frac{c_u u^2}{2} - c_B\frac{B^2(1-\Phi)}{2}\right\} \tag{4}$$

Where $t - r(\alpha - B\sigma)$ is the marginal revenue for A and she only pays for the real disasters subtracting the part that blockchain helps to avoid loss ($B\sigma$). Moreover, $c_B\frac{B^2\Phi}{2}$ is the blockchain investments supported by Firm I. Note that Φ is the new decision variable for I, which is set jointly with t. Regarding A's profit, there are two changes when compared to Eq. (2). The investment in blockchain technology includes I's support Φ and A's effort becomes $c_B\frac{B^2(1-\Phi)}{2}$. Moreover, $ur(\alpha - \sigma B)$ represents the total reimbursement that Firm A receives without any delay ($\delta = 0$) from I, as there is no possibility of fake claims ($\gamma = 0$).

4. Equilibrium analysis

In this section, we present the equilibria for the T-Game and the C-Game. We then derive the conditions under which each of the optimal solutions is feasible.

4.1. Independent investment (T-game) equilibria

In the T-Game, as I will play in an independent investment manner; hence, A invests in blockchain on their own to reduce product loss. Consequently, the game moves according to the following steps: 1) since I is the chain leader and plays in an independent investment manner, A moves for first and sets the optimal production level (u^{T^*}), as well as the optimal blockchain investments (B^{T^*}); 2) I takes this information into consideration and optimally sets her service price per unit of product (t^{T^*}). To clarify the main assumptions of this scenario, we need to explain some points in the following. First, using blockchain makes the reimbursement parametric according to the data collected and recorded on the blockchain, bringing transparency among partners. Second, eliminating fraud means that, as we use parametric insurance, the final decision will be based on trustworthy data and parameters calculated automatically by the system (as in the real case of Arbol). Third, the verification cost is a part of the investment in the blockchain technology, as the parametric insurance is automated. Removing the delay in payment (or immediate payment) does not mean that there is no gap between the disaster and the payment at all. In the first scenario, the payment duration exceeds the expected timeframe. We consider the parameter δ as the financial impact related to the abnormal delay in payment due to further verification and paperwork, which will be eliminated in the second scenario. For instance, on the Arbol website, it is mentioned that using blockchain, the payment expectation time is two weeks, not zero.

When Firm I does not support the investments in blockchain technology, A's strategies will depend on I's strategy t^{T^*}, being the business leader; more specifically, the optimal solution for the T-game results is as follows (See Appendix B1 in the Online Appendix):

$$u^{T^*} = \frac{c_B((1-\alpha)p + r(1-\delta)(\alpha+\gamma) - t^{T^*})}{c_B c_u - \sigma^2(p-(1-\delta)r)^2} \tag{5}$$

$$B^{T^*} = \frac{\sigma(p-(1-\delta)r)((1-\alpha)p + (1-\delta)r(\alpha+\gamma) - t^{T^*})}{c_B c_u - \sigma^2(p-(1-\delta)r)^2} \tag{6}$$

$$t^{T^*} = \left\{\begin{array}{l} c_B c_u((\alpha+\gamma)(c_v - 2\delta r + 2r) + (1-\alpha)p + \\ \sigma^2(p-(1-\delta)r)\big(c_v p(\alpha-\gamma-2) - c_v(1-\delta)r(\alpha+\gamma) - (1-\alpha)p^2 + (\delta-1)pr(\alpha+2\gamma+1)\big) \end{array}\right\}\frac{}{2(c_B c_u - \sigma^2(c_v+p)(p-(1-\delta)r))} \tag{7}$$

Condition 1. *The optimal product level will be feasible ($u^{T^*} > 0$) if $(1-\alpha)p + r(1-\delta)(\alpha+\gamma) > t^{T^*}$ and $c_B c_u > \sigma^2(p-(1-\delta)r)^2$.*

The term $r(1-\delta)(\alpha+\gamma)$ can be interpreted as the marginal reimbursement that A receives from I; the term $p-(1-\delta)r$ indicates the revenue that A loses per unit of damaged product, considering the reimbursement that he receives from I with delay δ. Moreover, $(1-\alpha)p + r(1-\delta)(\alpha+\gamma)$ is the expected unit revenue considering the marginal sales revenue of a perfect product plus the marginal revenue from the reimbursement. Therefore, $(1-\alpha)p + r(1-\delta)(\alpha+\gamma) > t^{T^*}$ indicates the necessity that the revenue of a unit of the product is greater than the cost that A pays per each unit to the insurance company. Furthermore, the term $c_B c_u > \sigma^2(p-(1-\delta)r)^2$ can be interpreted as $c_B > \sigma(p-(1-\delta)r)$ and $c_u > \sigma(p-(1-\delta)r)$, which shows that the marginal investment in blockchain technology should be greater than the unit revenue concerning blockchain's ability to prevent crop losses. Blockchain technology is not supposed to provide additional revenue; it only prevents the loss of damages to A since the information recorded on the blockchain platform through the oracles is validated and transferred to smart systems to adopt proactive actions. Furthermore, it is not feasible to consider the marginal production cost less than the marginal loss proportion that blockchain can prevent from being damaged.

Condition 2. *The optimal investment in blockchain technology will be feasible ($B^{T^*} > 0$) if $(1-\alpha)p + r(1-\delta)(\alpha+\gamma) > t^{T^*}$, $c_B c_u > \sigma^2(p-(1-\delta)r)^2$, and $p-(1-\delta)r > 0$.*

The first two terms in Condition (2) are the same as the terms we analyzed in Condition (1). The last term, $p-(1-\delta)r$, must be positive, as the unit revenue cannot be less than the marginal reimbursement. Otherwise, the reimbursement covers the production cost with an amount greater than the revenue. This is not feasible in real business models and, in that case, A prefers to lose all the products aiming to gain more profit. Firm I's strategy regarding the insurance price is influenced by A's strategies for investing in the blockchain as well as the production level. To analyze its feasibility, we need to ensure that Condition (3) holds.

Condition 3. *To ensure that $t^{T^*} > 0$, it must be that $c_B c_u > \sigma^2(p-(1-\delta)r)$ and $c_B c_u > \sigma^2(c_v+p)(p-(1-\delta)r)$.*

The first term in Condition (3) is extracted from considering the numerator of Eq. (7), which is greater than zero. To prove this condition, as the numerator of the proposed equation provides a complicated relationship between different parameters, we summarize it as $c_B c_u W_1 - \sigma^2(p-r(1-\delta))W_2$ where $W_1 = (\alpha+\gamma)(c_v - 2\delta r + 2r) - \alpha p + p$ and $W_2 = c_v p(\alpha-\gamma-2) - c_v(1-\delta)r(\alpha+\gamma) - (1-\alpha)p^2 - (1-\delta)pr(\alpha+2\gamma+1)$. Subtracting W_2 from W_1 will result in $(1-\alpha)p^2 + (1-\alpha)p + c_v p(2+\gamma-\alpha) + (\alpha+\gamma)(c_v + 2(1-\delta)r) + c_v(1-\delta)r(\alpha+\gamma) + (1-\delta)pr(\alpha + 2\gamma + 1)$ and we can deduce that $W1 - W_2 > 0$. Therefore, if the numerator of Eq. (7) is greater than zero, we conclude that $c_B c_u > \sigma^2(p-(1-\delta)r)$ assures the feasibility of the optimal unit insurance cost.

Furthermore, from the term $c_B c_u > \sigma^2(c_v+p)(p-(1-\delta)r)$, we interpret $c_u > \sigma(p-r(1-\delta))$ and $c_B > \sigma(c_v+p)$, in which the first term was discussed previously and the latter identifies the relationship between the cost efficiency parameter of adopting blockchain with the marginal revenue of A, as well as the verification cost per unit of product for Firm I. In other words, although Firm I does not invest in blockchain technology, the efficiency of implementing this technology by Firm A influences I's pricing strategy for the insurance cost and, consequently, her profit. This is due to the potential of fraud and fake claims from Firm A, who increases the costs of Firm I by spending more on inspection activities and reimbursement fees. Hence, the marginal cost of the blockchain (c_B) should exceed the value it provides in order to prevent revenue loss, as well as inspection costs (higher than a value equal to $\sigma(c_v+p)$), ensuring that Firm A does not easily invest in blockchain with the intention to increasing fraudulent claims.

Lemma 1. *In the independent investment scenario, if $(1-\alpha)p - c_v(\alpha+\gamma) > 0$, by increasing the unit production cost (c_u) or the marginal blockchain cost (c_B), Firm I will increase her optimal unit insurance cost (t^{T^*}).*

Proof. See Appendix A1 in the Online Appendix.

Proposition 1. *In the independent investment scenario considering $(1-\alpha)p - c_v(\alpha+\gamma) > 0$, increasing c_u or c_B will increase t^{T^*} and, accordingly, A will decrease the optimal blockchain investment (B^{T^*}).*

Proof. See Appendix B3 in the Online Appendix.

According to Proposition (1), in the independent investment scenario, when the unit production cost or the marginal blockchain cost increases, I will raise the unit insurance price due to the possibility of the increase in fake claims by A trying to offset his additional production or blockchain investment cost. In that case, the insurance company decides to increase the unit insurance price, requiring A to dedicate more budget toward production and insurance costs. This, in turn, limits the ability of A to invest further in blockchain technology, given its impact on overall profitability.

Lemma 2. *In the independent investment scenario, if $(1-\alpha)p - c_v(\alpha+\gamma) > 0$, by increasing the blockchain performance in preventing damages (σ), the insurance company will decrease her optimal unit insurance cost (t^{T^*}).*

Proof. See Appendix A2 in the Online Appendix.

Proposition 2. *In the independent investment scenario considering $(1-\alpha)p - c_v(\alpha+\gamma) > 0$, the increment of σ reduces the optimal unit insurance cost (t^{T^*}), and consequently, leads to an increment in the optimal blockchain investment (B^{T^*}) by A.*

Proof. See Appendix B4 in the Online Appendix.

As a result of Proposition (2), when the preventive capability of the blockchain technology to reduce damaged products decreases, considering the same reimbursement cost (r), I decreases the unit insurance cost to help A obtain a better opportunity to invest in the blockchain technology and decrease the amount of damaged products that favors both firms.

Proposition 3. *In the independent investment scenario, if an increase in the damage rate (α) or fake claims (γ) leads to an increase in the optimal unit insurance cost (t^{T^*}) by the insurance company, A will increase his optimal production level (u^{T^*}) and decrease his optimal investment in blockchain (B^{T^*}). Otherwise, if t^{T^*} decreases, A reduces u^{T^*} and increases B^{T^*}.*

Proof. See Appendix B5 in the Online Appendix.

Based on Proposition (3), the higher the risk of having damaged products and fake claims, the higher the reimbursement cost of the insurance company. Accordingly, when the rate of damaged products or fake claims increases, I may increase the unit insurance cost as well. Hence, the agricultural firm will increase the production level to offset the additional insurance costs, aiming to cover the extra expenses by increasing its product sales. Moreover, in this case, the increment in the production investment, in addition to the possibility of fake claims, discourages A from investing in the blockchain technology. However, if the optimal unit insurance fee decreases, A prefers to reduce his investment in production and alternatively focus on improving the blockchain system to mitigate potential damages. By applying the optimal strategies, it is possible to obtain the optimal profits $\Pi_A^{T^*}$ and $\Pi_I^{T^*}$ as follows (See Appendix B1 in the Online Appendix):

$$\Pi_A^{T^*} = \frac{c_B(c_v(\alpha+\gamma) - p(1-\alpha))^2 (c_B c_u - \sigma^2(p - r(1-\delta))^2)}{8(c_B c_u - \sigma^2(c_v + p)(p - r(1-\delta)))^2} \tag{8}$$

$$\Pi_I^{T^*} = \frac{c_B(c_v(\alpha+\gamma) - p(1-\alpha))^2}{4(c_B c_u - \sigma^2(c_v + p)(p - r(1-\delta)))} \tag{9}$$

According to Eq. (8), the profit of A is always positive, based on Conditions (1) and (2), where we discussed the term $c_B c_u > \sigma^2(p-(1-\delta)r)^2$ to reach the feasible solutions for u^{T^*} and B^{T^*}. Therefore, as long as A adopts the blockchain technology properly (with an efficient c_B), he would be satisfied by obtaining positive profits from his business. In addition, the I's profit will be positive if its denominator is positive, which means that $c_B c_u > \sigma^2(c_v + p)(p - r(1-\delta))$, which was previously discussed in Condition (3).

4.2. Joint investment (C-game) equilibria

In the C-Game, I is willing to play a joint investment game with A, supporting the blockchain investments with the share Φ. With this commitment, I will have access to the blockchain system, preventing A from declaring fraudulent claims regarding the damages ($\gamma = 0$). Moreover, with shared access to blockchain technology, I automatically proceeds with the reimbursements without the need for verification ($c_v = 0$ and $\delta = 0$). Therefore, the C-Game moves according to the following steps: 1) since I plays a joint investment game, A optimally sets the production level, u^{C^*}, and the blockchain investments, B^{C^*}; 2) I takes into consideration A's decisions and optimally sets the insurance cost, t^{C^*}, and its investment share in blockchain technology, Φ^{C^*}. Accordingly, when Firm I supports the investments in the blockchain technology, A's strategies will depend on I's strategy t^{C^*} and ϕ^{C^*}, being the business leader; more specifically, the optimal solution for the C-game results is as follows (See Appendix B2 in the Online Appendix):

$$u^{C^*} = \frac{c_B(1-\phi^{C^*})((1-\alpha)p + \alpha r - t^{C^*})}{c_B c_u(1-\phi^{C^*}) - \sigma^2(p-r)^2} \tag{10}$$

$$B^{C^*} = \frac{\sigma(p-r)(t^{C^*} - (1-\alpha)p - \alpha r)}{\sigma^2(p-r)^2 - c_B c_u(1-\phi^{C^*})} \tag{11}$$

$$\phi^{C^*} = \frac{p+r}{3p-r} \tag{12}$$

$$t^{C^*} = \frac{4c_B c_u(2\alpha r + (1-\alpha)p) + \sigma^2(3p-r)(\alpha(p-r)^2 - p(p+r))}{8c_B c_u - \sigma^2(r-3p)^2} \tag{13}$$

Condition 4. *To have feasible strategies for Firm A ($u^{C^*} > 0$ and $B^{C^*} > 0$), $(1-\alpha)p + \alpha r > t^{C^*}$, and $c_B c_u(1 - \phi^{C^*}) > \sigma^2(p-r)^2$.*

Term $t^{C^*} - (1-\alpha)p - \alpha r$ represents the difference between the marginal insurance cost and the average marginal revenue, considering both damaged and undamaged products. Moreover, $\sigma(p-r)$ is the value by which implementing blockchain technology reduces the loss per unit of damaged product, while $c_B(1-\phi^{C^*})$ denotes the share of the marginal blockchain cost for Firm I. Accordingly, the first term in Condition (4) illustrates that the marginal insurance cost must not exceed the average marginal revenue of Firm A; otherwise, it would not be economically feasible for A to continue production.

Term $\sigma^2(p-r)^2 < c_B c_u(1-\phi^{C^*})$ can be interpreted as $\sigma(p-r) < c_u$ and $\sigma(p-r) < c_B(1-\phi^{C^*})$. The first term indicates the value implementing blockchain technology can prevent in terms of the loss per unit of damaged product ($\sigma(p-r)$), which is less than the marginal production cost. Otherwise, it implies that the blockchain can also provide additional profit for damaged products, making it more profitable for Firm A, even if all products are lost. In reality, to have a feasible model, blockchain technology seeks to prevent loss rather than create additional profit. The latter, $\sigma(p-r) < c_B(1-\phi^{C^*})$, emphasizes that the marginal cost of the blockchain technology for Firm A must be greater than the value that the blockchain can save per unit of damaged product; otherwise, it can be interpreted that the blockchain technology can offer additional profit per unit of damaged product that compensates for its marginal implementation cost.

Regarding the optional quantity for the investment share of Firm I in the blockchain technology, it is easy to prove the feasibility of Eq. (12) as $p > r$, so the numerator and denominator acquire positive values. However, for the insurance price strategy (t^{C^*}), all earlier conditions for the joint investment scenario (Condition 4) apply. Eq. (13) illustrates the complex relationship between the various parameters. Accordingly, we provide some propositions to discuss it in more detail.

Lemma 3. *In the joint investment scenario, the increment in the unit production cost (c_u), or in the marginal blockchain cost (c_B), or the damage prevention rate of blockchain technology (σ), causes growth (a decrease) in the optimal unit insurance cost (t^{C^*}) if $r > \frac{p}{3}$ $\left(r < \frac{p}{3}\right)$.*

Proof. See Appendix A3 in the Online Appendix.

Proposition 4. *In the joint investment scenario, if the unit reimbursement (r) is greater than a specific value ($\frac{p}{3}$) by increasing the unit production cost (c_u) or the marginal blockchain cost (c_B), I increases the unit insurance cost (t^{C^*}) and, accordingly, the agricultural producer decreases his optimal production level (u^{C^*}) and the optimal blockchain investment (B^{C^*}).*

Proof. See Appendix B6 in the Online Appendix.

According to Proposition (4), when the reimbursement cost is high ($r > \frac{p}{3}$), increasing the production cost and the marginal blockchain cost leads to a reduction in production levels as higher investment becomes necessary to maintain the previous operation capacity. Hence, I decides to raise her unit insurance price to compensate for the revenue losses resulting from reduced production level and instantaneous reimbursement. Accordingly, A reduces his production level and investment in blockchain technology due to higher insurance costs.

Proposition 5. *In the joint investment scenario, if $r < \frac{p}{3}$, by using a more efficient blockchain platform with a higher performance in terms of preventing damages (increasing σ), I reduces the unit insurance cost, and consequently, A decreases both the optimal production level as well as the blockchain investment.*

Proof. See Appendix B7 in the Online Appendix.

The aforementioned proposition indicates when the unit reimbursement cost is not very high or is reasonable ($r < \frac{p}{3}$). By increasing the efficiency of blockchain technology in preventing damages, I faces a lower level of risk for reimbursement and, consequently, decreases the unit insurance price. The agricultural firm then decreases his production level, as well as the total investment in blockchain technology, as he can achieve a larger profit despite lower investments in technology and production effort. In other words, adopting more effective blockchain technology helps lower insurance costs and investment in blockchain technology, and consequently the total production costs.

Considering the optimal strategies of the players, we obtain the optimal profits $\Pi_A^{C^*}$ and $\Pi_I^{C^*}$, as follows (See Appendix B2 in the Online Appendix):

$$\Pi_I^{C^*} = \frac{2(1-\alpha)^2 c_B p^2}{8c_B c_u - \sigma^2(r-3p)^2} \tag{14}$$

$$\Pi_A^{C^*} = \frac{4(1-\alpha)^2 c_B p^2 (2c_B c_u - \sigma^2(3p^2 + r^2 - 4pr))}{\left(8c_B c_u - \sigma^2(r-3p)^2\right)^2} \quad (15)$$

Note that Eqs. (14) and (15) are positive when the following conditions occur.

Condition 5. To ensure $\Pi_I^{C^*} > 0$, it is required that $8c_B c_u > \sigma^2(r-3p)^2$.

The term $8c_B c_u > \sigma^2(r-3p)^2$ in Condition (5) illustrates the relationships between the five primary parameters: c_B, c_u, σ, r, and p. According to Eq. (3), the profit of Firm I has a positive relationship with σ, meaning that the greater the efficiency of the blockchain technology in preventing damages, the less she pays for reimbursement. Moreover, her profit has a negative relationship with c_B and r, which shows that a higher value for these parameters increases her total costs. To increase the profit of Firm I, we need to consider the minimum value for c_B and r and the maximum value for σ satisfying the proposed term in Condition (5). In other words, Firm I should only accept the *joint investment* scenario when the blockchain technology provides an efficient system at a reasonable cost and damage prevention capability, considering the unit production cost and the unit reimbursement fee.

Condition 6. To have $\Pi_A^{C^*} > 0$, it should result that $2c_B c_u > \sigma^2(3p^2 + r^2 - 4pr)$.

To discuss the term mentioned in Condition (5), we recall Eq. (4). According to Eq. (4), to increase the revenue and profit, Firm A needs to minimize c_u and c_B while also preventing damages by adopting blockchain technology with the highest level of preventing ability (the highest value for σ). Considering these assumptions, the lower the left-hand side of the inequality ($c_B c_u$) and the higher the σ on the right-hand side, the higher the profit of A. Therefore, decreasing $c_B c_u$ on the left-hand side and increasing σ on the other side of the inequality $2c_B c_u > \sigma^2(3p^2 + r^2 - 4pr)$ does not assure its satisfaction. In that case, satisfying the proposed inequality only occurs when the term $3p^2 + r^2 - 4p$ on the right-hand side is very low. If we revise this term to $(p-r)^2 + 2p(p-r)$, to reach this goal, the difference between the marginal revenue and the marginal reimbursement should be minimized. In other words, when both players collaborate in implementing the blockchain technology, it will not be possible for A to make fake claims. Therefore, Firm A aims to minimize the difference between his marginal revenue and the marginal reimbursements.

Lemma 4. *In the joint investment scenario, if $r > \frac{p}{2}$, then the higher the rate of damaged products (α), the higher the unit optimal insurance cost.*

Proof. See Appendix A4 in the Online Appendix.

Proposition 6. *In the joint investment scenario, when $r > \frac{p}{2}$, by increasing the damage rate (α), Firm I increases the unit insurance cost (t^{C^*}) and, accordingly, Firm A will decrease the investment amount (B^{C^*}) and his production level (u^{C^*}).*

Proof. See Appendix B8 in the Online Appendix.

According to Proposition (6), when the reimbursement cost is higher than half of the unit price, increasing the likelihood of having damaged products prompts the insurance company to increase her unit insurance cost to compensate for the higher risk associated with more damaged products and, consequently, increased reimbursement costs. As a result, A decreases his production level and the total investment in blockchain technology, as he must pay more insurance costs per unit of product while facing more damaged products when increasing his production level. Moreover, under this condition, both companies decrease their investment in blockchain technology when the damage rate increases and there is no possibility of improving the efficiency of blockchain in terms of preventing (σ) crop losses.

5. Comparison between equilibria and solutions

To analyze the benefits of joint investment in blockchain to mitigate the issue of frauds in agriculture, we compare the optimal strategies of the C-Game and T-Game for each of the players. To reach this goal, we calculate $\Delta_u = u^{C^*} - u^{T^*}$, $\Delta_B = B^{C^*} - B^{T^*}$, and $\Delta_t = t^{C^*} - t^{T^*}$ and show their results in Appendix C in the Online Appendix. Although these comparisons can be obtained analytically, determining their signs requires a numerical analysis due to the complexity of the interfaces among all parameters. So, we provide both analytical and numerical analyses.

5.1. Analytical analysis

In this section we focus on two conditions: 1) blockchain technology does not have an efficient capability to prevent damages ($\sigma \to 0$) and only is used for eliminating fake claims and immediate reimbursement payments, 2) the damage rate is very high ($\alpha \to 1$).

Proposition 7. *When the the blockchain technology is not efficient in preventing damages ($\sigma \to 0$), the insurance cost in the joint investment scenario (t^{C^*}) will be greater than the insurance cost in the independent investment scenario (t^{T^*}) when the delay in payment can compensate for the verification cost and the cost for fake claims.*

Proof. See Appendix B9 in the Online Appendix.

As the ability to prevent damages in the products has a positive impact on the profit of both players (I reduces the reimbursement and A increases his revenue), we consider $\sigma \to 0$ to only focus on the traceability function of blockchain technology that can eliminate delay in payment for A and can remove verification cost for I. As $\delta r(\alpha + \gamma) > \frac{1}{2}c_v(\alpha + \gamma) + r\gamma$, the delay in payment can compensate for the average verification cost per unit (for real and fake claims) and the reimbursement that I pays for fake claims in T-Game. In other words, when the delay in payment offsets the proposed costs, player I does not need to invest in blockchain technology unless she increases the unit insurance fee.

Proposition 8. *When $2p(1-\alpha) > c_v(\alpha + \gamma)$, the companies jointly invest in blockchain technology because of its traceability advantages (eliminating delay in payments and verification costs) rather than because of its capability in preventing damages ($\sigma \to 0$).*

Proof. See Appendix B10 in the Online Appendix.

The previous result states that, even without the ability of blockchain technology to prevent damages ($\sigma \to 0$), the profit of both players in the joint investment scenario is higher than the independent investment scenario. In fact, if $p > \frac{c_v(\alpha+\gamma)}{2(1-\alpha)}$, we can conclude that both players improve their profits using the traceability function of blockchain technology, ensuring that there are no fraud and delays in payments, even in the case when the blockchain cannot prevent the damages. Although the investment in blockchain technology can be helpful to the insurance company to eliminate the fake claims for reimbursement, Proposition (8) informs that these results are more significant for the agriculture company since it results that $\frac{\lim_{\sigma \to 0} \Pi_A^{C^*} - \Pi_A^{T^*}}{\lim_{\sigma \to 0} \Pi_I^{C^*} - \Pi_I^{T^*}} = 2$.

Proposition 9. *When the risk of facing natural crises and damaging products is very high ($\alpha \to 1$), both companies prefer not to invest in blockchain technology. In that case, the independent investment scenario is more beneficiary for them in terms of profit.*

Proof. See Appendix B11 in the Online Appendix.

According to Proposition (9), when the damage rate is very high ($\alpha \to 1$), the independent investment scenario will be more profitable for both players, independent of the blockchain's capability to detect the disruptions. Therefore, in a highly uncertain and volatile environment, the insurer prefers not to collaborate in implementing blockchain technology, as it is expected to provide immediate payment for a large volume of damaged products, in addition to the cost of blockchain adoption.

Proposition 10. *The decrease in the difference between the unit reimbursement and the unit price of the product (by increasing r), the insurer increases its interest in the adoption of blockchain, in which, when the proposed difference is minimum ($r \rightarrow p$), the insurance company adopts the blockchain technology on her own ($\phi \rightarrow 1$) as a part of its service. However, the total investment in blockchain technology decreases.*

Proof. See Appendix B12 in the Online Appendix.

This proposition suggests that in cases where the insurance program covers the entire loss of the agricultural producer, the insurer prefers to increase her investment share in the blockchain to prevent product damage and potential fraudulent claims. Nevertheless, as the insurer invests in blockchain alone ($\phi \rightarrow 1$), the total investment in blockchain reduces compared to the condition that both players participate in this investment. This proposition clarifies that insurance companies prefer to invest in blockchain solely or with a minimum participation from the agricultural producers if the regulations force them to consider a higher reimbursement ($r \rightarrow p$), which consequently drives them to increase transparency using blockchain technology. In other words, if the reimbursement is very low, then the motivation among the insurers is low as well to adopt blockchain technology, and in that case, the agricultural producer will have the main investment share in blockchain, aiming to take advantage of its capability in reducing crop loss, besides eliminating the verification period and benefiting from immediate reimbursement.

Furthermore, this proposition justifies the reason that the optimal investment share of the insurer in Equation (12) depends only on p and r. Investing in blockchain technology becomes essential for insurers when the difference between the unit price and unit reimbursement decreases ($r \rightarrow p$). In that case, the insurer tries to focus on preventing damage when her profit margin per unit loss is low. So, the insurer benefits indirectly from the positive effects of blockchain adoption on reducing damaged products and increasing the producer's production level. Accordingly, the difference between product prices and reimbursement costs has a significant role in the insurer's decision on his optimal investment share in blockchain technology.

Moreover, as an extension, we analyze the impact of considering a minimum blockchain investment level (B_{min}) and a minimum investment share (ϕ_{min}) on the optimal solutions of the *C*-Game. This assumption can ensure the appropriate adoption of this technology by defining the minimum investment level and also guaranteeing the minimum investment share that is required for a joint investment in a market. The results are available in Appendix F in the Online Appendix for further reading.

Table (3) summarizes the main results of our analysis according to the propositions. This Table also provide a good understanding of the model sensitivity to the changes in the most important parameters.

Table 3
The main results and sensitivity analysis.

	Model	Condition	B^*	u^*	t^*	Φ^*
$c_u\uparrow$	*T-Game*	$(1-\alpha)p - c_v(\alpha+\gamma) > 0$	$B^{T^*}\downarrow$	-	$t^{T^*}\uparrow$	-
$c_B\uparrow$	*T-Game*	$(1-\alpha)p - c_v(\alpha+\gamma) > 0$	$B^{T^*}\downarrow$	-	$t^{T^*}\uparrow$	-
$\sigma\uparrow$	*T-Game*	$(1-\alpha)p - c_v(\alpha+\gamma) > 0$	$B^{T^*}\uparrow$	-	$t^{T^*}\downarrow$	-
$\alpha\uparrow$	*T-Game*	-	$B^{T^*}\downarrow$	$u^{T^*}\uparrow$	$t^{T^*}\uparrow$	-
$\gamma\uparrow$	*T-Game*	-	$B^{T^*}\downarrow$	$u^{T^*}\uparrow$	$t^{T^*}\uparrow$	-
$c_u\uparrow$	*C-Game*	$r > \frac{p}{3}$	$B^{C^*}\downarrow$	$u^{C^*}\downarrow$	$t^{C^*}\uparrow$	-
$c_B\uparrow$	*C-Game*	$r > \frac{p}{3}$	$B^{C^*}\downarrow$	$u^{C^*}\downarrow$	$t^{C^*}\uparrow$	-
$\sigma\uparrow$	*C-Game*	$r < \frac{p}{3}$	$B^{C^*}\downarrow$	$u^{C^*}\downarrow$	$t^{C^*}\downarrow$	-
$\alpha\uparrow$	*C-Game*	$r > \frac{p}{2}$	$B^{C^*}\downarrow$	$u^{C^*}\downarrow$	$t^{C^*}\uparrow$	-
$\sigma\rightarrow 0$	*T-Game & C-Game*	-	-	-	$t^{C^*} > t^{T^*}$	-
$r\rightarrow p$	*C-Game*	-	-	-	-	$\phi\rightarrow 1$
$\sigma\rightarrow 0$	*T-Game & C-Game*	Both players prefer the Joint Investment Scenario (C-Game)				
$\alpha\rightarrow 1$	*T-Game & C-Game*	Both players prefer the Independent Investment Scenario (T-Game)				

5.2. Numerical analysis

To provide further discussions, we fix the following baseline of parameters: $p = 1.8$, $r = 1.2$, $c_B = 1$, $c_U = 1$, $c_v = 0.2$, $\alpha = 0.5$, $\sigma = 0.1$, $\gamma = 0.2$, and $\delta = 0.1$. These parameter settings are essential to analyze the dynamics of blockchain's influence on the strategic interactions between the sectors involved. We compare the optimal solutions with the results of the benchmark values, considering three different scenarios for each of the aforementioned parameters. Appendix D of the Online Appendix presents the outputs of this analysis, from which we derive the observations in this section. Moreover, Figure (1) and Figure (2) show the variations in the optimal strategies in accordance with changes in some of the main parameters. In these figures, we define $\Delta A = \Pi_A^{C^*} - \Pi_A^{T^*}$ and $\Delta I = \Pi_I^{C^*} - \Pi_I^{T^*}$ to indicate the players' preferences in the joint investment scenario. Additionally, these figures, as a complement to Appendix D, help to have a better understanding of the difference between the optimal decision variables considering both *C*-Game and *T*-Game.

Observation 1. *The collaboration between an insurance company and an agricultural producer on blockchain technology leads to the following results:*

a. $\phi^{C^*} \in (0,1)$
b. $u^{C^*} - u^{T^*} > 0$
c. $B^{C^*} - B^{T^*} > 0$
d. $t^{C^*} - t^{T^*} < 0$ if $\delta < \bar{\delta}$
e. $\Pi_I^{C^*} - \Pi_I^{T^*} > 0$
f. $\Pi_A^{C^*} - \Pi_A^{T^*} > 0$

Proof. See the simulation results in Figs. 1 and 2, and in the table in Appendix D in the Online Appendix.

The findings in Observation (1) outline that the support rate is feasible as it results in $\phi^{C^*} \in (0,1)$; accordingly, the support rate, which represents the proportion of blockchain investment costs covered by *I*, is positive but does not reach full coverage (100%). This suggests a sharing of costs between the companies, which may be seen as an investment in mutual risk management and technological advancement. The interior solution associated to the support rate indicates a balanced approach in which both parties can share the benefits linked to the adoption of blockchain technology. This result on the support rate leads to greater investment in blockchain technology by *A*. Considering the possible collaboration, *A* can invest in a broader and comprehensive blockchain as, while creating a better system for enhancing traceability, reducing fraud, and improving contractual enforcement, it creates efficiency through the collaboration.

This collaboration leads *I* to charge lower insurance fees since the chances of predicting the event of a disaster affecting agricultural products and the related cheating are mitigated through the blockchain. Therefore, considering the lower risks incurred by *I* along with the reduced uncertainty about the extent of losses, precise damage assessments and possibly even preventive measures, *A* enjoys the payment of a lower fee. At the same time, the positive effects of collaboration induce *A* to produce more when collaboration on blockchain technology is present, considering the higher confidence in risk management and supply chain transparency provided by blockchain technology. Overall, the adoption of collaborative approaches on blockchain results in Pareto-

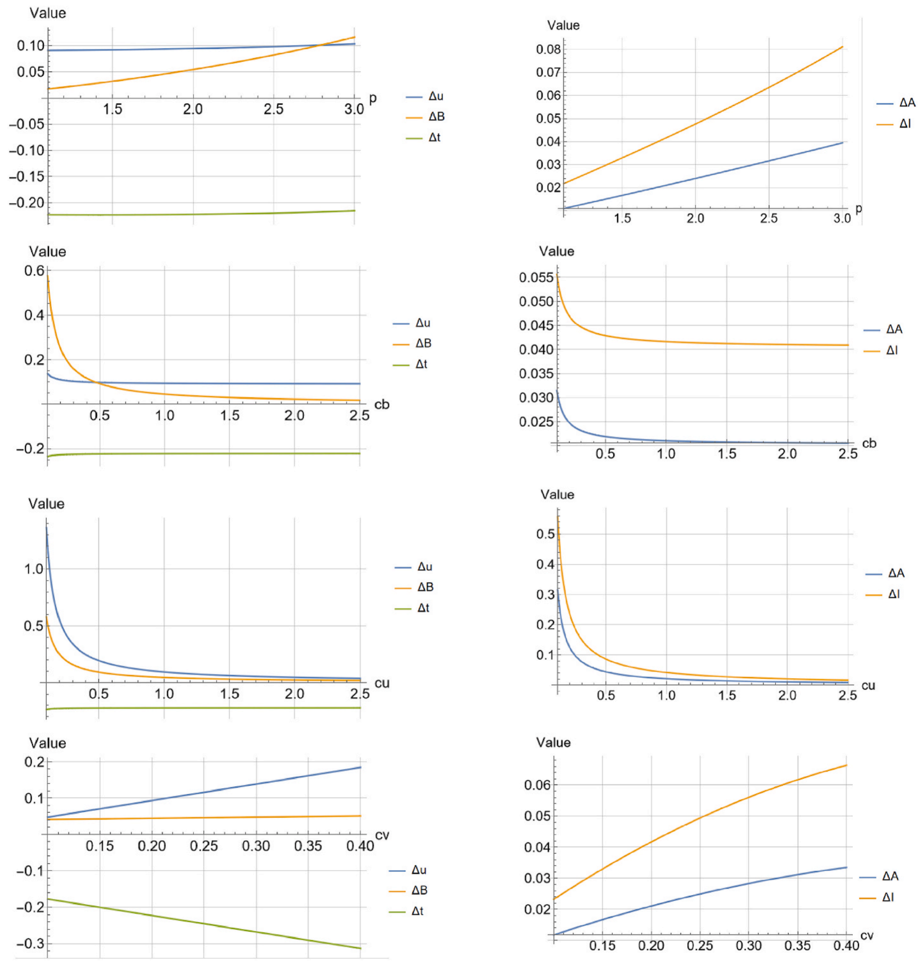

Fig. 1. Numerical analysis related to p, c_B, c_u, and c_v. Note: cb stands for c_B, cu stands for c_u, and cv stands for c_v (Source: Authors).

improving as both firms show higher profits when sharing the costs as well as the risks deriving from blockchain technology. However, when the I's profit from the delay in payment is higher than a threshold ($\delta > \overline{\delta}$), she increases the insurance fee in the C-Game compared to the T-Game to compensate for the profit loss. Moreover, the next observation reveals the cases that do not cause a Pareto-improving situation.

Observation 2. *The collaboration between insurance company I and agricultural producer A on blockchain technology fails to result in a Profit-Pareto-Improving situation when:*

a. $p = r$: in this particular case, A does not invest in blockchain technology ($B = 0$) while I wishes to provide full support ($\phi = 1$); this couple leads to a corner solution where collaboration becomes not feasible.
b. $\alpha \to 1$: As the reimbursement increases towards complete coverage, the collaborative model yields lower profits since I is obligated to cover all of A's losses, making the collaborative strategy not appealing from a financial point of view.
c. $c_V < \overline{c_V}$: With minimal costs associated with verifying claims, the economic advantages potentially linked to collaboration decrease, leading I not to be interested in a collaborative investment.
d. $\delta > \overline{\delta}$: The I's preference to delay payments as much as possible will reduce the attractiveness of collaborating in blockchain, which fully removes the delays when transferring money.

Proof. See the simulation results in Figs. 1 and 2, and in the table in Appendix D in the Online Appendix.

Observation (2) shows all cases in which the collaborative strategy on the blockchain does not create any mutual benefit in terms of real needs and benefits from operations. When a company can realize a high benefit on its own, such as disaster avoidance, the motivation to invest jointly is low. The situations when an insurer would compensate for all losses illustrate how the costs derived outweigh the benefits related to collaboration; the statement is of specific importance in those contexts where coverage vs. profitability needs to be balanced. Moreover, the verification costs may be low, which again would lower the economic rationale for blockchain. This suggests that a proper cost-benefit analysis should be conducted before such technological investments are undertaken. Conflicting operational tactics, such as late payments, and efficiencies that blockchain might bring about, such as acceleration of transactions, highlight the potential strategic misalignments.

6. Endogenizing the operational effects of blockchain and cooperation

A key modeling choice concerns how blockchain adoption and cooperation affect operational frictions such as fraud, verification costs, and reimbursement delays. In the baseline model, these effects are represented through a simplified structure in which joint blockchain implementation eliminates such frictions. This assumption is introduced

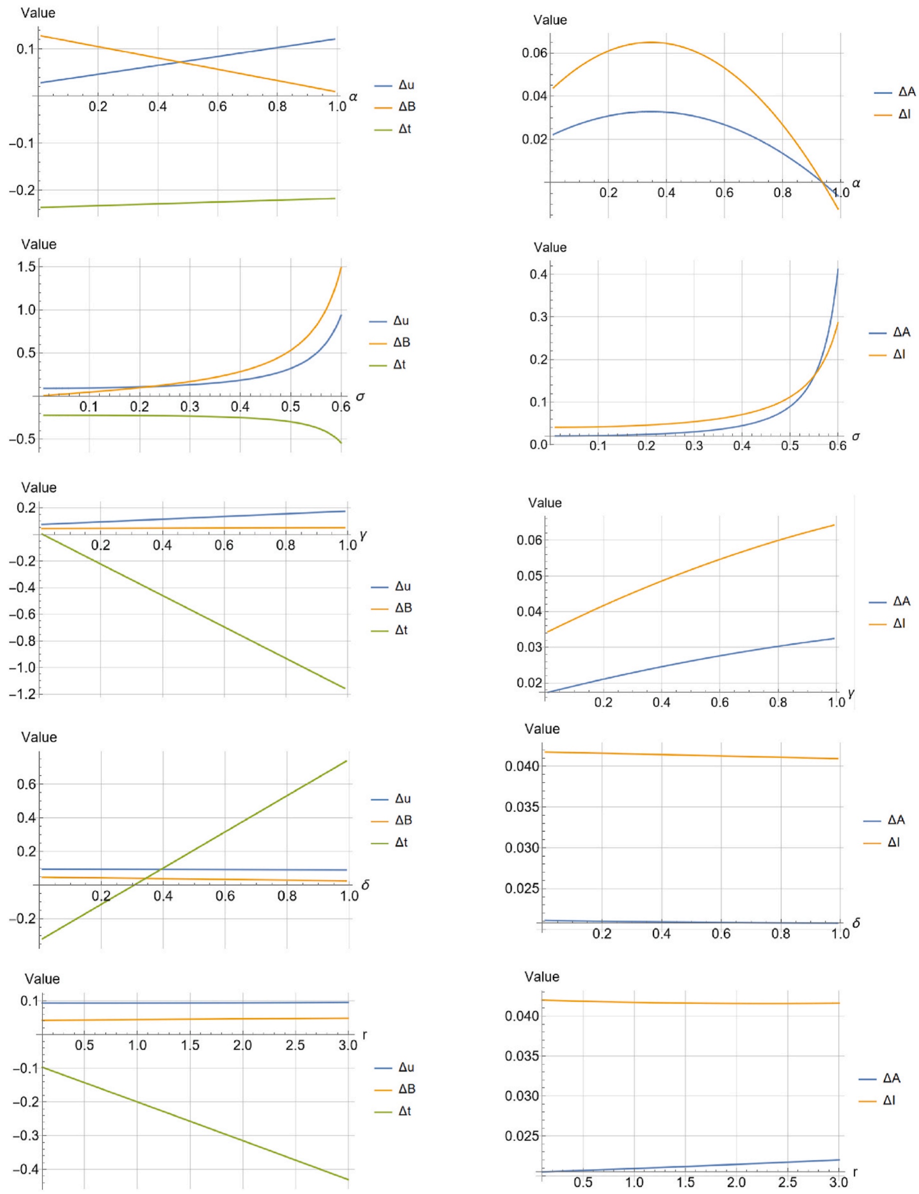

Fig. 2. Numerical analysis related to $\alpha, \delta, \gamma, \sigma$, and r (Source: Authors).

to preserve analytical tractability and enable closed-form solutions, as a more general specification would introduce significant nonlinearities and potentially multiple equilibria, thereby limiting analytical insights. Such a phenomenon emerges when we extend the model by relaxing this assumption and allowing these frictions to be endogenously reduced —rather than eliminated—through the interaction between blockchain investment and the degree of collaboration between the agricultural producer and the insurer. Specifically, we define the following structure:

$$\gamma = \gamma_0\left(1 - k_\gamma \Phi B\right),$$

$$c_v = c_{v0}\left(1 - k_{c_v} \Phi B\right),$$

$$\delta = \delta_0\left(1 - k_\delta \Phi B\right),$$

where γ_0, c_{v0}, and δ_0 represent the baseline levels of fraud, verification cost, and delay, respectively; B denotes the level of blockchain investment; $\Phi \in (0, 1)$ captures the insurer's participation in the blockchain system; and $k_\gamma, k_{c_v}, k_\delta > 0$ are efficiency parameters reflecting the effectiveness of blockchain and collaboration in reducing each friction. This specification captures a key economic intuition: blockchain technology enhances data transparency, traceability, and automation, while collaboration ensures that both parties can access and trust the same information infrastructure. As a result, higher levels of joint engagement—represented by the interaction term ΦB—lead to a gradual reduction in opportunistic behavior (fraud), lower verification effort, and faster reimbursement processes. Importantly, these effects are not assumed to occur instantaneously; rather, they emerge progressively as the system becomes more integrated and information flows become more reliable.

By endogenizing these operational mechanisms, the model allows us to disentangle the direct effect of cost-sharing in blockchain investment from the indirect benefits arising from improved information quality and reduced frictions. This endogenous formulation introduces nonlinearities into the game, which generate the multiple candidate equilibria, as the interaction term ΦB directly links decision variables to operational frictions. As a result, the first-order conditions may admit multiple candidate equilibria. More generally, the number of roots tends to increase with the number of active attenuation channels, reflecting the richer set of strategic interactions introduced in the cooperative framework.

Table 4
The main results for the endogenous case.

Parameter	$\Pi_I^{C^*} - \Pi_I^{T^*}$	$\Pi_A^{C^*} - \Pi_A^{T^*}$
$\eta_\gamma = 0.4$	−0.0004611	−0.000001
$\eta_\gamma = 0.5$	0.000010	0.000107
$\eta_\gamma = 0.6$	0.000325	0.0000122
$\eta_{cv} = 0.4$	0.000205	0.000947
$\eta_{cv} = 0.5$	0.000335	0.001107
$\eta_{cv} = 0.6$	0.000485	0.001267
$\eta_\delta = 0.4$	0.001021	−0.000671
$\eta_\delta = 0.5$	0.001185	−0.001054
$\eta_\delta = 0.6$	0.001375	−0.001507

This effect is illustrated through numerical solutions under alternative parameter configurations. When only the fraud-reduction channel is active, i.e., $k_\gamma = 0.4$, $k_{cv} = 0$, and $k_\delta = 0$, the model yields 11 roots (approximately 8 distinct solutions). Among these, three are real and two satisfy economic feasibility conditions. One admissible interior equilibrium is given by $(t_C, \Phi) = (1.26774, 0.952121)$, with corresponding producer decisions $(u_C, B) = (0.389126, 0.0837317)$. A second admissible solution arises at $(t_C, \Phi) = (1.27226, 0.118604)$, indicating that even a single active attenuation mechanism can generate equilibrium multiplicity.

When only the verification-cost channel is active, i.e., $k_\gamma = 0$, $k_{cv} = 0.4$, and $k_\delta = 0$, the model again produces 11 roots (approximately 7 distinct solutions). Among these, five are real, but only two are interior and economically admissible. The most regular equilibrium is $(\Phi, t_C) = (0.739942, 1.2699)$, with $(u_C, B) = (0.393952, 0.10907)$, while a second admissible solution emerges at $(\Phi, t_C) = (0.962469, 64.2454)$, although associated with more extreme values. This comparison highlights that the specific channel through which frictions are reduced affects the equilibrium structure.

The multiplicity of equilibria becomes more pronounced when multiple attenuation mechanisms are simultaneously active. For instance, when $k_\gamma = 0.4$, $k_{cv} = 0.4$, and $k_\delta = 0$, the model generates 21 roots (approximately 15 distinct solutions). Among these, only three are real, and a single interior equilibrium satisfies all economic feasibility conditions. This equilibrium is given by $(t_C, \Phi) = (1.26416, 0.962339)$, with corresponding decisions $(u_C, B) = (0.392813, 0.100552)$. The increase in the number of candidate solutions confirms that activating multiple attenuation channels amplifies nonlinearities and, consequently, equilibrium multiplicity. Similar results are obtained when imposing $k_\delta > 0$. Therefore, we can conclude that the introduction of multiple attenuation channels $(k_\gamma, k_{cv}, k_\delta)$ increases the multiplicity of candidate equilibria by amplifying the nonlinear interactions between decision variables and operational frictions.

Considering the substantial nonlinearities and the multiple candidate equilibria generated when endogenizing policy, the use of a simplified benchmark model, where frictions are immediately eliminated, is a necessary step to obtain closed-form solutions and isolate the core strategic effects. The extended formulation can then be interpreted as a robustness analysis, showing that the main economic insights remain valid despite the presence of additional equilibria, as displayed in Table 4.

Overall, the results show that endogenizing the attenuation mechanisms does not alter the qualitative behavior of the players' strategies, which remains consistent with the baseline model with exogenous frictions. This finding provides support for the validity of the simplified formulation used to derive analytical results. At the same time, the endogenous specification leads to a reduction in the magnitude of the observed effects, as the interaction between decision variables and attenuation parameters introduces additional feedback mechanisms that smooth strategic responses. This suggests that the baseline model captures the core economic trade-offs, while the extended formulation provides a more nuanced representation of the system without changing its fundamental insights.

7. Managerial insights

Our findings can be analyzed through the lens of firms, allowing us to derive a set of managerial implications. Firms should conduct detailed scenario analyses to better understand the cost-benefit ratios of blockchain investments in different operational contexts and determine whether or not the technology should be implemented and managed as a stand-alone company phenomenon or as a supply chain phenomenon. Within the specific context we analyzed, insurance companies can use the detailed data provided by the blockchain to assess risks and adjust their insurance fees accordingly. In addition, we recommend that they evaluate the value of information obtainable through the technology. Precise information in risk assessments can lead to more competitive pricing, lower claims costs, and higher customer satisfaction; however, its integration depends on the agricultural companies' willingness to share their recorded information on the blockchain with the insurance companies.

While agricultural producers can exploit the blockchain as a way to enhance operational efficiencies, the traceability provided by the blockchain helps address issues quickly, which can imply lower insurance premiums. The key is for managers to evaluate the trade-offs of the potential savings from reduced damages against the costs of implementing and managing the blockchain. When the companies decide to invest jointly, they should set a plan for their blockchain investments to maximize their mutual benefits. This includes negotiating to spread the cost and risk fairly and optimizing the blockchain infrastructure to benefit all parties involved.

Our findings reveal that:

- Managers should prioritize blockchain's traceability functions, which are essential for ensuring the integrity of the supply chains. This capability can significantly reduce the likelihood of fraud and expedite the claims process when issues arise. For example, when joint investment on the blockchain, the agricultural producer does not overestimate the production and, consequently, the related damages, since these pieces of information are accessible and transparent in the blockchain by the insurance company.
- Companies can adjust their strategies based on real-time data coming from oracles and set up important decisions, such as damage rates and the costs of reimbursements, accordingly. In areas or periods with high rates of product damage, increased blockchain investment can be justified as a preventative measure. Conversely, if damage rates are low, firms may opt to scale back on blockchain spending, while increasing the insurance cost.
- Decision-makers need to continuously evaluate the financial interplay between reducing production costs and investing in blockchain technology by conducting regular cost-benefit analyses to ensure that the technology's deployment expenses do not offset the savings from reduced production and insurance costs due to blockchain implementation. Companies can engage in collaborative blockchain strategies because of its capacity to eliminate both the verification costs and the payment delays, even with a weak capacity to prevent damages.
- Companies should keep in mind that when the risk of experiencing natural crises is high, the blockchain loses potential, since it is a technology to record information, rather than predict capacity. Therefore, other alternative technologies might be implemented, such as remote sensing, IoT, big data, drones and automated vehicles, artificial intelligence and machine learning.
- Over the research, we also highlight the cases in which mutually reinforcing blockchain strategies fail to emerge; managers should carefully consider whether such investments align with genuine operational needs. Where a firm could independently achieve

substantial disaster avoidance systems, the incentive to jointly invest in the blockchain is not justified. Managers should also note that low verification costs can lower the economic rationale for blockchain. Therefore, a careful cost-benefit analysis must be carried out well in advance to ensure that investments in blockchain make economic sense. Furthermore, a strategic misalignment may result from operational practices like slow payment, vs. the efficiencies blockchain may bring about faster transactions. These insights can assist managers in making informed judgments about when and how blockchain technology can be effectively integrated into business strategy.

8. Conclusions

Agricultural insurance programs can mitigate the consequences of disasters, such as pests, for agricultural firms. While the efficiency of these insurance programs is undeniable, this sector still requires more innovative solutions to facilitate recognition and reimbursement procedures. Blockchain technology has the potential to enhance traceability and transparency in the insurance sector, which can reduce transaction costs and claim cycles, and enable automated payouts. This paper analyzes the trade-offs between an insurance company and an agricultural firm to investigate the impact of adopting blockchain technology on their profits, considering both joint investment and independent investment scenarios. The literature shows that this sector can benefit from blockchain technology by facilitating transaction tracing and damage assessment, as well as helping agricultural producers prevent natural damage to their crops.

In the first scenario, the insurance company does not collaborate in implementing blockchain technology and does not have access to the system, which increases the possibility of receiving fake claims from the agricultural producer. However, the agricultural Invests in this technology independently, and the capacity of blockchain technology can prevent damages that can benefit both parties. In the second scenario, both players collaborate in the implementation of blockchain technology, enjoying both economic and operational benefits in terms of no information asymmetry, no delays in payments, no verification costs, and no fake claims.

After solving the game theory models and comparing the solutions, our findings highlight the advantages of collaboration through blockchain technology. The results show positive shifts in investment strategies and reduced insurance fees due to the chance to reduce the risks in the supply chain. In general, both firms can benefit from a collaborative approach, which leads to increased investments, improved efficiencies, lowered risks, and, in turn, higher profits. In addition, the independent investment scenario will be more profitable for both parties if the damage rate is very high. However, we identify the conditions under which the benefits of blockchain do not compensate for the costs or the economic implications. These conditions include equal price and reimbursement rates, high avoidable disaster impacts that negate the need for joint investment, maximum coverage scenarios that impose financial burdens on insurers, low verification costs making collaboration redundant, and scenarios with delayed payments where blockchain's efficiency is not sufficiently beneficial. Moreover, our outputs indicate that excluding blockchain's ability to prevent damages, and only focusing on its potential to reduce delays in payments, eliminate fake claims, and lower verification costs, results in an increase in unit insurance costs. These findings suggest that while blockchain has potential benefits, its effectiveness and financial viability are contingent upon specific operational and market conditions, which suggest whether to activate a collaboration based on blockchain technology.

This paper is not free of limitations, which are listed here to inspire future research in this topic. We recommend that future studies explore the different ways blockchain is utilized, such as examining how smart contracts automate insurance claims and sensor network technologies to provide better real-time data collection and analysis. These new tools can provide agricultural firms with the needed speed and accuracy. Additionally, a significant portion of the issue might be addressed through empirical experiments. Another possible course for future research is the collection of data from real blockchain implementations in the agricultural and insurance sectors. This evidence can help to refine the models, demonstrating their practical applications. Furthermore, applying concepts from behavioral economics could shed light on the psychological factors that influence decision-making processes in insurance companies and agricultural businesses when deciding on blockchain adoption. This approach may uncover latent biases or incentives that influence technology uptake and decision-making processes. Additionally, the question of whether blockchain technology and artificial intelligence or machine learning can be used together in an innovative way remains unexplored. This integration could mark the beginning of predictive analytics development, benefitting all players in the value chain. Blockchain should also be evaluated in other ways within the same sectors. For example, blockchain can be used to verify organic farming practices or monitor the carbon footprint of agricultural products, ensuring alignment with environmental and sustainability goals. This is an avenue that the authors are currently exploring.

CRediT authorship contribution statement

Behzad Maleki Vishkaei: Formal analysis, Project administration, Validation, Writing – original draft. **Maria Alice Trindade:** Formal analysis, Investigation, Visualization, Writing – original draft. **Pietro De Giovanni:** Conceptualization, Funding acquisition, Methodology, Software, Supervision, Writing – review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpe.2026.110120.

Data availability

No data was used for the research described in the article.

References

Adalja, A., Lichtenberg, E., Page, E.T., 2023. Collective investment in a common pool resource: grower associations and food safety guidelines. Am. J. Agric. Econ. 105 (1), 144–173.

Anderson, E., Monjardino, M., 2019. Contract design in agriculture supply chains with random yield. Eur. J. Oper. Res. 277 (3), 1072–1082.

Assa, H., Sharifi, H., Lyons, A., 2021. An examination of the role of price insurance products in stimulating investment in agriculture supply chains for sustained productivity. Eur. J. Oper. Res. 288 (3), 918–934.

Bai, Y., Fan, K., Zhang, K., Cheng, X., Li, H., Yang, Y., 2021. Blockchain-based trust management for agricultural green supply: a game theoretic approach. J. Clean. Prod. 310, 127407.
Barrett, C.B., 2021. Overcoming global food security challenges through science and solidarity. Am. J. Agric. Econ. 103 (2), 422–447.
Behl, A., Gaur, J., Pereira, V., Yadav, R., Laker, B., 2022. Role of big data analytics capabilities to improve sustainable competitive advantage of MSME service firms during COVID-19–A multi-theoretical approach. J. Bus. Res. 148, 378–389.
Biswas, D., Jalali, H., Ansaripoor, A.H., De Giovanni, P., 2023. Traceability vs. sustainability in supply chains: the implications of blockchain. Eur. J. Oper. Res. 305 (1), 128–147.
Bodkhe, U., Tanwar, S., Bhattacharya, P., Kumar, N., 2022. Blockchain for precision irrigation: opportunities and challenges. Trans. Emerging Telecommun. Technol. 33 (10), e4059.
Chen, Z., Lu, Y., Zhang, J., Zhu, W., 2024. Managing Weather Risk with a Neural Network-Based Index Insurance. Manag. Sci. 70 (7), 4306, 432.
Cui, Y., Gaur, V., Liu, J., 2024. Supply chain transparency and blockchain design. Manag. Sci. 70 (5), 3245–3263.
De Giovanni, P., 2020. Blockchain and smart contracts in supply chain management: a game theoretic model. Int. J. Prod. Econ. 228, 107855.
De Giovanni, P.D., 2026. A dynamic game of circular economy with environmental producer responsibility and digital product passport. Int. Game Theor. Rev. 28 (1), 2540003.
De Haen, H., Hemrich, G., 2007. The economics of natural disasters: implications and challenges for food security. Agric. Econ. 37, 31–45.
Dionne, G., 2013. The empirical measure of information problems with emphasis on insurance fraud and dynamic data. In: Handbook of Insurance. Springer, New York, pp. 423–448.
Dong, L., 2021. Toward resilient agriculture value chains: challenges and opportunities. Prod. Oper. Manag. 30 (3), 666–675.
Dong, L., Qiu, Y., Xu, F., 2023. Blockchain-enabled deep-tier supply chain finance. Manuf. Serv. Oper. Manag. 25 (6), 2021–2037.
Dutta, P., Choi, T.M., Somani, S., Butala, R., 2020. Blockchain technology in supply chain operations: applications, challenges and research opportunities. Transport. Res. E Logist. Transport. Rev. 142, 102067.
Fang, L., Hu, R., Mao, H., Chen, S., 2021. How crop insurance influences agricultural green total factor productivity: evidence from Chinese farmers. J. Clean. Prod. 321, 128977.
FAO, 2018. How blockchain can help smallholder farmers. Retrieved from. https://www.fao.org/e-agriculture/blog/how-blockchain-can-help-smallholder-farmers. (Accessed 7 September 2024).
FAO, 2019. Blockchain for agriculture. Opportunities and challenges. Retrieved from. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1178062/. (Accessed 7 September 2024).
Finger, R., Lehmann, N., 2012. The influence of direct payments on farmers' hail insurance decisions. Agric. Econ. 43 (3), 343–354.
Glauber, J.W., 2004. Crop insurance reconsidered. Am. J. Agric. Econ. 86 (5), 1179–1195.
Golmohammadi, A., Hassini, E., 2019. Capacity, pricing and production under supply and demand uncertainties with an application in agriculture. Eur. J. Oper. Res. 275 (3), 1037–1049.
Hastig, G.M., Sodhi, M.S., 2020. Blockchain for supply chain traceability: business requirements and critical success factors. Prod. Oper. Manag. 29 (4), 935–954.
Hawashin, D., Nemer, M., Gebreab, S.A., Salah, K., Jayaraman, R., Khan, M.K., Damiani, E., 2024. Blockchain applications in UAV industry: review, opportunities, and challenges. J. Netw. Comput. Appl. 230, 103932.
Huang, J., Wang, Y., Wang, J., 2015. Farmers' adaptation to extreme weather events through farm management and its impacts on the mean and risk of rice yield in China. Am. J. Agric. Econ. 97 (2), 602–617.
Jha, N., Prashar, D., Khalaf, O.I., Alotaibi, Y., Alsufyani, A., Alghamdi, S., 2021. Blockchain based crop insurance: a decentralized insurance system for modernization of Indian farmers. Sustainability 13 (16), 8921.
Kahan, D., 2008. Managing risk in farming. Rome: Food and Agriculture Organization of the United Nations. FAO.
Kao, Y.M., Keskin, N.B., Shang, K., 2022. Impact of information asymmetry and limited production capacity on business interruption insurance. Manag. Sci. 68 (4), 2824–2841.
Kim, K., Kang, T., 2017. Does technology against corruption always lead to benefit? The potential risks and challenges of the blockchain technology. In: Oecd's Anti-corruption and Integrity Forum.
Kovak, E., Blaustein-Rejto, D., Qaim, M., 2022. Genetically modified crops support climate change mitigation. Trends Plant Sci. 27 (7), 627–629.
Leduc, G., Kubler, S., Georges, J.P., 2021. Innovative blockchain-based farming marketplace and smart contract performance evaluation. J. Clean. Prod. 306, 127055.
Lee, S., Shin, J.S., 2023. A new location verification protocol and blockchain-based drone rental mechanism in smart farming. Comput. Electron. Agric. 214, 108267.
Li, H., Zha, Y., Bi, G., 2023. Agricultural insurance and power structure in a capital-constrained supply chain. Transport. Res. E Logist. Transport. Rev. 171, 103037.
Luo, Q., Liao, R., Li, J., Ye, X., Chen, S., 2022. Blockchain enabled credibility applications: extant issues, frameworks and cases. IEEE Access 10, 45759–45771.
Lyu, K., Barré, T.J., 2017. Risk aversion in crop insurance program purchase decisions: evidence from maize production areas in China. China Agric. Econ. Rev. 9 (1), 62–80.
Vishkaei, B.M., De Giovanni, P., 2024. Smart food-sharing platforms for social sustainability: a heuristic algorithm approach. Int. Trans. Oper. Res. 33 (5), 2893–2920. (Accessed 5 September 2024).
Miranda, B.V., Monteiro, G.F.A., Rodrigues, V.P., 2021. Circular agri-food systems: a governance perspective for the analysis of sustainable agri-food value chains. Technol. Forecast. Soc. Change 170, 120878.
Mol, J.M., Botzen, W.W., Blasch, J.E., 2020. Risk reduction in compulsory disaster insurance: experimental evidence on moral hazard and financial incentives. J. Behav. Exp. Econ. 84, 101500.
Omar, I.A., Jayaraman, R., Salah, K., Hasan, H.R., Antony, J., Omar, M., 2023. Blockchain-based approach for crop index insurance in agricultural supply chain. IEEE Access 11, 118660–118675.
Pan, X., Pan, X., Song, M., Ai, B., Ming, Y., 2020. Blockchain technology and enterprise operational capabilities: an empirical test. Int. J. Inf. Manag. 52, 101946.
Pun, H., Swaminathan, J.M., Hou, P., 2021. Blockchain adoption for combating deceptive counterfeits. Prod. Oper. Manag. 30 (4), 864–882.
Qian, X., 2021. Production planning and equity investment decisions in agriculture with closed membership cooperatives. Eur. J. Oper. Res. 294 (2), 684–699.
Rao, N.H., 2007. A framework for implementing information and communication technologies in agricultural development in India. Technol. Forecast. Soc. Change 74 (4), 491–518.
Risk Management Agency, 2023. Payment Integrity Scorecard: FY 2022 Overpayment Report (Q2 2023). Federal Crop Insurance Corporation.
Risk Management Agency, 2024. Payment Integrity Scorecard: FY 2023 Overpayment Report (Q3 2024). Federal Crop Insurance Corporation.
Ruzza, D., Cesaretto, R., De Giovanni, P., 2025. Blockchain technology and physical oracles in the collectibles industry: a dynamic game approach. Dynamic Games and Applications 1–46.
Sadiq, B.O., Buhari, M.D., Danjuma, Y.I., Zakariyya, O.S., Shuaibu, A.N., 2024. High-tech herding: exploring the use of IoT and UAV networks for improved health surveillance in dairy farm system. Sci. Afr. 25, e02266.
Schoengold, K., Ding, Y., Headlee, R., 2015. The impact of AD HOC disaster and crop insurance programs on the use of risk-reducing conservation tillage practices. Am. J. Agric. Econ. 97 (3), 897–919.
Sharma, M., Khalil, A.A., Daim, T., 2022. Blockchain technology adoption: multinational analysis of the agriculture supply chain. IEEE Trans. Eng. Manag. 71, 12400–12417.
Singh, P.K., Sharma, A., 2022. An intelligent WSN-UAV-based IoT framework for precision agriculture application. Comput. Electr. Eng. 100, 107912.
Skevas, T., Stefanou, S.E., Lansink, A.O., 2014. Pesticide use, environmental spillovers and efficiency: a DEA risk-adjusted efficiency approach applied to Dutch arable farming. Eur. J. Oper. Res. 237 (2), 658–664.
Sun, R.T., Garimella, A., Han, W., Chang, H.L., Shaw, M.J., 2020. Transformation of the transaction cost and the agency cost in an organization and the applicability of blockchain—A case study of peer-to-peer insurance. Front. Blockchain 3, 24.
Sunny, J., Undralla, N., Pillai, V.M., 2020. Supply chain transparency through blockchain-based traceability: an overview with demonstration. Comput. Ind. Eng. 150, 106895.
Torky, M., Hassanein, A.E., 2020. Integrating blockchain and the internet of things in precision agriculture: analysis, opportunities, and challenges. Comput. Electron. Agric. 178, 105476.
Tseng, F.M., Liang, C.W., Nguyen, N.B., 2023. Blockchain technology adoption and business performance in large enterprises: a comparison of the United States and China. Technol. Soc. 73, 102230.
Vessal, S.R., De Giovanni, P., Hassanzadeh, A., 2022. Technology and service investments in the presence of feature fatigue and word-of-mouth. Eur. J. Oper. Res. 301 (3), 923–941.
Vishkaei, B.M., De Giovanni, P., 2025. A smart mobility game with blockchain and hardware oracles. Int. J. Prod. Econ., 109533
Walters, C.G., Shumway, C.R., Chouinard, H.H., Wandschneider, P.R., 2015. Asymmetric information and profit taking in crop insurance. Appl. Econ. Perspect. Pol. 37 (1), 107–129.
Wang, Z., Zheng, Z., Jiang, W., Tang, S., 2021. Blockchain-enabled data sharing in supply chains: model, operationalization, and tutorial. Prod. Oper. Manag. 30 (7), 1965–1985.
Yadav, V.S., Singh, A.R., Raut, R.D., Mangla, S.K., Luthra, S., Kumar, A., 2022. Exploring the application of Industry 4.0 technologies in the agricultural food supply chain: a systematic literature review. Comput. Ind. Eng. 169, 108304.
Yen-Ting, L., Pyke, D.F., Swaminathan, J.M., 2022. Identifying and overcoming barriers to implementing blockchain in supply chains. Management and Business Review 2 (4), 56–63.
Young, C.E., Vandeveer, M.L., Schnepf, R.D., 2001. Production and price impacts of US crop insurance programs. Am. J. Agric. Econ. 83 (5), 1196–1203.
Zhang, D., 2020. The innovation research of contract farming financing mode under the block chain technology. J. Clean. Prod. 270, 122194.