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A study on benefit distribution of agricultural product quality governance under the perspective of digital supply chain

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Abstract: As the strategy for building a robust agricultural nation gains momentum and agricultural science and technology advances, the quality of agricultural products has seen significant improvement, accompanied by an increase in the economic income of agricultural producers and operators. Therefore, the fair and reasonable implementation of the revenue distribution of the agricultural supply chain is of great significance in improving the quality of agricultural products and ensuring the stable operation of the supply chain. The article focuses on the three main bodies of the agricultural supply chain, namely production and price co-integration enterprises, logistics service enterprises and sales enterprises, and utilises the matrix semi-tensor product to establish the Shapley value revenue allocation model of the interval cooperation game, so as to make the revenue allocation of the governance of agricultural products' quality in the digital supply chain more reasonable and scientific. Finally, numerical examples verify the Shapley value model, demonstrating that this revenue allocation scheme, when applied, can boost the overall supply chain's revenue through cooperative agricultural product quality management, elevate agricultural product quality and market competitiveness, and foster collaboration to ensure the stability of supply chain operations.

Keywords: Agricultural product quality and safety; benefit distriution; digital supply chain; interval Shapley value

The governance of agricultural product quality and safety is a crucial approach to ensuring the quality and safety of these products and enhancing their market competitiveness. With the rapid development of digital technology and the intelligent trend of supply chain management, the quality and safety governance of agricultural products under the perspective of a digital supply chain has become a hot spot of current research. The development of agricultural science and technology has stimulated the innovative vitality of the agricultural supply chain, and the construction and development of new agricultural management subjects have driven the close integration of agricultural parks with leading enterprises and farmers. The integration and sharing of information and other resources can reduce the cost of quality management in the circulation of agricultural products, disperse the risk of quality management subjects of agricultural products, and improve the economic benefits

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of supply chain participants. However, the agricultural supply chain faces widespread issues during operation, including disconnected participants, inadequate information flow, and unequal benefit distribution, all of which harm the interests of the involved parties. The problem of agriculture's large-scale but weak competitiveness remains prominent. The quality, efficiency and competitiveness of agricultural products need to be improved urgently. The government plays an important role in solving the problems of the agricultural supply chain (Hamidoğlu 2024). Through subsidies and reasonable taxation, it can effectively promote the participation of multiple subjects in the application of digital technology and low-carbon technology to a certain extent, and promote the effective collaboration of multiple subjects and links in the agricultural product supply chain (Hamidoğlu et al. 2024; Hamidoğlu and Weber 2024), thus helping to improve the efficiency of the supply chain, reduce transaction costs, and enhance the competitiveness of the entire supply chain. To meet the high-quality, green, differentiated needs of consumers. The newly revised Law on Quality and Safety of Agricultural Products clearly stipulates the quality and safety responsibilities to be borne by agricultural product producers and operators, including wholesale markets for agricultural products, agricultural product sales enterprises, cold chain logistics enterprises and network operators. Studying the distribution of benefits of agricultural product quality and safety governance can help participants in each supply chain link better understand the importance and risks of agricultural product quality and safety. A reasonable benefit distribution mechanism can make all parties more motivated to invest in quality and safety governance to improve the quality, safety and traceability of agricultural products. Through a fair benefit distribution mechanism, all parties involved will actively cooperate and share the risks and responsibilities to promote the efficient operation of the supply chain. This will help reduce costs and improve efficiency while also better meeting market demand and enhancing the competitiveness and sustainability of the supply chain. In addition, studying the distribution of benefits from agricultural product quality and safety governance under the supply chain perspective can promote the development of the agricultural economy. The improvement of agricultural product quality and safety will increase consumers' trust and willingness to buy agricultural products and improve the added value and market competitiveness of products. At the same time, a reasonable distribution of benefits will incentivise farmers and agribusinesses to invest more resources and technology and promote the improvement of agricultural production efficiency and the sustainable development of the agricultural industry.

From the perspective of a digitalised chain, the thesis researches the profit distribution mechanism obtained by each participant with the help of digitalised technical means for agricultural product quality governance. The thesis uses the interval Shapley value for revenue allocation with reference to the use of matrix half tensor product, the matrix calculation method of Shapley interval value containing discount factor in the interval cooperation game (Wang et al. 2019; Zhao et al. 2020; Zhu et al. 2022). According to the different contributions of the three main bodies of digital supply chain production and processing integrated enterprises, logistics enterprises and sales enterprises to the input of agricultural product quality management, this paper discusses the distribution of benefits, so as to promote the production of agricultural product management enterprises, promote the efficient operation of supply chain while improving the quality of agricultural products, and increase the profits of enterprises.

Literature review

Digital supply chain related research. The digital transformation of the supply chain has a profound impact on its operation and development. The integration of information flow, logistics and capital flow can significantly enhance the elasticity of the supply chain, promote the diversification of the supply chain (Yuan et al. 2023), the concentration of suppliers and the diversification of the customer base, and improve the anti-risk ability of the supply chain (Gao et al. 2022; Yin and Ran 2022).

With the further application of blockchain technology in the supply chain, it has a positive impact on product traceability, data and information transparency, and operational efficiency. On the one hand, blockchain technology can effectively improve the production process of the supply chain, providing long-term agility, resilience and responsiveness to the existing supply chain (Mukherjee et al. 2022). On the one hand, blockchain technology can also effectively solve the challenges faced by supply chains in information sharing, maintaining full process traceability, and improving operational efficiency (Lim et al. 2021). Especially in the agricultural supply chain, the application of blockchain technology is crucial for achieving traceability, which is the most important reason for its implementation in the agricultural sector (Criss et al. 2020; Demestichas et al. 2020). In addition, the

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food supply chain is increasingly relying on big data management solutions to facilitate collaboration across the chain and improve business performance (Carmela et al. 2021).

Research related to the governance of agricultural product quality and safety. In the governance of agricultural product quality and safety, foreign scholars have carried out extensive and in-depth research. The research reveals that farmers' green production behaviour has a positive effect on improving the quality of agricultural products, and this behaviour is influenced by multiple factors such as farmers' personality traits, government guidance, industrial organisation promotion and market regulation (Teng et al. 2022). At the same time, farmers' attitude towards green production behaviour also determines their willingness to participate in collaborative supervision of agricultural product quality and safety to a certain extent (Wang and Liu 2021). However, due to the lack of awareness of agricultural product safety hazards, lack of food safety knowledge and improper safety practices, farmers' enthusiasm to participate in the co-management and autonomy of agricultural products is relatively low (Wang and Jiang 2020). At the same time, some scholars pointed out that factors affecting the quality improvement of the agricultural supply chain also include corporate social responsibility, altruistic reciprocity and fairness issues (Qin and Xiang 2021), as well as government regulation and market incentives (Zhao et al. 2018). In the implementation of agricultural product quality and safety management, process control (such as unified production standards or unified agricultural input supply), outcome control (such as safety inspection) and social control (such as rewards and punishments incentives or training) have a positive impact on improving food quality and safety capabilities (Zhou et al. 2019). In addition, enhanced sampling intensity and information disclosure will also help improve the traceability of suppliers, thus further strengthening the effectiveness of the government in food supervision (Zhou et al. 2022). At the same time, the introduction of advanced technologies and the application of big data methods are also regarded as important means to improve the quality and safety level of agricultural products (Shen et al. 2022). Specifically, big data technology can be applied to the study of critical control points in the traceability process of agricultural products to provide a scientific basis for the quality and safety management of agricultural products (Wan 2022). The application of blockchain technology can significantly improve the qualification rate of agricultural products and the efficiency of the agricultural products circulation system, thus bringing significant economic benefits (Wang et al. 2022).

Research related to income distribution. In the study of profit distribution among agricultural supply chain disciplines, scholars use different methods to distribute profit according to the different characteristics of the supply chain composed of different disciplines. One is to adopt the core distribution method. For example, Wang (2015) adopted the minimum core method to reasonably distribute the comprehensive profits of enterprise technology alliances. The first method is Nash negotiation. For example, Chen et al. (2023) used asymmetric Nash bargaining theory to build a profit distribution model for participants to ensure that cooperation surplus can be fairly distributed between buyers and sellers. However, Shapley value method is more commonly used. For example, Meng et al. (2023) constructed a cooperative game model of suppliers, manufacturers and retailers under the cross-level guarantee of order decomposition and used Shapley to reasonably allocate the value of the cooperative game to the total revenue of the supply chain. Sha and Zheng (2021) study a mixed-channel supply chain model consisting of manufacturers, traditional retailers, and online retailers, using production and sales costs to modify traditional Shapley values to achieve a reasonable distribution of individual benefits. Zhao et al. (2023) based on the Aumann-Shapley value method, a cost allocation strategy ensures a reasonable distribution of benefits among multiple agents. Gan et al. (2018) proposed an improved interval Shapley value method that considers both satisfaction and contribution, so as to provide a guarantee for improving stakeholder satisfaction and promoting social logistics providers to establish strategic alliances. Wang et al. (2023) established a multi-weight interval Shapley value model of profit distribution to ensure the scientific and reasonable profit distribution of agricultural products co-investment, considering that the profit distribution of cooperation is affected by the dynamic changes of resource input ratio, distribution operation scale, risk bearing and other factors.

According to the characteristics and applicability analysis of each model, the interval Shapley value is more applicable than the core allocation method, Nash negotiation method and Aumann-Shapley in solving the problem of benefit allocation of agricultural product quality management. Compared with Aumann-Shapley pricing, the interval Shapley value is more flexible in dealing with uncertainties and dynamic changes. Compared with the

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core allocation method, the possible stable distribution solution can be found in a wider range, thus improving the feasibility of distribution. Compared with Nash negotiation rule, it pays more attention to the contribution and overall benefit in the process of cooperation and strives to reflect fairness and efficiency in the distribution, rather than just the distribution based on bargaining power. Compared with traditional Shapley values, the interval Shapley method allows for a more flexible and comprehensive assessment of participants' contributions in situations of uncertainty or incomplete information. In the quality management of agricultural products, the contribution of participants is often difficult to quantify precisely due to a variety of factors (such as weather, pests and diseases, market fluctuations, etc.), and the interval Shapley model can deal with this uncertainty.

Research gap. By analysing the current research status of related scholars on the quality and safety governance of agricultural products under the perspective of the digital supply chain, it can be found that the research results in this area are relatively new and the existing results are relatively few, and the scholars generally carry out research on the quality and safety governance of agricultural products in the aspects of agricultural product production, incentive and constraint mechanism and government supervision. In addition, to the application of digital technology in the agricultural supply chain, scholars mostly focus on the digital transformation of the supply chain, supply chain resilience and supply chain operational efficiency. As a result, scholars have gained a lot of research results in the quality and safety governance of agricultural products under the perspective of the supply chain, and a few of the results stay in the qualitative analysis of the current problem of agricultural product quality or quantitative analysis of the cost-benefit coordination contract of agricultural product supply chain. In view of this, this study starts from the governance mechanism of agricultural product quality and safety under the perspective of the digital supply chain, quantitatively analyses the governance behaviour of agricultural product supply chain subjects and explores the effective mechanism to enhance the effectiveness of agricultural product quality and safety governance.

Analysis of agricultural product quality governance from the perspective of digital supply chain

Closed-loop supply chain for digital quality governance of agricultural products. The formation of a digitalised closed-loop supply chain for agricultural product quality governance relies mainly on the organic combination of data collection and sharing, quality control and monitoring, quality traceability and certification, risk early warning and emergency management, and participant synergy and cooperation. The application of digital technology can enhance the efficacy and effectiveness of agricultural product quality governance and promote the whole process of quality control and optimisation. Utilising technologies such as the Internet of Things (IoT) and sensors, data collection is carried out at all stages of the production and supply chain, including the production environment, cultivation, processing, storage and distribution of agricultural products. Utilise digital technology to establish monitoring systems and combine sensors and real-time data for quality control. For example, using temperature sensors, humidity sensors and other equipment, real-time monitoring of the storage environment of agricultural products, timely warning and adjustment to ensure that the quality is not compromised. Record and trace the data of the production environment, production process, transportation process and other aspects of agricultural products, and establish a complete quality traceability system.

A digitised closed-loop supply chain allows for synergy and cooperation among participants (Figure 1). By sharing data and information, the participants can better collaborate and work together to address issues and risks that arise in the process of agricultural quality governance.

The main body and function of digital quality management of agricultural products

Production and processing integrated enterprise. The production and processing chain is the most important link in improving the quality of agricultural products. Environmental pollution in the production area, irrational use of agricultural inputs (pesticides and veterinary drugs, chemical fertilisers, feed, etc.), and the use of illegal additives are the main challenges facing the production and processing of agricultural products. The characteristics of the small-scale and decentralised operation of China's agriculture make the quality management of the production and processing of agricultural products even more arduous. In recent years, with the cultivation and development of new agricultural production and management bodies (family farms, agricultural enterprises, farmers' cooperatives), the production and management bodies of the 'production-type + service-type' production and management bodies have driven the support of small farmers, provided land trusteeship, substitute plowing

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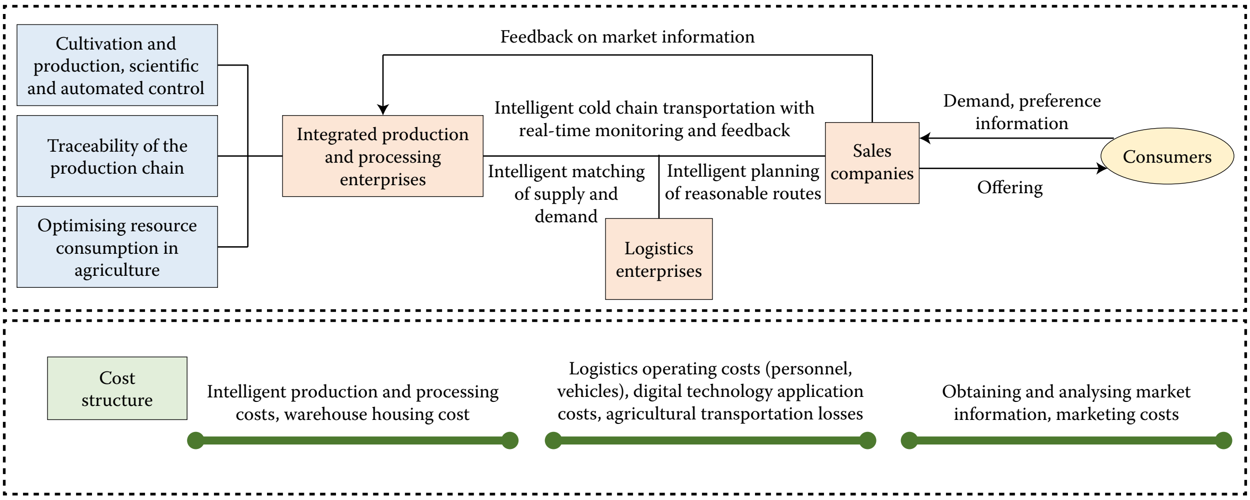

Figure 1. Collaborative process of agricultural product quality governance from a digital supply chain perspective

Source: Author's own elaboration

and planting, unified prevention and control, and agro-technology promotion services to agricultural producers, solved the problems of large-scale operation, and cultivated the Agricultural industrialisation consortium. Agricultural enterprise is a new type of main body of agricultural production and management.

Smart agriculture is the combination of digital technology and agricultural science and technology, which is a specific form of digitalisation of the agricultural industry. Digital technology, as a new input element, makes the production and processing of agricultural products more refined, standardised and scientific. Information technology service providers assist agribusinesses in completing the digitalised control of the upstream production and processing of agricultural products. Big data helps the production process to provide predictive insights and drive real-time decision-making (Xie et al. 2021). Rational deployment of agricultural machinery, automated and scientific management and control of agricultural products such as seeding, fertilisation, irrigation, etc., agricultural land monitoring, optimisation of resource consumption, and improvement of agricultural production and quality. Through the application of digital technology in the agricultural production process, the traceability of the production chain is guaranteed, and the ability of agricultural enterprises to collect, store and process agricultural products is improved, and the freshness and quality of agricultural products are preserved more effectively. Optimise the agricultural industry with the help of digitalisation and realise the upgrading of the agricultural industry (Trivelli et al. 2019; Valecce et al. 2019; Hrustek 2020). As shown in Figure 2.

Logistics service enterprises. The process of circulation of agricultural products, from production to consumption will inevitably go through the logistics and transportation links. Outdated transportation equipment and non-standard operation during logistics transportation can cause microbial and chemical pollution of agricultural products. In addition, China's fresh agricultural products cold chain transportation equipment and other infrastructure are lagging behind, the transportation efficiency is not high. Therefore, logistics service area enterprises are the important main body of agricultural product quality management.

An intelligent logistics system is a kind of intelligent logistics management system based on the Internet of Things, big data, cloud computing, and other technologies (Dawkins 2016). It realises real-time monitoring and data collection of logistics links through sensors, RFID, GPS and other technologies, and realises optimisation of the logistics process and intelligent decision-making through cloud computing and big data analysis, so as to improve the logistics efficiency, reduce the logistics cost, and improve the logistics service quality. Real-time monitoring of logistics links through sensors and other technologies, collecting data on logistics links, including cargo information, transportation information, storage information, etc. The collected data are analysed through cloud computing and big data analysis to achieve optimisation of the logistics process and intelligent decision-making. The precise matching of supply and demand is realised. In China, the de-

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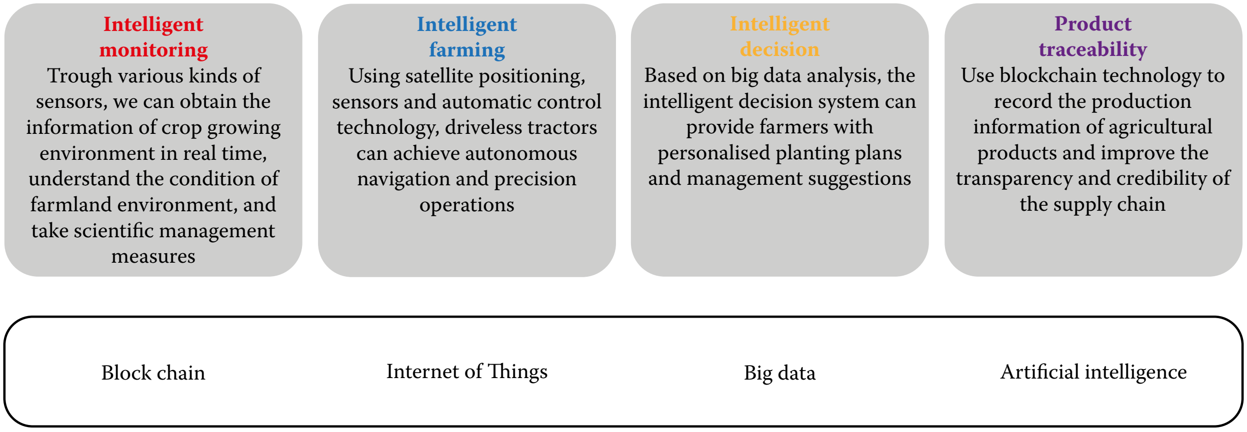

Figure 2. Application of digital technology in the production and processing of integrated enterprise

Source: Author's own elaboration

mand for agricultural intelligent logistics technology has greatly increased due to the large market size, low cold chain circulation rate, and large post-production losses of agricultural products. Agricultural intelligent logistics not only helps to meet the strong domestic demand but also improves the competitiveness of Chinese agricultural products in the international market, promotes industrial modernisation, and helps to ensure food safety. As shown in Figure 3.

The fresh and perishable characteristics of fresh agricultural products require the whole process of cold chain logistics to be coherent and intelligently regulated. The development of intelligent + cold chain logistics provides users with intelligent, precise, efficient and operable intelligent logistics solutions, improves logistics efficiency, and reduces cargo losses and delays. 'Intelligent + cold chain logistics' can ensure that the goods maintain a stable temperature and humidity throughout the transportation process, safeguard the quality of the goods, and reduce the loss of goods. It reduces logistics costs by optimising transportation routes and saving energy.

Sales companies. Consumption of agricultural products is the final link in the quality management of agricultural products. Consumer demand for agricultural products is large, and the consumer demand shows uncertainty due to different consumer ages, habits, cognition, i.e. income level and so on. With the development of the economy and society, the diversification of market competition, consumer demand is not only affected by the price, but also by the quality of products. Consumer demand preferences are gradually upgraded to the direction of quality, diversity, green and health. Sellers need to accurately capture consumer demand

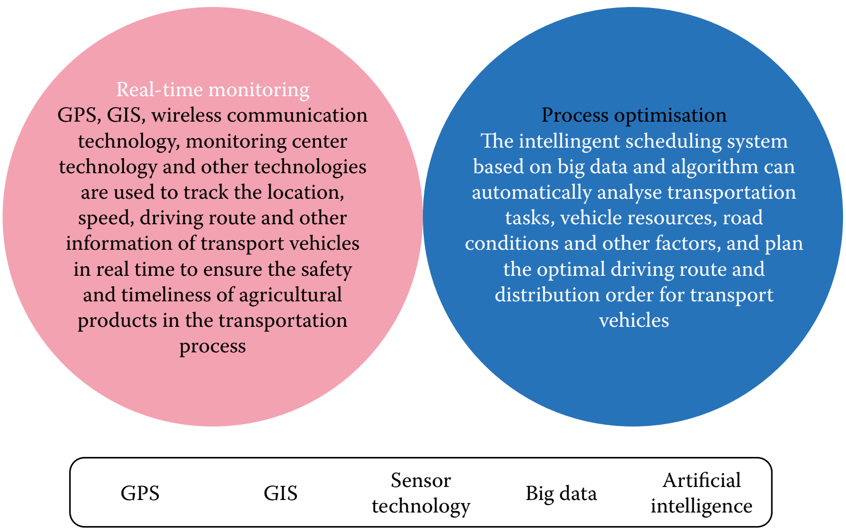

Figure 3. Application of digital technology in logistics service enterprises

Source: Author's own elaboration

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for agricultural products, help consumers establish the last line of defence in the consumption of agricultural products, identify problematic agricultural products, and avoid the inflow of low-quality agricultural products that do not meet the quality standards into the market.

Under the digital economy, the new sales model of agricultural products is constantly exploring and developing new paths, and the innovative new retail marketing model of agricultural products of 'new retail + agricultural products + digital precision marketing' has been constructed. Using big data technology, machine learning and other methods from social media, search engines, online shopping platforms, mobile applications and other channels to collect multi-dimensional data, including user basic information, purchase history, browsing habits, social interaction and other multi-dimensional data, analyse user data, find the user's potential demand, purchase intention and behaviour pattern, according to the analysis results, the user is divided into different groups. Achieve more accurate targeting of the target market. At the same time, build detailed user portraits for each user group, including age, gender, occupation, interests, hobbies, consumption habits and other characteristics, based on user portraits and behavioural analysis, recommend suitable products and services for different users to achieve precision marketing. As shown in Figure 4.

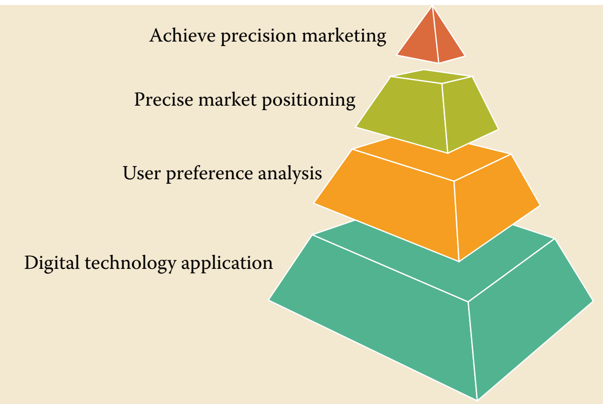

Figure 4. Application of digital technology in sales companies

Source: Author's own elaboration

Distribution of benefits from agricultural quality governance

Parametrisation of agricultural product quality governance based on interval cooperative game. The main players in the agricultural supply chain – production and processing enterprises, logistics service enterprises, and marketing enterprises – often face uncertainties and risks in the process of agricultural product quality management. Influenced by seasonal changes, market demand fluctuations, natural disasters and other factors, the gains from quality management in the agricultural supply chain will also fluctuate. The interval cooperation game method sets the benefits of the participating subjects as an interval, which can take the uncertainty and risk factors into account, consider the cooperation and competition between multiple participants, and better simulate the actual situation, guarantee the reasonableness and fairness of the benefit distribution of enterprises in each link of the supply chain, and improve the effect of the digital quality management of agricultural products.

An interval cooperative game can be represented by a binary structure (N, v), where a finite set of elements $N = \{x_1, x_2, \ldots, x_n\}$ denotes a finite set of participants in the supply chain of agricultural products, including integrated production and processing enterprises, logistics enterprises, and sales enterprises. Interval cooperative game characteristic function v: $2N \rightarrow \tau(\mathrm{R})$, satisfies $v(\varnothing) = (0.0)$, and the set of all formed supply chain alliances of set N is denoted as $2_N = \{S|S\subseteq N\}$. For supply chain participation as the main coalition $S\in 2^N$, $v(S)$ is the gain function of the subset S. The function value is an interval, denoted as $(\underline{a_S}, \overline{a_S})$, $v(S) \in (\underline{a_S}, \overline{a_S})$ denotes the value of the interval of the gain of the supply chain participation in the main coalition S, $\underline{a_S}$ is the minimum value of the gain of the supply chain coalition S, $\overline{a_S}$ is the maximum value of the gain of the supply chain coalition S gain the maximum value. When $\underline{a_S} = \overline{a_S}$, the interval cooperation game degenerates into a classical cooperation game.

In the digital agricultural supply chain alliance, the profit distribution obtained by the participant's conducting agricultural product quality governance is expressed using the Shapley value of the interval cooperation game:

$$\Phi_i(v) = \sum_{S\in 2^{N/i}} \frac{|S|!(n-1-|S|)!}{n!}[v(S\cup i) - v(S)] \tag{1}$$

where: $[v(S\cup i - v(S)]$ – the contribution of supply chain participant i to the cooperation on agricultural quality governance; $|S|!(n-1-|S|)! \,/\, n!$ – the weight of the cooperative contribution to agricultural quality governance as determined by the number of actors involved in the supply chain; $[v(S\cup i - v(S)] \in \tau(R)$, $\Sigma_{S\in 2^{N/i}} \times |S|!(n-1-|S|)! \,/\, n! = 1$

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Introducing the discount factor into the interval cooperative game Shapley value gives the interval discount Shapley value:

$$\Phi_i(v) = \sum_{S \in 2^{N/i}} \frac{|S|!(n-1|S|)!}{n!} \lambda^{n-s-1} [v(S \cup i) - \lambda v(S)] \quad (2)$$

where: λ ∈ [0.1]×λ – discount factor, i.e. the contribution of different supply chain alliance subjects to the total benefits of agricultural product quality management. The introduction of a discount factor may hinder the equitable distribution of benefits, reduce participants' motivation for ensuring agricultural product quality control, and mitigate the effects of uncertainty factors on the allocation of benefits derived from such quality control measures.

Under the digital supply chain perspective, three enterprises, $A_{production\text{-}processing}$, $B_{logistics}$, C_{sales} form a closed-loop supply chain in the process of agricultural product quality governance.

Parametrisation of costs and benefits for supply chain participants. Assuming that the integrated production and processing enterprise (hereinafter denoted by $A_{production\text{-}processing}$) carries out automated and scientific management and control of agricultural products at the production stage, such as sowing, fertilising, and irrigating, and carries out processing such as sorting and packaging, to preserve the freshness and quality of agricultural products more effectively. Costs are incurred in this process (k_1, K_2), At the same time $A_{production\text{-}processing}$ firms sell agricultural products at wholesale prices (p_A^1, p_A^2). The logistics enterprise (hereinafter denoted by $B_{logistics}$) adopts the Internet of Things, cloud computing and other technologies to collect data and plan intelligently to realise the precise matching of supply and demand and improve the efficiency of logistics. Costs (l_1, l_2) are incurred in the process, and the logistics offer is (m_1, m_2). The sales enterprise (hereinafter denoted by C_{sales}) collects data on sales and purchases of agricultural products, analyses consumer demand with precision, and guarantees that the quality of agricultural products meets consumer demand. Costs (n_1, n_2) are incurred in this process, and the selling price of the agricultural products is (p_C^1, p_C^2). When the agricultural products are transported to the sales enterprise C_{sales} to be sold to the consumers, the agricultural products will incur a certain degree of loss, and the assumption of agricultural products preservation rate is (q_1, q_2). The model parameter settings are shown in Table 1.

$A_{production\text{-}processing}$ the earnings range for the business is:
$(a_1, a_2) = (p_A^1 - k_1; p_A^2 - k_2)$

$B_{logistics}$ the earnings range for the business is:
$(b_1, b_2) = (m_1 - l_1; m_2 - l_2)$

C_{sales} the earnings range for the business is:
$(c_1, c_2) = (q_1 p_C^1 - n_1; q_2 p_C^2 - n_2)$

Parametrisation of alliance costs and benefits for different supply chain participants. When $A_{production\text{-}processing}$ and $B_{logistics}$ are in alliance, the warehousing cost of $A_{production\text{-}processing}$ will be reduced (Δk_1, Δk_2), meanwhile, the $B_{logistics}$ obtains stable orders, and the operation cost will be reduced (Δl_1, Δl_2). Let the returns to the alliance between firms $A_{production\text{-}processing}$ and $B_{logistics}$ be (d_1, d_2).

Therefore,

$$d_1 = p_A^1 + m_1 - (k_1 - \Delta k_1) - (l_1 - \Delta l_1)$$
$$d_2 = p_A^2 + m_2 - (k_2 - \Delta k_2) - (l_2 - \Delta l_2)$$

When $A_{production\text{-}processing}$ and C_{sales} are in alliance, $A_{production\text{-}processing}$ can effectively predict the demand for agricultural products from C_{sales} sales information and consumer demand information, thus saving part of the production and processing costs (Δk_1, Δk_2), C_{sales} with $A_{production\text{-}processing}$ for a long period of time, so the wholesale price is reduced (Δp_A^1, Δp_A^2). Let the returns to the alliance between firms $A_{production\text{-}processing}$ and C_{sales} be (d_1, d_2).

Therefore,

$$e_1 = p_A^1 - \Delta p_A^1 + p_C^1 - n_1 - (k_1 - \Delta k_1)$$
$$e_2 = p_A^2 - \Delta p_A^2 + p_C^2 - n_2 - (k_2 - \Delta k_2)$$

When $B_{logistics}$ and C_{sales} are in alliance, logistics companies to ensure that agricultural products are fresher and faster to reach the hands of consumers, will provide better quality services, the corresponding logistics offer will be increased (Δm_1, Δm_2), Higher logistics operating costs to ensure quality and timeliness of services (Δl_1, Δl_2), At the same time, produce losses are reduced and freshness is improved (Δq_1, Δq_2), C_{sales} also need to improve storage techniques to guarantee the quality of agricultural products before they are sold to consumers, thus increasing costs (Δn_1, Δn_2). Let the returns to the alliance between firms $B_{logistics}$ and C_{sales} be (f_1, f_1).

Therefore,

$$f_1 = m_1 + \Delta m_1 + (q_1 + \Delta q_1) p_C^1 - (n_1 + \Delta n_1) - (l_1 + \Delta l_1)$$
$$f_2 = m_2 + \Delta m_2 + (q_2 + \Delta q_2) p_C^2 - (n_2 + \Delta n_2) - (l_2 + \Delta l_2)$$

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After forming the supply chain alliance, the three enterprises $A_{production\text{-}processing}$, $B_{logistics}$, C_{sales} cooperate more smoothly, so that the whole supply chain alliance gets better opportunities in the market and realises higher market profits. Let $A_{production\text{-}processing}$, $B_{logistics}$, C_{sales} three enterprises alliance gains as (g_1, g_2).

Therefore,

$$g_1 = (p_A^1 - \Delta p_A^1) + (m_1 + \Delta m_1) + (q_1 + \Delta q_1)$$
$$p_C^1 - (k_1 - \Delta k_1) - (l_1 + \Delta l_1) - (n_1 + \Delta n_1);$$
$$g_2 = (p_A^2 - \Delta p_A^2) + (m_2 + \Delta m_2) + (q_2 + \Delta q_2)$$
$$p_C^2 - (k_2 - \Delta k_2) - (l_2 + \Delta l_2) - (n_2 + \Delta n_2)$$

The values of the interval returns for each of the participating subject coalitions are shown in Table 2.

Based on the interval gain values of agricultural product quality governance under different alliances in Table 1 and Equation (2), the interval Shapley values of the three supply chain participants' quality governance of agricultural products using digital technology when the discount factor λ = 1 is first calculated (shown in Tables 3, 4, 5).

Table 2. Value of interval gains in agricultural product quality governance under different alliances

S	$v(S)$	$\underline{a}_S$	$\overline{a}_S$
$\{A_{production\text{-}processing}; B_{logistics}; C_{sales}\}$	(g_1, g_2)	g_1	g_2
$\{A_{production\text{-}processing}; B_{logistics}\}$	(d_1, d_2)	d_1	d_2
$\{A_{production\text{-}processing}; C_{sales}\}$	(e_1, e_2)	e_1	e_2
$\{A_{production\text{-}processing}\}$	(a_1, a_2)	a_1	a_2
$\{B_{logistics}; C_{sales}\}$	(f_1, f_2)	f_1	f_2
$\{B_{logistics}\}$	(b_1, b_2)	b_1	b_2
$\{C_{sales}\}$	(c_1, c_2)	c_1	c_2
Ø	(0, 0)	0	0

Source: Author's own processing

Benefit distribution matrix for agricultural product quality governance based on matrix semi-tensor product-interval Shapley values

Definition of matrix semi-tensor product function. Matrix semi-tensor product is the main tool of the state space method of logic system, using the semi-tensor

Table 1. Model parameters and their meanings

Parameter	Meaning
k	cost of quality and safety management of $A_{production\text{-}processing}$
p_A	unit wholesale price of agricultural products
l	cost of quality and safety management of $B_{logistics}$
m	transport unit price of agricultural products
n	cost of quality and safety management of C_{sales}
p_C	unit selling price of agricultural products
a	$A_{production\text{-}processing}$ enterprise profit
b	$B_{logistics}$ enterprise profit
c	C_{sales} enterprise profit
d	$A_{production\text{-}processing}$ and $B_{logistics}$ enterprise alliance profit
e	$A_{production\text{-}processing}$ and C_{sales} enterprise alliance profit
f	$B_{logistics}$ and C_{sales} enterprise alliance profit
g	$A_{production\text{-}processing}$, $B_{logistics}$ and C_{sales} enterprise alliance profit
q	agricultural products preservation rate
λ	quality and safety governance digital input coefficient
Δk	cost change parameters of enterprise $A_{production\text{-}processing}$ after the alliance
Δl	cost change parameters of enterprise $B_{logistics}$ after the alliance
Δp_A	unit wholesale price change parameters of agricultural products
Δm	transport unit price change parameters of agricultural products
Δn	cost change parameters of enterprise C_{sales} after the alliance
Δp_C	unit selling price change parameters of agricultural products

Source: Author's own processing

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Table 3. Interval Shapley values for firm $A_{production\text{-}processing}$

S	$\frac{(n-s)!(s-1)!}{n!}$	$v(S \cup \{A\})$	$v(S)$	$v(S \cup \{A\}) - v(S)$
Ø	1/3	(a_1, a_2)	0	(a_1, a_2)
$\{B\}$	1/6	(d_1, d_2)	(b_1, b_2)	$(d_1 - b_2, d_1 - b_2)$
$\{C\}$	1/6	(e_1, e_2)	(c_1, c_2)	$(e_1 - c_2, e_1 - c_2)$
$\{BC\}$	1/6	(g_1, g_2)	(f_1, f_2)	$(g_1 - f_2, g_1 - f_2)$

Source: Author's own processing

Table 4. Interval Shapley values for firm $B_{logistics}$

S	$\frac{(n-s)!(s-1)!}{n!}$	$v(S \cup \{B\})$	$v(S)$	$v(S \cup \{B\}) - v(S)$
Ø	1/3	(b_1, b_2)	0	(b_1, b_2)
$\{A\}$	1/6	(d_1, d_2)	(a_1, a_2)	$(d_1 - a_2, d_2 - a_2)$
$\{C\}$	1/6	(f_1, f_2)	(c_1, c_2)	$(f_1 - c_2, f_2 - c_1)$
$\{AC\}$	1/6	(g_1, g_2)	(f_1, f_2)	$(g_1 - e_2, g_2 - e_1)$

Source: Author's own processing

Table 5. Interval Shapley values for firm C_{sales}

S	$\frac{(n-s)!(s-1)!}{n!}$	$v(S \cup \{C\})$	$v(S)$	$v(S \cup \{C\}) - v(S)$
Ø	1/3	(c_1, c_2)	0	(c_1, c_2)
$\{A\}$	1/6	(e_1, e_2)	(a_1, a_2)	$(e_1 - a_2, e_2 - a_1)$
$\{B\}$	1/6	(f_1, f_2)	(b_1, b_2)	$(f_1 - b_2, f_2 - b_1)$
$\{AB\}$	1/6	(g_1, g_2)	(d_1, d_2)	$(g_1 - d_2, g_2 - d_1)$

Source: Author's own processing

product theory of matrices to represent the interval cooperation game characteristic function by matrix. In the limited game of agricultural product quality governance, the revenue functions of the supply chain participating subjects production and processing integration enterprises, logistics service enterprises, and sales enterprises can be regarded as pseudo-Boolean functions. It plays a key role in the matrix calculation method of Shapley value. Referring to relevant literature (Cheng 2001; Guo et al. 2013; Wang and Cheng 2017), the following definitions, propositions, and lemmas can be obtained.

Definition 1: Let matrix $A \in M_{m\times n}$, $B \in M_{p\times q}$, and remember that $t = \text{l cm}\ (n, p)$ is the least common multiple of n and p. The semi-tensor product of matrices A and B is defined as follows:

$$A \ltimes B = (A \otimes I_{t/n})(B \otimes I_{t/p}) \in M_{mt/n \times qt/p} \quad (3)$$

When $n = p$, the half-tensor product of matrices is the ordinary matrix multiplication. In this paper, all matrix multiplications are half-tensor products, and $\ltimes$ is usually omitted.

Definition 2: Define the permutation matrix $W_{(m,\,n)} \in M_{mn\times mn}$,

$$W_{[m,n]} = \delta_{mn}[11 + m \cdots 1 + (n-1)m \cdots mm + m \cdots m + (n-1)m] \quad (4)$$

The exchange of vector multiplications in the sense of semi-tensor products can be realised under the action of permutation matrices. Let the vectors $\alpha = \delta_2^1$, $\beta = \delta_4^3$, be calculated that $\delta_2^1 \ltimes \delta_4^3 = \delta_8^3$, $\delta_4^3 \ltimes \delta_2^1 = \delta_8^5$.

Proposition 1: Let $f = (x_1, x_2, \dots x_n) : Dm \longrightarrow \mathbb{R}$ be a pseudo-logic function, then there exists a unique matrix $M_f \in M_{1\times 2}{}^n$, such that:

$$f = (x_1, x_2, \dots x_n) = M_f \ltimes_{i=1}^{n} x_i$$

where: M_f – structure matrix of the pseudo-logic function f.

Lemma 1: Let $f = (x_1, x_2, \dots x_n) : Dm \longrightarrow \tau(R)$ a pseudo-logistic interval function, then there exists a unique interval matrix M_f that:

$$f = (x_1, x_2, \dots x_n) = M_f \ltimes_{i=1}^{n} x_i$$

$M_f = [\underline{M}, \overline{M}]$ ($\underline{M}, \overline{M} \in M_{1\times 2}{}^n$) is called the structure matrix of the pseudo-logic interval function f.

Construct the interval Shapley value matrix. The integrated production and processing enterprises, logistics enterprises and sales enterprises in the supply chain are different due to their own enterprise scale and business scope. They have different inputs, resource contributions and quality control effects in the quality control of agricultural products. The Shapley value can measure the contribution of each participant in the supply chain in forming alliances for quality control of agricultural products, so as to avoid the reduction of inputs and motivation of quality control of agricultural products caused by the simple average distribution method.

Agricultural supply chain subjects for quality governance interval cooperation game (N, v), for any coalition of supply chain participating subjects $S \in 2^N$, $v(S)$ denotes the characteristic function of the interval cooperation game, construct $X_s = (X_1^S, X_2^S, \dots, X_n^S)$, where:

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$$X_i^S = \begin{cases} \delta_2^1, & i \in S \\ \delta_2^2, & i \notin S \end{cases} \tag{5}$$

From Lemma 1, the characteristic function $v(S)$ of the interval cooperation game can be expressed as:

$$v(S) = Mx^S$$

where: $M = [\underline{M}, \overline{M}]$ – interval of the gain value of the participating subject coalition for agricultural product quality governance under the perspective of digital supply chain. $\underline{M}$ denotes the minimum value of the benefit value, and $\overline{M}$ denotes the maximum value of the benefit distribution. x^S denotes the different subject coalition benefit distribution solutions in the process of agricultural product quality governance.

$$\underline{M}, \overline{M} \in M_{1\times 2^n}, x^S = x_1^S \ltimes \cdots \ltimes x_n^S \in \Delta_{2^n}$$

Below the interval cooperative game eigenfunctions are represented as matrices using the semi-tensor product theory of matrices in . Noting $x_1^S \cdots x_{i-1}^S x_{i+1}^S \cdots x_n^S = \delta_{2^{n-1}}^j$, the calculation of the quality governance coalition returns in Equation (2) can be transformed into:

$$v(S \cup i) = Mx_1^S \cdots x_{i-1}^S \delta_2^1 x_{i+1}^S \cdots x_n^S = [\underline{M}, \overline{M}] W_{[2.2^{i-1}]} \delta_2^1 \delta_{2^{n-1}}^j$$

$$v(S \cup i) = Mx_1^S \cdots x_{i-1}^S \delta_2^2 x_{i+1}^S \cdots x_n^S = [\underline{M}, \overline{M}] W_{[2.2^{i-1}]} \delta_2^2 \delta_{2^{n-1}}^j$$

$$v(S \cup i) - \lambda v(S) = [\underline{M}, \overline{M}] W_{[2.2^{i-1}]} \delta_2^1 \delta_{2^{n-1}}^j + \lambda [\underline{M}, \overline{M}] W_{[2.2^{i-1}]} \delta_2^2 \delta_{2^{n-1}}^j$$

Constructing a vector sequence $\alpha_k \in \mathbb{R}^{2k}$

$$\alpha_1 = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \alpha_{k+1} = \begin{bmatrix} \alpha_k + 1_{2^k} \\ \alpha_k \end{bmatrix}$$

$$k = 1,2,\cdots, 1_{2^k} = (1,1,\ \cdots,\ 1)^T$$

Lemma 2: Let the set $S \subset N = \{x_1, x_2, \cdots x_n\}$, and remember that $x^S = x_1^S \ltimes \cdots \ltimes x_n^S = \delta_{2n}^j$, and then $s = |S| = \alpha_n^j$, where α_n^j denotes the j^{th} component of α_n.

$$\alpha_{n-1} = [\alpha_1, \alpha_2, \cdots \alpha_{2^{n-1}}]^T \in \mathbb{R}^{2^{n-1}}$$

Constructing a vector sequence $\gamma = [c_1, c_2, \cdots c_{2^{n-1}}]^T$, which $c_j = \dfrac{\lambda^{n-\alpha_j-1}(n-\alpha_j-1)!(\alpha_j)!}{n!}, j = 1,2,\ldots,2^{n-1}$

Equalise the vector into k-block vectors in turn, where $k = 1,2,2^2 \cdots, 2^{n-1}$, these are denoted as:

$$\gamma = \gamma_1^1 = \begin{pmatrix} \gamma_2^1 \\ \gamma_2^2 \end{pmatrix} = \cdots\cdots = \begin{pmatrix} \gamma_n^1 \\ \gamma_n^2 \\ \vdots \\ \vdots \\ \gamma_n^{2^{n-1}} \end{pmatrix}, \gamma_1^j \in \mathbb{R}^{2^{n-1}}$$

$$i = 1,2,\cdots n,\ j = 1,2,\cdots, 2^{n-1}$$

Theorem 1: The interval cooperative game (N, v) of agricultural product quality governance, where the number of participating subjects $N = \{1,2, \cdots, n\}$ and is the structure matrix of the interval eigenfunctions $v(S)$, then the Shapley value of this interval cooperative game matrix is:

$$\varphi(v) = [\underline{M}E - \lambda\overline{M}F,\ \overline{M}E - \underline{M}F] \tag{6}$$

$E = [E_1, E_2, \cdots E_n]$, $F = [F_1, F_2, \cdots F_n]$ are the vector matrices constructed according to Lemma 2, $\underline{M}$ and $\overline{M}$ are the minimum and maximum values of each supply chain alliance's gain interval, and λ is a measure of the contribution of subjects $A_{production\text{-}processing}$, $B_{logistics}$ and C_{sales} to quality governance of agricultural products. The subsequent distribution of earnings based on λ in the text primarily utilises Equation (6).

$$E_i = \begin{bmatrix} \begin{pmatrix} \gamma_i^1 \\ 0_{2^{n-i}} \end{pmatrix} \\ \vdots \\ \vdots \\ \begin{pmatrix} \gamma_i^{2^i} \\ 0_{2^{n-i}} \end{pmatrix} \end{bmatrix}, F_i = \begin{bmatrix} \begin{pmatrix} 0_{2^{n-i}} \\ \gamma_i^1 \end{pmatrix} \\ \vdots \\ \vdots \\ \begin{pmatrix} 0_{2^{n-i}} \\ \gamma_i^{2^i} \end{pmatrix} \end{bmatrix}, i = 1,2, \cdots n$$

Agricultural product quality governance interval Shapley value gain distribution

The enterprises form a cooperative and win-win relationship and jointly promote the digital quality governance of agricultural products through consultation and cooperation. From the calculation results of Table 2, Table 3, and Table 4, the Shapley values of the benefit distribution of the three enterprises, $A_{production\text{-}processing}$,

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$B_{logistics}$ and C_{sales} participating in the supply chain of agricultural products, when they invest in the application of different digitalisation technologies for quality governance at the production-processing end, the logistics end, and the sales end, respectively, are as follows:

The interval shapley value of $A_{production\text{-}processing}$ is:

$$\varphi(A)=1/3\,(a_1,a_2)\oplus 1/6\,(d_1-b_2,d_2-b_1)\oplus$$
$$\oplus 1/6\,(e_1-c_2,e_1-c_1)\oplus 1/3\,(g_1-f_2,g_2-f_1)$$
$$=\begin{bmatrix}1/3\,a_1+1/6\,(d_1-b_2)+1/6\,(e_1-c_2)+1/3\,(g_1-f_2),\\ 1/3\,a_2+1/6\,(d_2-b_1)+1/6\,(e_2-c_1)+1/3\,\theta\,(g_2-f_1)\end{bmatrix}$$

The interval shapley value of $B_{logistics}$ is:

$$\varphi(B)=1/3\,(b_1,b_2)\oplus 1/6\,(d_1-a_2,d_2-a_1)\oplus$$
$$\oplus 1/6\,(f_1-c_2,f_2-c_1)\oplus 1/3\,(g_1-e_2,g_2-e_1)$$
$$=\begin{bmatrix}1/3\,b_1+1/6\,(d_1-a_2)+1/6\,(f_1-c_2)+1/3\,(g_1-e_2),\\ 1/3\,b_2+1/6\,(d_2-a_1)+1/6\,(f_2-c_1)+1/3\,(g_2-e_1),\end{bmatrix}$$

The interval shapley value of C_{sales} is:

$$\varphi(C)=1/3(c_1,c_2)\oplus 1/6(e_1-a_2,e_2-a_1)\oplus$$
$$\oplus 1/6(f_1-b_2,f_2-b_1)\oplus 1/3(g_1-d_2,g_2-d_1)=$$
$$=\begin{bmatrix}1/3c_1+1/6(e_1-a_2)+1/6(f_1-b_2)+1/3(g_1-d_2),\\ 1/3c_2+1/6(e_2-a_1)+1/6(f_2-b_1)+1/3(g_2-d_1)\end{bmatrix}$$

According to Theorem 1, the set of benefits of different coalitions consisting of $A_{production\text{-}processing}$, $B_{logistics}$, C_{sales} which are involved in the agricultural supply chain for quality governance, is $M_v = [(a_1, a_2)\,(b_1, b_2)\,(c_1, c_2)\,(d_1, d_2)\,(e_1, e_2)\,(f_1, f_2)\,(g_1, g_2)\,(0, 0)]$. The minimum value of the quality governance benefit interval under different coalitions is $\underline{M} = [a_1, b_1, c_1, d_1, e_1, f_1, g_1, 0]$, and the maximum value is $\overline{M} = [a_2, b_2, c_2, d_2, e_2, f_2, g_2, 0]$.

When the participating subjects $n = 3$ and the discount factor $\lambda = 1$, the vectors $\alpha_2 = [2\ 1\ 1\ 0]^T$ $\gamma_2 = [\ 2\ 1\ 1\ 2]^T$, which gives that:

$$E=\frac{1}{3!}\begin{bmatrix}2&1&1&2&0&0&0&0\\2&1&0&0&1&2&0&0\\2&0&1&0&1&0&2&0\end{bmatrix}^T,\quad F=\frac{1}{3!}\begin{bmatrix}0&0&0&0&2&1&1&2\\0&0&2&1&0&0&1&2\\0&2&0&1&0&1&0&2\end{bmatrix}^T$$

According to the above equation, the income distribution interval of the Shapley value of the cooperative game in the agricultural product quality and safety governance interval can be calculated, as shown below.

The minimum value interval for the distribution of gains from agricultural product quality governance is:

$$\underline{M}E-\lambda\overline{M}F=[a_1,b_1,c_1,d_1,e_1,f_1,g_1,0]\frac{1}{3!}\begin{bmatrix}2&1&1&2&0&0&0&0\\2&1&0&0&1&2&0&0\\2&0&1&0&1&0&2&0\end{bmatrix}^T$$
$$-[a_2,b_2,c_2,d_2,e_2,f_2,g_2,0]\frac{1}{3!}\begin{bmatrix}0&0&0&0&2&1&1&2\\0&0&2&1&0&0&1&2\\0&2&0&1&0&1&0&2\end{bmatrix}^T=$$
$$=\begin{bmatrix}\dfrac{2a_1+b_1+c_1+2d_1-2e_2-f_2-g_2}{6},\\ \dfrac{2a_1+b_1+e_1+2f_1-2c_2-d_2-g_2}{6},\\ \dfrac{2a_1+c_1+e_1+2g_1-2b_2-d_2-f_2}{6}\end{bmatrix}$$

The maximum interval of the distribution of the benefits of agricultural quality governance is:

$$\overline{M}E-\lambda\underline{M}F=[a_2,b_2,c_2,d_2,e_2,f_2,g_2,0]\frac{1}{3!}\begin{bmatrix}2&1&1&2&0&0&0&0\\2&1&0&0&1&2&0&0\\2&0&1&0&1&0&2&0\end{bmatrix}^T-$$
$$[a_1,b_1,c_1,d_1,e_1,f_1,g_1,0]\frac{1}{3!}\begin{bmatrix}0&0&0&0&2&1&1&2\\0&0&2&1&0&0&1&2\\0&2&0&1&0&1&0&2\end{bmatrix}^T=$$
$$=\begin{bmatrix}\dfrac{2a_2+b_2+c_2+2d_2-2e_1-f_1-g_1}{6}\\ \dfrac{2a_2+b_2+e_2+2f_2-2c_1-d_1-g_1}{6}\\ \dfrac{2a_2+c_2+e_2+2g_2-2b_1-d_1-f_1}{6}\end{bmatrix}$$

In summary, under the perspective of digital supply chain, the gain intervals obtained by three supply chain participants, $A_{production\text{-}processing}$, $B_{logistics}$, C_{sales} in the governance of agricultural product quality is shown in Table 6.

Depending on the value of λ taken, the distribution of benefits among the three subjects of the agricultural supply chain is discussed.

Analysis of Shapley value – λ change in agricultural quality governance benefits

In the process of agricultural product quality management, the supply chain participating subjects of production-processing integrated enterprises, logistics enterprises and marketing enterprises have different degrees of contribution to the quality management of agricultural products, bear different risks, and therefore the distribution of benefits is also different.

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Table 6. The benefits of the participants

Supply chain participants	Minimum benefits	Maximum benefits
$A_{production\text{-}processing}$	$\frac{2a_1+b_1+c_1+2d_1-2e_2-f_2-g_2}{6}$	$\frac{2a_2+b_2+c_2+2d_2-2e_1-f_1-g_1}{6}$
$B_{logistics}$	$\frac{2a_1+b_1+e_1+2f_1-2c_2-d_2-g_2}{6}$	$\frac{2a_2+b_2+e_2+2f_2-2c_1-d_1-g_1}{6}$
C_{sales}	$\frac{2a_1+c_1+e_1+2g_1-2b_2-d_2-f_2}{6}$	$\frac{2a_2+c_2+e_2+2g_2-2b_1-d_1-f_1}{6}$

Source: Author's own processing

The interval Shapley values can be categorised into two extreme cases when discount factors are considered:

When λ = 1, Equation (2) degenerates into Equation (1) to avoid evenly distributed interval Shapley values. The process of calculating Shapley values for the three subjects $A_{production\text{-}processing}$, $B_{logistics}$, C_{sales} for λ = 1 can be obtained:

$$\underline{\mathrm{ME}}-\overline{\mathrm{MF}}=\begin{bmatrix}\frac{2a_1+b_1+c_1+2d_1-2e_2-f_2-g_2}{6}, \\ \frac{2a_1+b_1+e_1+2f_1-2c_2-d_2-g_2}{6}, \\ \frac{2a_1+c_1+e_1+2g_1-2b_2-d_2-f_2}{6}\end{bmatrix}$$

$$\overline{\mathrm{ME}}-\lambda\underline{\mathrm{MF}}=\begin{bmatrix}\frac{2a_2+b_2+c_2+2d_2-2e_1-f_1-g_1}{6}, \\ \frac{2a_2+b_2+e_2+2f_2-2c_1-d_1-g_1}{6}, \\ \frac{2a_2+c_2+e_2+2g_2-2b_1-d_1-f_1}{6}\end{bmatrix}$$

When λ = 0, it is the case of average distribution according to the total benefits of the cooperative union.

$$\underline{\mathrm{ME}}-\lambda\overline{\mathrm{MF}}=\left[a_1,b_1,c_1,d_1,e_1,f_1,g_1,0\right]\frac{1}{3!}\begin{bmatrix}2\,0\,0\,0\,0\,0\,0\,0 \\ 2\,0\,0\,0\,0\,0\,0\,0 \\ 2\,0\,0\,0\,0\,0\,0\,0\end{bmatrix}^T=\left[\frac{a_1}{3},\frac{a_1}{3},\frac{a_1}{3}\right]$$

$$\overline{\mathrm{ME}}-\lambda\underline{\mathrm{MF}}=\left[a_2,b_2,c_2,d_2,e_2,f_2,g_2,0\right]\frac{1}{3!}\begin{bmatrix}0\,0\,0\,0\,2\,0\,0\,0 \\ 0\,0\,2\,0\,0\,0\,0\,0 \\ 0\,2\,0\,0\,0\,0\,0\,0\end{bmatrix}^T=\left[\frac{e_2}{3},\frac{c_2}{3},\frac{b_2}{3}\right]$$

The three participating subjects of the supply chain, in order to ensure the benefits of agricultural product quality governance, continuously increase their own inputs. As the discount factor increases, the Shapley value of the participating subjects produces different degrees of increase. This means that the contribution of participating subjects in the cooperative game also becomes larger when considering future benefits. When the uncertainties in the supply chain can be solved and the return of the alliance is a definite value, the interval discount Shapley value degrades to the classical discount Shapley value.

Numerical analysis

This study takes Wuchang rice in China as the research object. A Wuchang rice producer and processor ($A_{production\text{-}processing}$) has 6 international rice production lines, an annual rice processing capacity of 400 000 tons, and uses advanced intelligent three-dimensional silos to realise the information of grain input and storage, inventory management, storage operations and other businesses. In the process of rice planting, the whole process of cultivated land management, integration of water and fertiliser, disease and pest control, agricultural planning and monitoring, and precise crop cultivation are realised based on digital technology. In the process of processing, rice husking, grinding white, polishing colour selection, packaging as one of the automatic production lines, to achieve intelligent processing, automation. A Wuchang rice logistics service enterprise ($B_{logistics}$) provides supply chain services of an intelligent logistics backbone network, avoiding problems such as cross-goods and switching in commodity circulation links. A Wuchang rice sales enterprise (C_{sales}) marketing network throughout the country's more than 300 cities, online settled in a number of e-commerce platforms, the offline layout of national supermarkets, grain and oil stores and other retail systems as well as chain catering systems, while combining community marketing, private customised and other new retail models, to create a combination of the online and offline global marketing model.

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Table 7. Benefits of mutual alliance and cooperation among subjects

S	$v(S)$	Min.	Max.
$\{ABC\}$	(6.45, 7.88)	6.45	7.88
$\{AB\}$	(2.86, 3.71)	2.86	3.71
$\{AC\}$	(3.62, 4.78)	3.62	4.78
$\{BC\}$	(3.47, 4.44)	3.47	4.44
$\{A\}$	(1.07, 1.58)	1.07	1.58
$\{B\}$	(0.92, 1.19)	0.92	1.19
$\{C\}$	(1.95, 2.50)	1.95	2.50
Ø	(0, 0)	0	0

Source: Author's own processing

Assume that in a certain period of time, the production and processing integration enterprise ($A_{production\text{-}processing}$), logistics service enterprise $B_{logistics}$, sales enterprise C_{sales} of the three main bodies of the independent operation of the gain are [1.07, 1.58], [0.92, 1.19], [1.95, 2.5], respectively. The gains from mutual alliance and cooperation between the subjects are shown in Table 7.

As shown in Table 7, compared with the quality governance of each participating subject in the agricultural supply chain alone, the participation of each supply chain subject in the quality governance cooperative alliance can increase the benefits, and the three subjects jointly participate in the cooperative formation of agricultural products quality governance alliance brings the greatest benefits.

Consider the impact of the discount factor on the distribution of gains from agricultural product quality governance of the three subjects. First, calculate the interval Shapley value of each participant when the discount factor λ = 1.

From Table 8, it can be concluded that firm $A_{production\text{-}processing}$'s share of the proceeds is:

$$\varphi_A(v) = \frac{1}{3} \times (1.07,1.58) \oplus \frac{1}{6} \times (1.67,2.79) \oplus \frac{1}{6} \times (1.12,2.83) \oplus \frac{1}{6} \times \ (2.01,4.41) = (1.16,2.20)$$

Similarly, the firm $B_{logistics}$ share of the revenue for λ = 1 can be calculated as $\phi_B(v) = (0.96, 1.96)$. C_{sales} share of the proceeds is $\phi_C(v) = (1.83, 2.88)$.

Then the set of returns for the three firms is M_v = [(6.45, 7.88)(3.62, 4.78)(3.47, 4.44)(2.86, 3.71) (1.96, 2.50)(1.07, 1.58)(0.92, 1.19)(0, 0)]. The set of return minima is $\underline{M}$ = (6.45, 3.62, 3.47, 2.86, 1.96, 1.07, 0.92, 0). The set of maximum values of returns is $\overline{M}$ = (7.88, 4.78, 4.44, 3.71, 2.50, 1.58, 1.19, 0). According to $\phi(v) = (\underline{M}E - \lambda\overline{M}F, \overline{M}E - \lambda\underline{M}F)$.

When $n = 3$, $\lambda = 1$, $\alpha_2 = [2\ 1\ 1\ 0]^T$, $\gamma_2 = [2\ 1\ 1\ 0]^T$.

$$E_\lambda = \frac{1}{3!}\begin{bmatrix} 2\,1\,1\,2\,0\,0\,0\,0 \\ 2\,1\,0\,0\,1\,2\,0\,0 \\ 2\,0\,1\,0\,1\,0\,2\,0 \end{bmatrix}^T,$$

$$F_\lambda = \frac{1}{3!}\begin{bmatrix} 0\,0\,0\,0\,2\,1\,1\,2 \\ 0\,0\,2\,1\,0\,0\,1\,2 \\ 0\,2\,0\,1\,0\,1\,0\,2 \end{bmatrix}^T$$

Therefore, $\underline{M}E - 1 \times \overline{M}F$ = [1.83, 1.16, 0.96]; $\overline{M}E - 1 \times \underline{M}F$ = [2.88, 2.20, 1.96]; $\phi_A(v) \in$ [1.16, 2.20]; $\phi_B(v) \in$ [0.96, 1.96]; $\phi_C(v) \in$ [1.83, 2.88]. It can be concluded that when the digital input coefficient λ = 1, the revenue interval obtained by $A_{production\text{-}processing}$ is [1.16, 2.20], the revenue interval obtained by $B_{logistics}$ is [0.96, 1.96], and the revenue interval obtained by C_{sales} is [1.83, 2.88].

When λ = 0.8,

$$E_\lambda = \frac{1}{3!}\begin{bmatrix} 2 & 0.8 & 0.8 & 1.28 & 0 & 0 & 0 & 0 \\ 2 & 0.8 & 0 & 0 & 0.8 & 1.28 & 0 & 0 \\ 2 & 0 & 0.8 & 0 & 0.8 & 0 & 1.28 & 0 \end{bmatrix}^T$$

$$F_\lambda = \frac{1}{3!}\begin{bmatrix} 0 & 0 & 0 & 0 & 2 & 0.8 & 0.8 & 1.28 \\ 0 & 0 & 2 & 0.8 & 0 & 0 & 0.8 & 1.28 \\ 0 & 2 & 0 & 0.8 & 0 & 0.8 & 0 & 1.28 \end{bmatrix}^T$$

Therefore, $\underline{M}E - 1 \times \overline{M}F$ = [2.74, 1.41, 1.23], $\overline{M}E - 1 \times \underline{M}F$ = [3.92, 2.61, 2.42].

$\phi_A(v) \in$ [1.41, 2.61], $\phi_B(v) \in$ [1.23, 2.42], $\phi_C(v) \in$ [2.74, 3.92]. It can be concluded that when the digital input coefficient λ = 0.8, the revenue interval obtained by $A_{production\text{-}processing}$ is [1.41, 2.61], the revenue interval obtained by $B_{logistics}$ is [1.23, 2.42], and the revenue interval obtained by C_{sales} is [2.74, 3.92].

When λ = 0.6,

$$E\lambda = \frac{1}{3!}\begin{bmatrix} 2 & 0.6 & 0.6 & 0.72 & 0 & 0 & 0 & 0 \\ 2 & 0.6 & 0 & 0 & 0.6 & 0.72 & 0 & 0 \\ 2 & 0 & 0.6 & 0 & 0.6 & 0 & 0.72 & 0 \end{bmatrix}^T$$

$$F\lambda = \frac{1}{3!}\begin{bmatrix} 0 & 0 & 0 & 0 & 2 & 0.6 & 0.6 & 0.72 \\ 0 & 0 & 2 & 0.6 & 0 & 0 & 0.6 & 0.72 \\ 0 & 2 & 0 & 0.6 & 0 & 0.6 & 0 & 0.72 \end{bmatrix}^T$$

Therefore, $\underline{M}E - 0.6\ \overline{M}F$ = [2.54, 1.65, 1.53], $\overline{M}E - 0.6\ \underline{M}F$ = [3.48, 2.62, 2.50]. $\phi_A(v) \in$ [1.65, 2.62],

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$\phi_B(v) \in [1.53, 2.50]$, $\phi_C(v) \in [2.54, 3.48]$. It can be concluded that when the digital input coefficient λ = 0.6, the revenue interval obtained by $A_{production\text{-}processing}$ is [1.65, 2.62], the revenue interval obtained by $B_{logistics}$ is [1.53, 2.50], and the revenue interval obtained by C_{sales} is [3.54, 2.48].

When λ = 0.4,

$$E\lambda = \frac{1}{3!}\begin{bmatrix} 2 & 0.4 & 0.4 & 0.32 & 0 & 0 & 0 & 0 \\ 2 & 0.4 & 0 & 0 & 0.4 & 0.32 & 0 & 0 \\ 2 & 0 & 0.4 & 0 & 0.4 & 0 & 0.32 & 0 \end{bmatrix}^T$$

$$E\lambda = \frac{1}{3!}\begin{bmatrix} 0 & 0 & 0 & 0 & 2 & 0.4 & 0.4 & 0.32 \\ 0 & 0 & 2 & 0.4 & 0 & 0 & 0.4 & 0.32 \\ 0 & 2 & 0 & 0.4 & 0 & 0.4 & 0 & 0.32 \end{bmatrix}^T$$

Therefore, $\underline{ME} - 0.4\overline{MF} = [2.37, 1.86, 1.79]$, $\overline{ME} - 0.4\underline{MF} = [3.13, 2.63, 2.57]$.

$\phi_A(v) \in [1.86, 2.63]$, $\phi_B(v) \in [1.79, 2.57]$, $\phi_C(v) \in [2.37, 3.13]$. It can be concluded that when the digital input coefficient λ = 0.4, the revenue interval obtained by $A_{production\text{-}processing}$ is , the revenue interval obtained by $B_{logistics}$ is [1.79, 2.57], and the revenue interval obtained by C_{sales} is [2.37, 3.13].

When λ = 0.2,

$$E_\lambda = \frac{1}{3!}\begin{bmatrix} 2 & 0.2 & 0.2 & 0.08 & 0 & 0 & 0 & 0 \\ 2 & 0.2 & 0 & 0 & 0.2 & 0.08 & 0 & 0 \\ 2 & 0 & 0.2 & 0 & 0.2 & 0 & 0.08 & 0 \end{bmatrix}^T$$

$$F_\lambda = \frac{1}{3!}\begin{bmatrix} 0 & 0 & 0 & 0 & 2 & 0.2 & 0.2 & 0.08 \\ 0 & 0 & 2 & 0.2 & 0 & 0 & 0.2 & 0.08 \\ 0 & 2 & 0 & 0.2 & 0 & 0.2 & 0 & 0.08 \end{bmatrix}^T$$

Therefore, $\underline{ME} - 0.2\ \overline{MF} = [2.24, 2.02, 1.99]$, $\overline{ME} - 0.2\ \underline{MF} = [2.84, 2.63, 2.61]$. $\phi_A(v) \in [2.02, 2.63]$, $\phi_B(v) \in [1.99, 2.61]$, $\phi_C(v) \in [2.24, 2.84]$.

It can be concluded that when the digital input coefficient λ = 0.2, the revenue interval obtained by $A_{production\text{-}processing}$ is [2.02, 2.63], the revenue interval obtained by $B_{logistics}$ is [1.99, 2.61] and the revenue interval obtained by C_{sales} is [2.24, 2.84].

When λ = 0, the benefits of quality governance are equally distributed across subjects.

Therefore, $\underline{ME} - 0 \times \overline{MF} = [2.15, 2.15, 2.15]$, $\overline{ME} - 0 \times \underline{MF} = [2.63, 2.63, 2.63]$. $\phi_A(v) \in [2.15, 2.63]$, $\phi_B(v) \in [2.15, 2.63]$, $\phi_C(v) \in [2.15, 2.63]$.

It can be concluded that when the digital input coefficient λ = 0, the revenue interval obtained by $A_{production\text{-}processing}$ is [2.15, 2.63], the revenue interval obtained by $B_{logistics}$ is [2.15, 2.63], and the revenue interval obtained by C_{sales} is [2.15, 2.63].

Compare Table 9, Figure 5, Figure 6, and Figure 7 that when λ = 0.8, the revenue range divided by the three enterprise subjects $A_{production\text{-}processing}$, $B_{logistics}$ and C_{sales} has the most obvious change. Among them, as increases between [0, 1], the returns shared by $A_{production\text{-}processing}$ and $B_{logistics}$ show a decreasing change, while the returns shared by C_{sales} show a first increasing and then decreasing change, and the maximum value is reached when λ = 0.8.

The revenue distribution interval of $A_{production\text{-}processing}$, $B_{logistics}$ and C_{sales} under different values of is

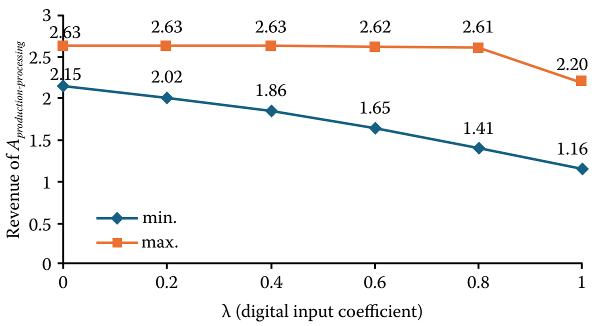

Figure 5. Trend in earnings received by firm $A_{production\text{-}processing}$ with λ

Source: Author's own processing

Table 9. Revenue interval of $A_{production\text{-}processing}$; $B_{logistics}$; C_{sales} and under different λ values

Stage	λ = 0	λ = 0.2	λ = 0.4	λ = 0.6	λ = 0.8	λ = 1
$A_{production\text{-}processing}$	[2.15, 2.63]	[2.02, 2.63]	[1.86, 2.63]	[1.65, 2.62]	[1.41, 2.61]	[1.16, 2.20]
$B_{logistics}$	[2.15, 2.63]	[1.99, 2.61]	[1.79, 2.57]	[1.53, 2.50]	[1.23, 2.42]	[0.96, 1.96]
C_{sales}	[2.15, 2.63]	[2.24, 2.84]	[2.37, 3.13]	[2.54, 3.48]	[2.74, 3.92]	[1.83, 2.88]

Source: Author's own processing

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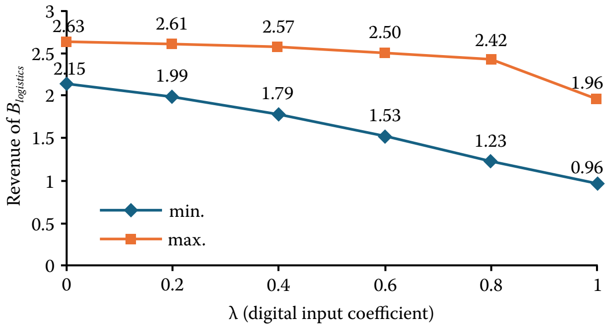

Figure 6. Trend in earnings received by firm $B_{logistics}$ with λ

Source: Author's own processing

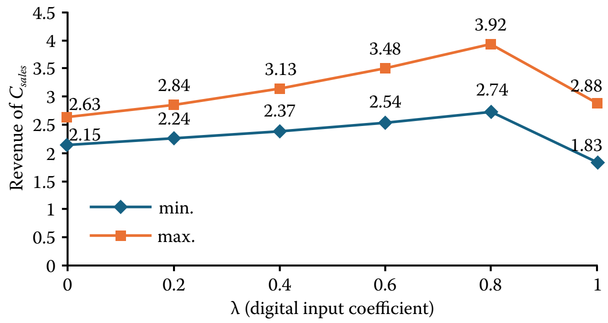

Figure 7. Trend in earnings received by firm C_{sales} with λ

Source: Author's own processing

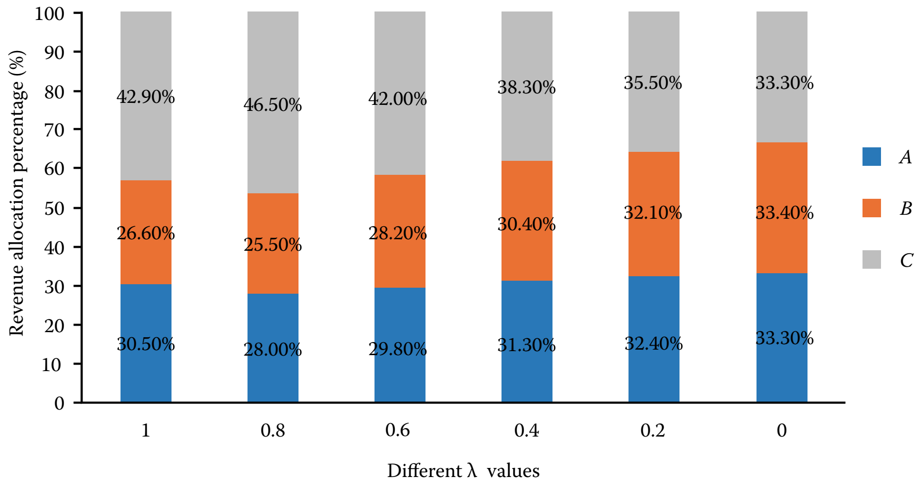

Figure 8. Revenue percentages of $A_{production\text{-}processing}$, $B_{logistics}$ and C_{sales} under different λ values

Source: Author's own processing

obtained by taking the middle number to obtain the histogram of income percentage. As can be seen from Figure 5–8, under different values, the income shared by the three subjects A, B, and C accounted for different proportions of the whole. The closer the value of λ is to 0, the closer the income distribution of the three subjects is to the average distribution.

In the actual application, the coalition of agricultural supply chain participants can choose the appropriate value of λ and the corresponding benefit distribution scheme according to their respective factors such as resource input in agricultural quality management and quality management effect.

DISCUSSION

Key findings

i) Digitalisation can effectively improve the quality of agricultural products. Integrated production and processing enterprises ($A_{production\text{-}processing}$) govern the quality of agricultural products from the source. As the planting and production of agricultural products are affected by the natural environment, seasons, pests and diseases, and other uncertainties, the production and processing enterprises of agricultural products accordingly bear greater risk factors. With the continuous investment of enterprises in digitalisation, intelligent technology has been applied to the production end of agricultural products, promoting production to be more scientific and standardised, and greatly avoiding the impact of uncertain risk factors on the quality of agricultural products. Due to the characteristics of agricultural products easy to rot, the process of logistics and transportation produce large, logistics service enterprises ($B_{logistics}$) in order to protect the freshness of agricultural products in the transportation process, reduce the loss of rot into the cold chain logistics transportation, intelligent monitoring of the transport temperature, and greatly ensure that agricultural products in the transportation process of freshness issues. At the same time, in order to im-

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prove transportation efficiency and reduce the waste of resources, logistics service enterprises adopt digital technologies such as the Internet of Things and big data to intelligently plan reasonable transportation routes, maximise the effectiveness of transportation vehicles, and reduce the transportation cost. In order to satisfy consumers' demand for high-quality agricultural products and avoid the phenomenon of 'lemon market' for high-quality agricultural products, sales enterprises (C_{sales}) need to constantly grasp the market demand and market changes and adjust their marketing strategies.

ii) Differential digital input coefficient affects the income distribution of quality governance.

Based on the cooperative game theory, considering the quality and safety governance mechanism of agricultural products from the perspective of digital supply chain, and aiming at the quality and safety governance behaviours of production-processing integrated enterprises, logistics enterprises and sales enterprises in agricultural product supply chain, the feature function of interval cooperative game is represented by matrix using the calculation method of matrix semi-tensor product. The Shapley value income model of the main range of the agricultural product supply chain was constructed to analyse the income distribution scheme of the quality and safety governance of each participant from the perspective of the digital supply chain. It is found that under different digital input coefficients, the benefits of each supply chain main body participating in agricultural product quality and safety governance are different, and the proportion of the whole is also different. When $\lambda = 0.8$, the revenue interval divided by the three subjects changes most obviously. When the value of λ is closer to 0, the revenue distribution of the three subjects is closer to the average distribution. Therefore, the multiple subjects should fully consider the degree of digital technology investment, which affects the benefit distribution, optimise the benefit distribution plan, so that the income distributed by each subject is more fair and reasonable, and achieve a virtuous cycle of agricultural product quality and safety management and benefit distribution.

iii) The matrix half-tensor product method is used to better measure the risk of each agent.

The matrix semi-tensor product can provide a clear and simple method for calculating the relationship between finite sets. For cooperative games, the matrix semi-tensor product method can transform their eigenfunctions into algebraic form and compute the Shapley values by matrix operations. Compared with previous methods, this matrix operation in algebraic form greatly reduces the complexity of solving the Shapley value. When $\lambda = 1$ and $\lambda = 0$, the interval Shapley value with discount factor degenerates into two extreme cases of avoiding the interval Shapley value of equal distribution and equal distribution of the total cooperative alliance revenue, respectively. When all uncertainties in the supply chain alliance are accurately known and the supply chain alliance revenue is deterministic, the interval discount Shapley value degenerates to the classical discount Shapley value. The Shapley value algorithm has been widely used in the apportionment of cooperative revenue. However, there are two problems with the method in practical application: First, in the process of distributing the benefits of the coalition, it is necessary to determine the benefits of each subset when it forms a coalition. Second, Shapley's algorithm takes into account the importance of each participant to the total benefits of the coalition and avoids an equal distribution of the benefits, but ignores the fact that each participant 's position in the coalition as well as the risks to be borne are different.

iv) Interval discount Shapley value is better for simulating the actual income distribution scheme.

So the Shapley value algorithm does not consider the full range. Artificial intelligence, big data, blockchain and other digital intelligence technologies are gradually applied to the development of agricultural quality and safety governance process, so that the real application of the fussy alliance value of the cooperation game problem is endless, interval discount Shapley value can pay more attention to the actual supply chain of each node of the enterprise's behaviour, such as agricultural quality and safety of agricultural products, such as technological inputs, agricultural products, quality of the competitive advantage of agricultural products, and other difficult to measure the value of a specific value. The Shapley value makes up for the fact that the Shapley value ignores the behaviour of each node. The Shapley value compensates for the fact that the Shapley value ignores uncertain factors such as the size of the investment of each participant in agricultural quality and safety governance in the alliance, and the degree of importance attached to the cooperation. Using the interval value to predict the contribution of the node main enterprise to the governance benefit of agricultural product quality and safety helps promote the formation of the supply chain ecosystem. In addition, the discount factor, which determines the benefit distribution of any sub-coalition in the cooperative game, makes the interval discount Shapley value closer to re-

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ality. In the actual application, the coalition of the agricultural supply chain can choose the appropriate value and the corresponding benefit distribution scheme according to their respective resource inputs and quality and safety management effects in the quality and safety management of agricultural products.

Importance and limitations of the study

Through theoretical analysis and modelling, the article proposes a more reasonable and feasible benefit distribution scheme of agricultural supply chain quality governance, which is of practical significance for the operation practice of agricultural supply chain subjects. Reasonable distribution of the benefits of agricultural product quality governance can motivate each participating body of the agricultural supply chain to jointly carry out quality governance. Through the economic returns, they are prompted to be more actively involved in the quality management of agricultural products. At the same time, the reasonable distribution of benefits can promote quality governance information sharing and cooperation among the participating subjects, help to strengthen the coordination and communication between the various links of the supply chain, and improve the effectiveness and efficiency of agricultural quality governance. It helps to enhance the competitiveness and sustainable development of the whole industry. In addition, after the quality of agricultural products is effectively regulated and improved, it enhances consumers' trust and satisfaction with agricultural products, and positive feedback promotes the active participation of supply chain actors. However, there are still some shortcomings in the research. On the one hand, the application of digital technologies such as big data, blockchain, and cloud computing in the agricultural supply chain still has certain deficiencies and barriers, and the fairness of the distribution of benefits for supply chain members is not guaranteed to a high degree. On the other hand, the article selects the enterprises that have applied digital technology as the research object for example research, and the model for the transformation enterprises that have not yet carried out digital transformation or are trying to apply digital technology needs to be further verified, so as to make the conclusion of the research more rigorous and more universal.

CONCLUSION

The article uses matrix semi-tensor product to transform the interval cooperative game with discount factor into matrix form, and through constructing the Shapley value matrix of the interval cooperative game, it calculates the distribution of benefits among the three supply chain participants, namely, production, processing and sales enterprises, logistics enterprises and sales enterprises, in the process of agricultural product quality management under the perspective of digital supply chain. The results show that the Shapley model of the interval cooperative game combined with the semi-tensor product of the matrix makes the weights of the influencing elements of the agricultural supply chain quality management more scientific and effective through certain constraints, and the calculation results are more in line with the actual state of the cooperative game. In addition, by improving the effect of digital quality management of agricultural products in the supply chain as a whole, promoting the integration of scientific and technological innovation with the agricultural industry, optimising and improving the operating environment of agricultural enterprises and the awareness of quality management of agricultural products, the benefit of the quality management cooperation of each supply chain subject is greater than that of the individual subjects in the individual quality management.

Based on the research results of the article, the following countermeasures and suggestions are proposed for the subjects involved in the distribution of benefits of agricultural product quality and safety governance under the perspective of the digital supply chain as well as the relevant government departments, so as to optimise the distribution of benefits and make all subjects get fair and reasonable benefits. In this way, we can promote the development of agriculture to high quality, improve the quality of agricultural products and economic returns.

i) Integration of digital technology to promote the integration of the agricultural industry to achieve profitability on multiple fronts.

The development of agricultural science and technology can improve the efficiency of agricultural production, reduce production costs, and thus promote the upgrading of the integration of the agricultural industry. For example, the integration of agriculture with the Internet, finance, logistics and other industries can realise the provision of e-commerce sales of agricultural products, financial support, cold chain logistics and other services, further enhancing the added value of the agricultural industry. Collaboration and cooperation between different industries can promote the sharing and optimisation of resources and improve

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production efficiency and quality. However, collaboration and cooperation are not easy to realise due to conflicting interests and competition among industries. Therefore, there is a need to strengthen communication and consultation and establish a good cooperation mechanism. The government can introduce relevant policies in the integration of agricultural industries, providing financial support, tax incentives, land policies and other support to provide a favourable policy environment for the integration of agricultural industries. The formulation and implementation of policies need to take into account the actual situation of different regions and industries, as well as the interests of various parties. At the same time, the implementation of policies needs to be strengthened in terms of supervision and evaluation to ensure the effectiveness and fairness of the policies.

ii) Building a science and technology platform for intelligent data resource integration.

Integrate and share various agricultural data with farmers, experts and policymakers through an agricultural data cloud platform. Establish a data collection and management system for agricultural product quality information to collect, record and manage data related to agricultural product quality through scientific methods and tools. Utilise IoT technology to connect data from farmland, warehousing, logistics and other links in real-time to form an intelligent data chain. Through big data analysis, the correlations and patterns in the data are mined to improve the prediction and control of agricultural product quality. A data-sharing mechanism is established in the technology platform to allow different stakeholders, including farmers, enterprises, governments and consumers, to share data on agricultural product quality. In this way, information transparency can be increased, information asymmetry can be reduced, and the participation and cooperation efficiency of all parties can be improved.

iii) Clarify the main bodies responsible for quality and safety governance and the differentiated interests among multiple main bodies.

Clarify the legal responsibilities and obligations of the main parties responsible for quality and safety governance. Through legal constraints, promote all parties to take responsibility and fulfil their obligations in the governance of agricultural product quality and safety. Establish a sound accountability mechanism to pursue responsibility for responsible subjects involved in agricultural product quality issues, including farmers, producers, processing enterprises, distribution enterprises, etc., to ensure that they assume the corresponding quality and safety governance responsibilities. And through incentive mechanisms to reward those producers, enterprises and operators who proactively improve the quality of agricultural products. For example, preferential policies such as quality certification, quality labelling, tax breaks and exemptions, and financial support are given to encourage them to continue to maintain and improve their quality level. In response to the differentiated demands of different interest groups, establish a multi-participation mechanism, including the government, enterprises, farmers, consumers and non-governmental organisations, to resolve conflicts of interest and safeguard the balance of interests of all parties through communication, consultation and cooperation. Promote transparency and openness in quality and safety governance. Information on the quality of agricultural products will be publicised to the public, so that consumers can understand the quality of products and enterprises and individuals will be prompted to strengthen quality management.

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REFERENCES

Carmela A.M., Federica B., Francesco B., Marianthi K. (2021): Digitalisation within food supply chains to prevent food waste. Drivers, barriers and collaboration practices. Industrial Marketing Management, 93: 208–220.

Chen Y., Pei W., Ma T., Xiao H. (2023): Asymmetric nash bargaining model for peer-to-peer energy transactions combined with shared energy storage. Energy, 278: 127980.

Cheng D. (2001): Semi-tensor product of matrices and its application to morgen's problem. Science in China Series: Information Sciences, 44: 195–212.

Criss S., Horhota M., Wiles K., Norton J., Hilaire K.J.S., Short M.A., Blomquist K.K. (2020): Food cultures and aging: A qualitative study of grandparents' food perceptions and influence of food choice on younger generations. Public Health Nutrition, 23: 221–230.

Dawkins M.S. (2016): Animal welfare and efficient farming: Is conflict inevitable? Animal Production Science, 57: 201–208.

Demestichas K., Peppes N., Alexakis T., Adamopoulou E. (2020): Blockchain in agriculture traceability systems: A review. Applied Sciences, 10: 4113.

Gan M., Yang S., Li D., Wang M., Chen S., Xie R., Liu J. (2018): A novel intensive distribution logistics network design and

https://doi.org/10.17221/311/2023-AGRICECON

profit allocation problem considering sharing economy. Complexity, 2018: 4678358.

Gao Y., Leng Y., Shan B. (2022): Control supply chain risks in digital transformation: A new way to improve supply chain resilience. Journal of Organizational and End User Computing (JOEUC), 34: 1–18.

Guo P., Wang Y., Li H. (2013): Algebraic formulation and strategy optimisation for a class of evolutionary networked games via semi-tensor product method. Automatica, 49: 3384–3389.

Hamidoğlu A. (2024): A game-theoretical approach on the construction of a novel agri-food supply chain model supported by the government. Expert Systems With Applications, 237: 121353.

Hamidoğlu A., Gül Ö.M., Kadry S.N. (2024): A game-theoretical approach for the adoption of government-supported blockchain application in the iot-enabled agricultural supply chain. Internet of Things, 26: 101163.

Hamidoğlu A., Weber G.W. (2024): A novel nash-based low-carbon implementation in agricultural supply chain management. Journal of Cleaner Production, 449: 141846.

Hrustek L. (2020): Sustainability driven by agriculture through digital transformation. Sustainability, 12: 8596.

Lim M.K., Li Y., Wang C., Tseng M.L. (2021): A literature review of blockchain technology applications in supply chains: A comprehensive analysis of themes, methodologies and industries. Computers & Industrial Engineering, 154: 107133.

Meng F., Li Z., Dong Q., Fu L., Zhang Y. (2023): Profit allocation on a four-echelon supply chain in perspective of cooperative games on augmenting systems. Expert Systems With Applications, 219: 119639.

Mukherjee A.A., Singh R.K., Mishra R., Bag S. (2022): Application of blockchain technology for sustainability development in agricultural supply chain: Justification framework. Operations Management Research, 15: 1–16.

Qin Y., Xiang L. (2021): Quality improvement of agricultural products supply chain under social preference and CRS by big data analysis. Journal of Global Information Management (JGIM), 30: 1–26.

Sha J., Zheng S. (2021): Revenue distribution of hybrid channel supply chain based on modified shapley value with cost. Discrete Dynamics in Nature and Society, 2021: 4405185.

Shen Z., Wang S., Boussemart J.P., Hao Y. (2022): Digital transition and green growth in chinese agriculture. Technological Forecasting and Social Change, 181: 121742.

Teng Y., Pang B., Zhang M., Guo X. (2022): Driving mechanism of farmers' green production behavior under normalisation of covid-19 prevention and control: A case study in china. Frontiers in Public Health, 10: 826846.

Trivelli L., Apicella A., Chiarello F., Rana R., Fantoni G., Tarabella A. (2019): From precision agriculture to industry 4.0: Unveiling technological connections in the agrifood sector. British Food Journal, 121: 1730–1743.

Valecce G., Strazzella S., Radesca A., Grieco L.A. (2019): Solarfertigation: Internet of things architecture for smart agriculture. In: Proceedings of the 2019 IEEE International Conference on Communications Workshops (ICC Workshops): 1–6.

Wan Z. (2022): The application of big data in the legal improvement of agricultural product quality and safety governance. Acta Agriculture Scandinavica, Section B – Soil & Plant Science, 72: 200–213.

Wang B. (2015): The study of enterprise technical alliance comprehensive profit allocation based on orthogonal projection. In: Proceedings of the 2015 Information Technology and Mechatronics Engineering Conference: 33–36.

Wang C., Jiang P. (2020): Farmers' willingness to participate in agricultural product safety cogovernance and self-governance in Jiangsu, China: A gender perspective. Journal of Food Protection, 83: 736–744.

Wang C., Liu W. (2021): Farmers' attitudes vs. government supervision: Which one has a more significant impact on farmers' pesticide use in China? International Journal of Agricultural Sustainability, 19: 213–226.

Wang C., Zhou Z., Yu X., Chen J., Li P., Wang Z. (2023): Research on profit allocation of agricultural products co-delivery based on modified interval shapley value. Sustainability, 15: 3303.

Wang L., Qi C., Jiang P., Xiang S. (2022): The impact of blockchain application on the qualification rate and circulation efficiency of agricultural products: A simulation analysis with agent-based modelling. International Journal of Environmental Research and Public Health, 19: 7686.

Wang Y., Cheng D. (2017): Stability and stabilisation of a class of finite evolutionary games. Journal of the Franklin Institute, 354: 1603–1617.

Wang Y., Cheng D., Liu X. (2019): Matrix expression of shapley values and its application to distributed resource allocation. Science China Information Sciences, 62: 1–11.

Xie L., Luo B., Zhong W. (2021): How are smallholder farmers involved in digital agriculture in developing countries: A case study from china. Land, 10: 245.

Yin W., Ran W. (2022): Supply chain diversification, digital transformation, and supply chain resilience: Configuration analysis based on fsQCA. Sustainability, 14: 7690.

Yuan Y., Tan H., Liu L. (2023): The effects of digital transformation on supply chain resilience: A moderated and mediated model. Journal of Enterprise Information Management, 37: 488–510.

https://doi.org/10.17221/311/2023-AGRICECON

Zhao G., Li H., Duan P., Alsaadi F.E. (2020): Survey on applications of semi-tensor product method in networked evolutionary games. Journal of Applied Analysis & Computation, 10: 32–54.

Zhao L., Wang C., Gu H., Yue C. (2018): Market incentive, government regulation and the behavior of pesticide application of vegetable farmers in china. Food Control, 85: 308–317.

Zhao L., Xue Y., Sun H., Du Y., Chang X., Su J., Li Z. (2023): Benefit allocation for combined heat and power dispatch considering mutual trust. Applied Energy, 345: 121279.

Zhou J., Jin Y., Liang Q. (2022): Effects of regulatory policy mixes on traceability adoption in wholesale markets: Food safety inspection and information disclosure. Food Policy, 107: 102218.

Zhou J., Yang Z., Li K., Yu X. (2019): Direct intervention or indirect support? The effects of cooperative control measures on farmers' implementation of quality and safety standards. Food Policy, 86: 101728.

Zhu S., Feng J.E., Sun L. (2022): Matrix expression of owen values. Asian Journal of Control, 24: 3408–3417.

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