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Selection of livestreaming mode: Impacts of blockchain technology

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A B S T R A C T

On the production side, blockchain is being widely applied to agricultural product supply chains (APSCs), which can effectively improve circulation efficiency and reduce transportation losses. On the sales side, many companies are utilizing key opinion leaders (KOLs) to promote and sell agricultural products. The combination of the two enhances the farm-to-fork transparency of agricultural products and stimulates consumer purchases. Based on these, we construct four theoretical models to study blockchain investment and livestreaming mode strategies in the APSC. The results show that investing in blockchain always stimulates consumer purchases of agricultural products, while KOL livestreaming increases consumer purchases only when the increase-traffic power is greater than a certain threshold. There is a win-win situation where the fresh product supplier (FPS) and the e-retailer can benefit from investing in blockchain and introducing KOL livestreaming, respectively. Investing in blockchain is always beneficial for the KOL, and there is free-riding behavior in the APSC. Interestingly, the enhanced increase-traffic power within a certain interval may become a negative driving force, seriously harming the FPS. In addition, we find that investing in blockchain and introducing KOL livestreaming does not always benefit consumer surplus and social welfare, which depend on the KOL's increase-traffic power, commission rate, and unit cost.

1. Introduction

During the COVID-19 epidemic, the supply chain of imported fresh products became one of the channels for spreading COVID-19 (Liu et al., 2022b). Many countries imposed strict commodity movement restrictions on roads and ports to prevent the spread of COVID-19 (Tortajada and Lim, 2021). This has led to a significant increase in consumer online demand for fresh products and further expansion of the fresh product e-commerce market. According to the data, the e-commerce market size of China's fresh products is expected to reach 419.83 billion yuan in 2023 (Iimedia, 2022). The rapid development of e-commerce and logistics has made it possible for people to shop beyond their region, and even fresh products can come from another part of the world. For example, cherries from Chile and avocados from Mexico are very popular with the Chinese. However, fresh products have a short expiration date and are discarded due to deterioration in the transportation process due to factors such as improper preservation, information asymmetry, and unexpected events, resulting in quantity losses. The loss rates of grain, fruits, and vegetables after harvest in China are 7%~11%, 15%~20%, and 20%~25%, respectively, causing considerable waste and losses (Zhao and Cheng, 2022). The vulnerability of fresh products in transportation increases the difficulty of management for APSCs. Therefore, APSCs need information technology to empower them, and the information management of modern agricultural products facilitates the tracking and control of the whole process of agricultural products from production to sale (Cheng and Pan, 2017). Countries around the world are looking for a new digital technology to accelerate the circulation of fresh products to optimize their supply chains (Liu et al., 2022b). Some studies have found multiple coupling between the technical features of blockchain and the circulation of agricultural products, which can solve the abovementioned problems in the circulation of agricultural products (Ahmed and Broek, 2017; Fu et al., 2020; Nayal et al., 2021). The initial application of blockchain technology as a cryptocurrency to enable the transfer of value among entities is known as blockchain 1.0. Nowadays, blockchain as a decentralized distributed ledger is widely used in various industries

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such as finance, logistics, food, carbon reduction, luxury goods, etc (Helo and Hao, 2019; Salah et al., 2019; Tönnissen and Teuteberg, 2020; Xu and Choi, 2021). Blockchains can group records into blocks that are made tamper resistant by adding a cryptographic signature of the block data. Applications for its related uses are commonly referred to as Blockchain 3.0 applications (Di Francesco Maesa and Mori, 2020). Blockchain technology is different from traditional traceability systems such as RFID and QR codes. It has three major characteristics: decentralization, difficulty in tampering, and transparent transactions without the need for intermediaries (Gad et al., 2022; Xu et al., 2023a). The application of blockchain in APSCs can enhance the transparency, traceability, and efficiency of the supply chain and improve trust and collaboration among stakeholders (Dutta et al., 2020). Despite the many benefits of implementing blockchain in the APSC, investing in blockchain by enterprises requires corresponding costs. Enterprises investing in blockchain need to balance the benefits and costs it brings. Therefore, how to open an outlet for high-quality fresh products and increase income has become an urgent problem that enterprises need to solve. Some scholars pointed out that livestreaming e-commerce is an effective way to develop modern agriculture and increase income (Parker et al., 2016; Song and Yang Morgan, 2019). According to the data, by December 2022, China's livestreaming e-commerce users reached 515 million. During the "Double Eleven" shopping carnival on Tmall, more than 600 livestreaming rooms had a turnover of more than 10 million yuan (CNNIC, 2023). Livestreaming e-commerce is replacing traditional e-commerce as the main driver of revenue for e-retailers. And the emergence of livestreaming e-commerce has led to changes in traditional e-commerce sales channels. In China, the user scale of traditional e-commerce platforms, mainly Tmall and JD.com, was growing slowly, and the usage rate was even declining (CNNIC, 2023). Emerging livestreaming and short video platforms such as Tik Tok and Kuaishou have quickly launched live e-commerce services to gain a share of the fierce market. This has also forced traditional e-commerce companies to accelerate their transformation and join the livestreaming army (Guo et al., 2021).

Since everyone at home can become a streamer to promote their products, this has led to an explosion of livestreaming e-commerce in China during the COVID-19 pandemic (Jiang et al., 2022). The current main body of marketing through livestreaming consists mainly of e-retailers and KOLs. The e-retailer's audience for livestreaming is the fans of their store, where they can demonstrate the features and uses of products and interact instantly with consumers through the danmaku (Pan et al., 2022). This has changed the traditional way of communication between sellers and consumers. However, limited by their own influence, e-retailers livestreaming is usually unable to find more potential consumers and has a weak ability to expand the market. Therefore, many e-retailers will choose to hire professional KOLs to promote and sell their products (Niu et al., 2023). KOLs are usually online celebrities with a large number of followers and can usually get lower prices from suppliers due to their celebrity effect (Liu et al., 2022a). And they usually have more professional marketing skills, for example, KOLs can reduce the psychological distance with consumers and create an environment of trust through talk shows, singing, and dancing (Chen and Lin, 2018). Consumers are immersed in the shopping environment under the guidance of the KOL, which quickly stimulates their purchase intention (Zhang et al., 2023a). However, hiring a professional KOL to promote fresh products is not cheap. The e-retailer has to pay a signing fee in addition to a commission to the KOL (Xiong et al., 2023). So, under what circumstances will the e-retailer hire a KOL for livestreaming, and what impact will it have on other members of the APSC? To answer the above questions, we construct a dual-channel APSC consisting of a direct channel controlled by the FPS and an e-retailing channel operated by the e-retailer. We assume that blockchain technology can speed up the circulation of fresh products and reduce losses. The FPS can consider whether to invest in blockchain technology, but it has to pay the corresponding costs. To coordinate the interests among supply chain members, the e-retailer using blockchain technology has to pay a unit verification fee to the FPS. The e-retailer can choose to go livestreaming by itself or hire a KOL to do so. We assume that the KOL effect is not always positive, which means that the introduction of KOL livestreaming may not always increase potential demand. The e-retailer needs to use the KOL by signing a revenue-sharing contract and paying him a signing fee. Therefore, there are multiple operational strategies in the APSC, whether the FPS invests in blockchain or not, and the livestreaming modes of the e-retailer are worth studying.

In these contexts, we seek to address the following issues: (1) How do different strategic choices by the FPS and the e-retailer affect pricing and demand for fresh products? (2) What are the prerequisites for the FPS to invest in blockchain technology, and what impact can blockchain technology have on APSC members? (3) What is the optimal livestreaming mode for the e-retailer, and can investing in blockchain and introducing KOL livestreaming enhance consumer surplus and social welfare?
The main contributions of this paper can be divided into theoretical contributions and managerial contributions. On the theoretical side, since the traditional e-commerce channel cannot meet the diverse purchasing needs of consumers, we construct a dual-channel APSC model with a direct channel controlled by the FPS and an e-retailing channel operated by an e-retailer to make the model more realistic and provide theoretical support for the operation strategies of APSC members. Secondly, we apply both blockchain and livestreaming to fresh products from production to sales and propose operational strategy choices that are beneficial to the APSC system and consumers, enriching the application of blockchain technology and live streaming in the APSC. On the managerial side, we propose conditions for the FPS to invest in blockchain and the e-retailer to introduce KOL livestreaming, which are reference values for the operations management of companies. Moreover, the results indicate that there is a win-win or even triple win situation that allows APSC members to profit from investing in blockchain and introducing KOL livestreaming, which has strong practical significance in improving the overall APSC performance.

The rest of this paper is organized as follows. In Section 2, we review the relevant literature. The problem assumptions and model descriptions of this paper are shown in Section 3. In Section 4, we derive the equilibrium results of the four models in the APSC. Section 5 presents the main analysis of this paper. In Section 6, we extend our models. Section 7 presents the conclusions of this paper and some managerial implications.

2. Literature Review

There are two literature streams reviewed in this section: applications of blockchain in APSCs and applications of livestreaming e-commerce.

2.1. Applications of blockchain in APSCs

With the continuous rise of Internet of Things technology and the digital economy, blockchain technology has been widely used in various industries. Blockchain 3.0 especially plays a key role in improving APSC management (Bigliardi and Galanakis, 2020). Traceability has become a prerequisite for the success of APSCs (Ye et al., 2022). Many studies have shown that implementing traceability in APSCs through blockchain can accelerate the circulation rate of agricultural products, reduce loss, prevent fraud, and strengthen food safety supervision (Ahmed and Broek, 2017; Feng et al., 2020; Liu et al., 2022b; Salah et al., 2019; Wu et al., 2023; Zhao et al., 2019). At the technical level, scholars have conducted many theories and case studies on the traceability of agricultural products. For example, Salah et al. (2019) proposed a blockchain-based soybean supply chain solution to improve the transparency and traceability of the APSC. Caro et al. (2018) proposed an IoT device capable of seamlessly generating consumption data from farm to fork and using two different blockchains for food traceability. Tian (2016) compared the advantages and disadvantages of blockchain technology and RFID in the application of APSCs. Nayal et al. (2021) used an empirical research method to integrate the influencing factors on the application of blockchain technology and proposed positive influencing factors that are beneficial for the APSC. Vangipuram et al. (2022) used private blockchain to enable consumer visualization of agricultural products, thereby increasing their trust in agricultural products.
From the operations management perspective, many scholars have specifically studied the stages, methods, benefits, obstacles, challenges, and scenarios of blockchain applications in supply chains. Wu et al. (2023) found that the implementation of blockchain under a two-part tariff contract can maximize the profits of the APSC. Ye et al. (2022) found that early adopters always gain more benefits from using blockchain than followers, but it does not always benefit consumer surplus and social welfare. However, Liu et al. (2022b) found that the adoption of blockchain can reduce consumers’ concerns about food safety and increase their surplus. Niu et al. (2021b) investigated the strategic options for cross-border e-commerce platforms to use blockchain to improve product quality. Xu et al. (2023b) studied the interaction between agricultural product enterprises adopting blockchain technology on e-commerce platforms and channel encroachment. Liu et al. (2021) found that competition between traditional and online channels would motivate companies to invest more in blockchain technology, thereby helping to improve the overall profits of the supply chain. Behnke and Janssen (2020) identified key boundary conditions for the successful use of blockchain in the APSC to ensure information sharing and traceability. Despite all the benefits of implementing blockchain in the APSC, there will inevitably be some obstacles and challenges. Kshetri (2019) used classic cases to analyze some of the challenges of blockchain implementation in APSCs, such as high costs, labor and skill shortages, and limited availability of blockchain talent. Peng et al. (2023) used bibliometric analysis methods to clarify the current situation, challenges, and development trends of implementing blockchain in APSCs. Zhao et al. (2019) concluded from a literature network analysis that blockchain combined with ICT and IoT can be used to improve APSCs but will face six challenges, including storage capacity, privacy breaches, high costs, regulation, latency, and lack of skills.

In summary, the research on the operation management of blockchain in APCSs is still in its infancy. The change from traditional shopping to online shopping makes blockchain technology more convenient for recording and monitoring various nodes of APSCs. We consider using blockchain to reduce the quantity loss of fresh products and propose thresholds for the FPS to invest in blockchain, as well as a win-win situation for APSC members. And we find that applying blockchain technology in the APSC can stimulate consumer demand for fresh products, aiming to make better decisions for companies to invest in blockchain.

2.2. Applications of livestreaming e-commerce

With the rise of network communication technology and e-commerce, live shopping has become a normalized shopping method for people. Livestreaming e-commerce platforms like Amazon and Tik Tok have seen rapid user growth globally, accompanied by the emergence of many KOLs in livestreaming (Ji et al., 2023). Livestreaming e-commerce is different from traditional e-commerce platforms, which can only display products through text and pictures. KOL can interact and display products to the viewers in real-time, and enhance consumers' awareness of the products through explanations and trials (Wongkitrungrueng and Assarut, 2020). Scholars' research on livestreaming e-commerce mainly focuses on the consumer perspective (Ji et al., 2023). Hedonism and utilitarianism are the main motivations for consumers to participate in livestreaming (Cai et al., 2018; Wongkitrungrueng and Assarut, 2020). Many factors, such as background music in the livestreaming room (Zhang et al., 2023a), product matching (Park and Lin, 2020), visual complexity in the background of the livestreaming room (Tong et al., 2022), and interaction between the audience and danmaku (Zhou et al., 2019), can affect consumers' purchase intention. From the perspective of livestreaming platforms, Sun et al. (2019) investigated the impact of the IT affordance of livestreaming platforms on consumers' willingness to pay. Peng et al. (2023) found that the adoption of randomized rewards by livestreaming platforms can enhance farmers' income from live sales. Many scholars also studied the impact of streamers' abilities on promoting sales. Meng et al. (2021) found that online celebrity livestreaming can enhance consumers' purchase intention by stimulating their emotions. Liao et al. (2023) found that streamers' cognitive and social skills can boost sales, while emotional skills have a negative impact. Niu et al. (2023) pointed out that it is not necessarily beneficial for brand owners to use KOL for product promotion and sales, and it may even seriously damage their interests, which depends on the commission rate, retention rate, and network effect.

Most of the above studies have used empirical analysis methods to study the impact of livestreaming on purchase intention. It has been confirmed that livestreaming e-commerce can increase consumers' purchase intention by reducing their psychological distance and uncertainty (Zhang et al., 2020). However, the study of the impact of livestreaming on supply chain decision making from an operations management perspective using game theory approaches is still in its infancy (Ji et al., 2023). Zhang et al. (2022b) studied the operational strategies of introducing livestreaming services in the supply chain of e-commerce platforms and found that the introduction of livestreaming services is always beneficial to e-commerce platforms and service providers. Gong et al. (2022) found that livestreaming has both advertising and cannibalization effects, and the strategy for introducing livestreaming depends on the standardization and quality of products. Zhang and Tang (2023) studied the strategic choice of whether a manufacturer should add a live channel to an e-commerce platform. Fan et al. (2022) studied the impact of livestreaming e-commerce and livestreaming spillover effects on pricing and streamer efforts. Zhang et al. (2022a) considered channel substitutability and tax differences and studied the operations strategies of the multinational corporation opening a live sales channel in its overseas online retail division and e-commerce platform. Most of the above literature has studied the introduction strategy of livestreaming services. The difference is that our model is a dual-channel APSC consisting of a direct channel and an e-retailing channel, while the e-retailer can choose to go livestreaming by itself or introduce KOL livestreaming.

In summary, the study of blockchain and livestreaming e-commerce for operational decision making in APSCs from an operations management perspective is still in its infancy, and most of the literature has only studied blockchain or livestreaming e-commerce alone. To our best knowledge, this study is the first to combine blockchain and livestreaming e-commerce using a game theory approach to study the impact of both on the operational decisions of the APSC. We not only propose thresholds for the FPS to invest in blockchain and the e-retailer to introduce KOL livestreaming, but also explore operations strategies for a win-win situation for both, making it beneficial for all members of the APSC. In addition, to enrich related studies and verify the robustness of models, we extend the model to further discuss consumer surplus, social welfare, and KOL's social responsibility. We also analyze how the pricing and profit of the FPS change under consideration of the traffic spillover effect.

3. Problem Description and Assumptions

In this paper, we construct a dual-channel APSC consisting of a FPS, an e-retailer, and a KOL. The FPS first decides whether to invest in blockchain technology. It can sell fresh products to the e-retailer at the wholesale price w and directly sell them to consumers through the direct channel at the direct sales price p_d. The e-retailer decides on livestreaming modes (either by itself or by introducing KOL livestreaming) and sells fresh products to consumers through the e-retailing channel at the retail price p_r. If the e-retailer goes livestreaming by itself, then its livestreaming effort is e_e. If the e-retailer introduces KOL livestreaming, then the KOL decides on his livestreaming efforts e_k and charges commissions and a signing fee to the e-retailer. We assume that the potential demand in the e-retailing channel is a, the potential demand in the direct sales channel is $1-a$, and the potential demand in the e-retailing channel after the introduction of the KOL is γa. Nowadays, more and more celebrities choose to live with goods, and not every KOL can increase the number of live viewers. For example, an e-commerce company in Nanning, China spent 200,000 yuan to hire a celebrity to live with goods, and only 278 yuan was sold in three months (BJNEWS, 2023). Niu et al. (2023) and Ji et al. (2023) also discussed the negative impacts of KOL livestreaming and given this we let $\gamma > 0$. Therefore, this paper can be divided into four models. For clarity, we use superscript NS (BS) to represent the e-retailer livestreaming model without (with) investment in blockchain and superscript NK (BK) to represent the KOL livestreaming model without (with) investment in blockchain.

Model NS (BS): The e-retailer does not introduce KOL, and the e-retailer decides on its livestreaming effort e_e. KOLs only market through livestreaming rooms during specific time periods, and the discounted prices of livestreaming products are usually only maintained for a short period of time; and consumers who watch livestreaming are greatly influenced by the KOLs themselves, they are not aware of the prices of other channels, by the KOL in the mouth of the so-called "lowest price" under the guidance of the order to buy (Lin et al., 2023). Therefore, referring to Zhang et al. (2022b) and Zhang et al. (2023b), the demand functions for the e-retailing channel and the direct channel in model NS (BS) are $D_r = a - \beta_r p_r + e_e$ and $D_d = 1 - a - \beta_d p_d$. Where β_r (β_d) represents the retail price (direct sales price) sensitivity coefficient of consumers. Since the price of fresh products is usually inelastic, to ensure that the equilibrium results of models are meaningful and realistic, we assume that $0.5 < \beta_r < 1$ and $0 < \beta_d < 1$.

Model NK (BK): The e-retailer introduces KOL livestreaming, and the KOL decides on his livestreaming effort e_k. KOLs are usually more professional than individual streamers, and they have large fan bases that can attract more consumers through marketing methods such as on-site trials, real-time interactions, and advertisements, which is referred to as the KOL effect (Niu et al., 2023). Therefore, in the model NK (BK), the demand functions for the e-retailing channel and the direct channel are $D_r = \gamma a - \beta_r p_r + e_k$ and $D_d = 1 - a - \beta_d p_d$.

The specific assumptions of this paper are as follows. Assumption 1: Fresh products are susceptible to quantity loss during transportation due to spoilage and improper preservation. Similar to Yan et al. (2020), we assume that the loss rate of fresh products is k, and the preservation rate is $1-k$. The number of fresh products that the FPS needs to deliver to ensure sufficient supply is $D/(1-k)$. Investment in blockchain can effectively accelerate the circulation rate of fresh products and reduce the loss, and its preservation rate grows to $1-k+ky$, where y is the level of blockchain technology. Obviously, the higher the level of blockchain technology, the lower the loss of fresh products will be, and $0 < y < 1$.

Assumption 2: According to Ji et al. (2022) and Liang and Xiao (2023), the fixed fee for the FPS investing in blockchain is F, such as building a blockchain information-sharing platform. The e-retailer needs to pay a unit verification fee f to the FPS to use blockchain technology.

Assumption 3: The e-retailer needs to pay both the commission and signing fee to introduce the KOL for livestreaming. The KOL signs a revenue-sharing contract with the e-retailer at a predetermined commission rate ρ (Niu et al., 2023). The signing fee paid by the e-retailer to KOL is $m\gamma a$, which indicates that the signing fee increases with the KOL's increase-traffic power, where m is the unit traffic cost.

Assumption 4: The unit cost of fresh products is c, $c > 0$. The livestreaming costs of the e-retailer and KOL are $\frac{1}{2}\eta_e e_e^2$ and $\frac{1}{2}\eta_k e_k^2$, respectively. We assume that the livestreaming cost coefficients of the e-retailer and KOL are $\eta_e = \eta_k = 1$, which does not affect the conclusions of this paper (Zhang et al., 2022b).

Notations and definitions of the models designed in this paper are shown in Table 1. Superscripts $i \in \{NS, BS, NK, BK\}$ represent models NS, BS, NK, and BK, respectively, and superscript * represents the optimal decision of different models. Subscripts $j \in \{s, e, k\}$ represent the FPS, the e-retailer, and the KOL, respectively, and subscripts $h \in \{d, r\}$ represent the direct channel and the e-retailing channel, respectively.

Table 1
Notations and definitions

Notations	Definitions
a	Potential market demand for the e-retailing channel
c	Unit cost of fresh products
k	Loss rate of fresh products in circulation
β_d / β_r	Direct sales price/retail price elasticity coefficient
y	Level of blockchain technology
f	Unit validation fee paid by the e-retailer to the FPS
F	A fixed fee for the FPS to invest in blockchain technology
γ	KOL's power of increasing traffic to livestreaming
m	Unit cost of livestreaming traffic paid by the e-retailer to the KOL
ρ	Revenue sharing proportion paid by the e-retailer to the KOL
λ	Degree of the traffic spillover effect
φ	Level of KOL's social responsibility
e_e / e_k	E-retailer's/KOL's livestreaming effort
w	Wholesale price
p_d / p_r	Unit Price for the direct channel/e-retailing channel
D_h^i	Demand for the channel h in model i
π_j^i	Profit of APSC member j in model i

4. Models

4.1. Model NS

In this model, the FPS doesn't invest in blockchain technology, and the e-retailer goes livestreaming by itself. They play a two-stage Stackelberg game: in the first stage, the FPS first decides the wholesale price w^{NS} and the direct sales price p_d^{NS};

in the second stage, the e-retailer then decides the retail price p_r^{NS} and the livestreaming effort e_e^{NS}. The profit-maximizing optimization models for the FPS and the e-retailer are as follows:

$$\max_{w^{NS}, p_d^{NS}} \pi_s^{NS} = [p_d^{NS} - c/(1-k)]D_d^{NS} + [w^{NS} - c/(1-k)]D_r^{NS}$$

$$\max_{p_r^{NS}, e_e^{NS}} \pi_e^{NS} = (p_r^{NS} - w^{NS})D_r^{NS} - \frac{1}{2}(e_e^{NS})^2$$

Solving by the backward induction, the optimal results for the model NS are obtained, as shown in Theorem 1.

Theorem 1. The optimal prices and livestreaming effort of the APSC in the model NS are given as follows:

$$w^{NS*} = \frac{a(1-k)+c\beta_r}{2\beta_r(1-k)} \qquad p_r^{NS*} = \frac{a(1-k)(3\beta_r-1)-c\beta_r(1-\beta_r)}{2\beta_r(1-k)(2\beta_r-1)}$$

$$p_d^{NS*} = \frac{(1-a)(1-k)+c\beta_d}{2\beta_d(1-k)} \qquad e_e^{NS*} = \frac{a(1-k)-c\beta_r}{2(1-k)(2\beta_r-1)}$$

Further, the optimal demands and profits in the model NS can be obtained as follows, respectively:

$$D_d^{NS*} = \frac{(1-k)(1-a)-c\beta_d}{2(1-k)} \qquad \pi_s^{NS*} = \frac{[(1-a)(1-k)-c\beta_d]^2}{4\beta_d(1-k)^2} + \frac{[a(1-k)-c\beta_r]^2}{4(1-k)^2(2\beta_r-1)}$$

$$D_r^{NS*} = \frac{\beta_r[a(1-k)-c\beta_r]}{2(1-k)(2\beta_r-1)} \qquad \pi_e^{NS*} = \frac{[a(1-k)-c\beta_r]}{8(1-k)^2(2\beta_r-1)}$$

4.2 Model BS

In this model, the FPS invests in blockchain technology in both channels, and it needs to pay the blockchain fixed fee F for this. The loss rate of fresh products in the e-retailing channel is reduced to $(1-y)k$, and the number of products actually transported by the FPS is reduced from $D_r/(1-k)$ to $D_r/(1-k+ky)$. The e-retailer still goes livestreaming by itself, and the e-retailer needs to pay the unit verification fee f to the FPS for using blockchain. In this model, the FPS and the e-retailer still play the two-stage Stackelberg game with the same game order. The profit-maximizing optimization models for the FPS and the e-retailer are as follows:

$$\max_{w^{BS}, p_d^{BS}} \pi_s^{BS} = [p_d^{BS} - c/(1-k+ky)]D_d^{BS} + [w^{BS} + f - c/(1-k+ky)]D_r^{BS} - F$$

$$\max_{p_r^{BS}, e_e^{BS}} \pi_e^{BS} = (p_r^{BS} - w^{BS} - f)D_r^{BS} - \frac{1}{2}(e_e^{BS})^2$$

Solving by the backward induction, the optimal results for the model BS are obtained, as shown in Theorem 2.

Theorem 2. The optimal prices and livestreaming effort of the APSC in the model BS are given as follows:

$$w^{BS*} = \frac{a(1-k+ky)+c\beta_r}{2\beta_r(1-k+ky)} - f \qquad p_r^{BS*} = \frac{a(1-k+ky)(3\beta_r-1)-c\beta_r(1-\beta_r)}{2\beta_r(1-k+ky)(2\beta_r-1)}$$

$$p_d^{BS*} = \frac{(1-a)(1-k+ky)+c\beta_d}{2\beta_d(1-k+ky)} \qquad e_e^{BS*} = \frac{a(1-k+ky)-c\beta_r}{2(1-k+ky)(2\beta_r-1)}$$

Further, the optimal demands and profits in the model BS can be obtained as follows, respectively:

$$D_d^{BS*} = \frac{(1-k+ky)(1-a)-c\beta_d}{2(1-k+ky)} \qquad \pi_s^{BS*} = \frac{[(1-a)(1-k+ky)-c\beta_d]^2}{4\beta_d(1-k+ky)^2} + \frac{[a(1-k+ky)-c\beta_r]}{4(1-k+ky)^2(2\beta_r-1)} - F$$

$$D_r^{BS*} = \frac{\beta_r[a(1-k+ky)-c\beta_r]}{2(1-k+ky)(2\beta_r-1)} \qquad \pi_e^{BS*} = \frac{[a(1-k+ky)-c\beta_r]^2}{8(1-k+ky)^2(2\beta_r-1)}$$

From Theorem 2, it can be seen that the optimal prices of both channels make changes after investing in the blockchain, thus affecting the optimal demands and profits. Interestingly, the unit validation fee only affects the wholesale price

($\frac{\partial w^{BS*}}{\partial f} = -1 < 0$), and the blockchain fixed fee only affects the FPS's profit ($\frac{\partial \pi_s^{BS*}}{\partial F} = -1 < 0$). Therefore, $w^{BS*} + f$ can be considered the wholesale price for the e-retailer, which means that the FPS subsidizes the e-retailer in the form of a lower wholesale price.

4.3. Model NK

In this model, the FPS does not invest in blockchain technology, and the e-retailer introduces KOL livestreaming by paying him commissions and signing fees. They play a three-stage Stackelberg game: in the first stage, the FPS first decides the wholesale price w^{NK} and the direct sales price p_d^{NK}; in the second stage, the KOL then decides on his livestreaming effort e_k^{NK}; in the third stage, the e-retailer ultimately decides the retail price p_r^{NK}. The KOL usually has bigger bargaining power than the e-retailer, so he first determines his livestreaming efforts (Zhang & Tang, 2023). The profit-maximizing optimization models for the FPS, the e-retailer, and the KOL are as follows:

$$\max_{w^{NK}, p_d^{NK}} \pi_s^{NK} = [p_d^{NK} - c/(1-k)]D_d^{NK} + [w^{NK} - c/(1-k)]D_r^{NK}$$

$$\max_{p_r^{NK}} \pi_e^{NK} = [(1-\rho)p_r^{NK} - w^{NK}]D_r^{NK} - m\gamma a$$

$$\max_{e_k^{NK}} \pi_k^{NK} = m\gamma a + \rho p_r^{NK} D_r^{NK} - (\frac{1}{2}e_k^{NK})^2$$

Solving by the backward induction, the optimal results for the model NK are obtained, as shown in Theorem 3.

Theorem 3. The optimal prices and livestreaming effort of the APSC in the model NK are given as follows:

$$w^{NK*} = \frac{2a\gamma(1-k)(1-\rho) + c(2\beta_r - \rho)}{2(2\beta_r - \rho)(1-k)} \qquad p_r^{NK*} = \frac{6a\gamma(1-k)(1-\rho) - c(2\beta_r - \rho)}{4\beta_r(1-k)(1-\rho)(2\beta_r - \rho)}$$

$$p_d^{NK*} = \frac{(1-a)(1-k) + c\beta_d}{2\beta_d(1-k)} \qquad e_k^{NK*} = \frac{a\gamma\rho}{2\beta_r - \rho}$$

Further, the optimal demands and profits in the model NK can be obtained as follows, respectively:

$$D_d^{NK*} = \frac{(1-k)(1-a) - c\beta_d}{2(1-k)} \qquad \pi_s^{NK*} = \frac{[(1-a)(1-k) - c\beta_d]^2}{4\beta_d(1-k)^2} + \frac{\beta_r[2a\gamma(1-k)(1-\rho) - c(2\beta_r - \rho)]^2}{8(1-k)^2(1-\rho)(2\beta_r - \rho)^2}$$

$$D_r^{NK*} = \frac{\beta_r[2a\gamma(1-k)(1-\rho) - c(2\beta_r - \rho)]}{4(1-k)(1-\rho)(2\beta_r - \rho)} \qquad \pi_e^{NK*} = \frac{\beta_r[2a\gamma(1-k)(1-\rho) - c(2\beta_r - \rho)]^2}{16(1-k)^2(1-\rho)(2\beta_r - \rho)^2} - m\gamma a$$

$$\pi_k^{NK*} = m\gamma a - \frac{(a\gamma\rho)^2}{2(2\beta_r - \rho)^2} + \frac{\beta_r\rho[2a\gamma(1-k)(1-\rho) - c(2\beta_r - \rho)][6a\gamma(1-k)(1-\rho) + c(2\beta_r - \rho)]}{16(1-k)^2(1-\rho)^2(2\beta_r - \rho)^2}$$

From Theorem 3, it can be intuitively observed that the price and demand of the direct channel in models NS and NK are equal and are not affected by the KOL effect ($p_d^{NS*} = p_d^{NK*}$, $D_d^{NS*} = D_d^{NK*}$). This is since the e-retailer or KOL only broadcasts live on the e-retailing channel, and streamers usually only broadcast live for a certain period of time, which makes the information have a certain timeliness and closeness so that it does not affect the direct channel. For example, Li Jiaqi will notify the followers in advance of the livestreaming time period, and the link to the product during the livestreaming is time limited. Once the purchase limit is reached, the streamer will remove the link to the product.

4.4. Model BK

In this model, the FPS invests in blockchain technology, and the e-retailer introduces KOL livestreaming. The FPS, the KOL, and the e-retailer still play the three-stage Stackelberg game with the same game order. The profit-maximizing optimization models for the FPS, the e-retailer, and the KOL are as follows:

$$\max_{w^{BK}, p_d^{BK}} \pi_s^{BK} = [p_d^{BK} - c/(1-k+ky)]D_d^{BK} + [w^{BK} + f - c/(1-k+ky)]D_r^{BK} - F$$

$$\max_{p_r^{BK}} \pi_e^{BK} = [(1-\rho)p_r^{BK} - w^{BK} - f]D_r^{BK} - m\gamma a$$

$$\max_{e_k^{BK}} \pi_k^{BK} = m\gamma a + \rho p_r^{BK} D_r^{BK} - (\frac{1}{2}e_k^{BK})^2$$

Solving by the backward induction, the optimal results for the model BK are obtained, as shown in Theorem 4.

Theorem 4. The optimal prices and livestreaming effort of the APSC in the model BK are given as follows:

$$w^{BK*} = \frac{2a\gamma(1-k+ky)(1-\rho)+c(2\beta_r-\rho)}{2(2\beta_r-\rho)(1-k+ky)} - f \qquad p_r^{BK*} = \frac{6a\gamma(1-k+ky)(1-\rho)+c(2\beta_r-\rho)}{4\beta_r(1-k)(1-\rho)(2\beta_r-\rho)}$$

$$p_d^{BK*} = \frac{(1-a)(1-k+ky)+c\beta_d}{2\beta_d(1-k+ky)} \qquad e_k^{BK*} = \frac{a\gamma\rho}{2\beta_r-\rho}$$

Further, the optimal demands and profits in the model BK can be obtained as follows, respectively:

$$D_d^{BK*} = \frac{(1-k+ky)(1-a)-c\beta_d}{2(1-k+ky)} \qquad D_r^{BK*} = \frac{\beta_r[2a\gamma(1-k+ky)(1-\rho)-c(2\beta_r-\rho)]}{4(1-k+ky)(1-\rho)(2\beta_r-\rho)}$$

$$\pi_e^{BK*} = \frac{\beta_r[2a\gamma(1-k+ky)(1-\rho)-c(2\beta_r-\rho)]^2}{16(1-k)^2(1-\rho)(2\beta_r-\rho)^2} - m\gamma a$$

$$\pi_s^{BK*} = \frac{[(1-a)(1-k+ky)-c\beta_d]^2}{4\beta_d(1-k+ky)^2} + \frac{\beta_r[2a\gamma(1-k+ky)(1-\rho)-c(2\beta_r-\rho)]^2}{8(1-k+ky)^2(1-\rho)(2\beta_r-\rho)^2} - F$$

$$\pi_k^{BK*} = m\gamma a - \frac{(a\gamma\rho)^2}{2(2\beta_r-\rho)^2} + \frac{\beta_r\rho[2a\gamma(1-k+ky)(1-\rho)-c(2\beta_r-\rho)][6a\gamma(1-k+ky)(1-\rho)+c(2\beta_r-\rho)]}{16(1-k+ky)^2(1-\rho)^2(2\beta_r-\rho)^2}$$

From Theorem 4, it can be intuitively observed that the price and demand of the sales channel in models BS and BK are equal and are not affected by the KOL effect ($p_d^{BS*} = p_d^{BK*}$, $D_d^{BS*} = D_d^{BK*}$). This is similar to the finding of Theorem 3 and will not be elaborated on here. In addition, the KOL's livestreaming effort before and after investing in blockchain is unchanged ($e_k^{NK*} = e_k^{BK*}$), which indicates that investing in blockchain does not affect the KOL's livestreaming effort.

5. Analysis

In this section, we first analyze the impact of commission rate, KOL's increase-traffic power, and blockchain technology level on the optimal decision in the four models, as shown in Subsection 5.1. In Subsection 5.2, we compare the optimal prices and demands of the four models to obtain the optimal pricing and sales strategies for the APSC. Finally, we derive the optimal operations strategies for the APSC members in Subsection 5.3.

5.1 Impact analysis of APSC members' optimal decisions

By analyzing the effect of the commission rate ρ on the optimal decisions of APSC members, we obtain Proposition 1 as follows.

Proposition 1. *The change trends of the optimal decisions of APSC members with the commission rate* ρ *are:*

(1) $\frac{\partial w^{NK*}}{\partial\rho} = \frac{\partial w^{BK*}}{\partial\rho} < 0$; $\frac{\partial p_d^{NK*}}{\partial\rho} = \frac{\partial p_d^{BK*}}{\partial\rho} = 0$; $\frac{\partial p_r^{NK*}}{\partial\rho} > \frac{\partial p_r^{BK*}}{\partial\rho} > 0$; $\frac{\partial e_k^{NK*}}{\partial\rho} = \frac{\partial e_k^{BK*}}{\partial\rho} > 0$.

(2) If $\gamma > \gamma_1$, then $\frac{\partial D_r^{NK*}}{\partial\rho} > 0$, otherwise $\frac{\partial D_r^{NK*}}{\partial\rho} < 0$; if $\gamma > \gamma_2$, then $\frac{\partial D_r^{BK*}}{\partial\rho} > 0$, otherwise $\frac{\partial D_r^{BK*}}{\partial\rho} < 0$; $\frac{\partial D_d^{NK*}}{\partial\rho} = \frac{\partial D_d^{BK*}}{\partial\rho} = 0$.

(3) If $\gamma > \gamma_3$ and $2(1-\beta_r) < \rho < 1$ or if $\gamma_3 < \gamma < \gamma_4$ and $0 < \rho < 2(1-\beta_r)$, then $\frac{\partial \pi_s^{NK*}}{\partial\rho} < 0$ and $\frac{\partial \pi_e^{NK*}}{\partial\rho} < 0$; If $\gamma > \gamma_5$ and

$2(1-\beta_r)<\rho<1$ or if $\gamma_5<\gamma<\gamma_6$ and $0<\rho<2(1-\beta_r)$, then $\frac{\partial \pi_s^{BK*}}{\partial \rho}<0$ and $\frac{\partial \pi_e^{BK*}}{\partial \rho}<0$; if $1.2\beta_r<\rho<1$ or if $0<\rho<1.2\beta_r$ and $0<\gamma<\gamma_7$, then $\frac{\partial \pi_k^{NK*}}{\partial \rho}<0$.

Proposition 1 (1) indicates that a higher commission rate will increase the retail price and KOL's livestreaming effort but reduce the wholesale price. This is because the high commission rate increases the livestreaming costs of the e-retailer, and it has to raise the retail price to make up for the losses. The FPS wants to induce the e-retailer to lower the retail price by lowering the wholesale price to increase sales in the e-retailing channel. A high commission rate gives the KOL an incentive to increase his livestreaming effort, which increases potential consumers and achieves more revenue. Proposition 1 (2) indicates that when the KOL's increase-traffic power is strong enough, a higher commission rate will increase sales in the e-retailing channel. This is an interesting finding that the KOL effect can stimulate consumers' desire to purchase, even if livestreaming products have higher prices. But this measure harms the interests of consumers and the FPS who purchase through livestreaming, reducing the cost performance of livestreaming products. For example, the price dispute between the streamer Li Jiaqi and L'OREAL PARIS's online store has caused damage to the interests of consumers and L'OREAL PARIS (Zhang and Tang, 2023). Proposition 1 (3) shows that the change trends of profits and the commission rate of APSC members are non-linear, which depends on the KOL's increase-traffic power and the commission rate. Interestingly, a higher commission rate does not always increase the KOL's profit. The intuition behind this result is that the KOL will balance the relationship between the retail price and sales volume rather than blindly increasing the commission rate to squeeze the profit margins of the e-retailer and the FPS.

By analyzing the effect of the KOL's increase-traffic power γ on the optimal decisions of APSC members, we have Proposition 2 as follows.

Proposition 2. *The change trends of the optimal decisions of APSC members with the KOL's increase-traffic power are:*

(1) $\frac{\partial w^{NK*}}{\partial \gamma}=\frac{\partial w^{BK*}}{\partial \gamma}>0$; $\frac{\partial p_d^{NK*}}{\partial \gamma}=\frac{\partial p_d^{BK*}}{\partial \gamma}=0$; $\frac{\partial p_r^{NK*}}{\partial \gamma}=\frac{\partial p_r^{BK*}}{\partial \gamma}>0$; $\frac{\partial e_k^{NK*}}{\partial \gamma}=\frac{\partial e_k^{BK*}}{\partial \gamma}>0$.

(2) $\frac{\partial D_r^{NK*}}{\partial \gamma}=\frac{\partial D_r^{BK*}}{\partial \gamma}>0$; $\frac{\partial D_d^{NK*}}{\partial \gamma}=\frac{\partial D_d^{BK*}}{\partial \gamma}=0$.

(3) If $\gamma>\gamma_8$, then $\frac{\partial \pi_s^{NK*}}{\partial \gamma}>0$; if $\gamma>\gamma_9$, then $\frac{\partial \pi_s^{BK*}}{\partial \gamma}>0$; if $0<m<m_1$, then $\frac{\partial \pi_e^{NK*}}{\partial \gamma}>0$; if $0<m<m_2$, then $\frac{\partial \pi_e^{BK*}}{\partial \gamma}>0$; if $m>m_3$, then $\frac{\partial \pi_k^{NK*}}{\partial \gamma}>0$; if $m>m_4$, then $\frac{\partial \pi_k^{BK*}}{\partial \gamma}>0$.

Proposition 2(1) shows that a stronger KOL's increase-traffic power will raise the wholesale price, retail price, and KOLs' livestreaming effort. The introduction of KOL livestreaming by the e-retailer does not yield benefits to consumers, but instead increases the retail price to achieve greater profits. The dominant FPS realizes that the e-retailer may proactively increase the number of orders, so it will correspondingly increase the wholesale price. The higher traffic and higher retail price make KOL actively market to generate greater revenue, so he will continuously improve his livestreaming effort. Proposition 2(2) shows that a stronger KOL's increase-traffic power will increase the demand of the e-retailing channel. The KOL will recommend products to viewers and drive their emotions, forming a herd effect and word-of-mouth effect, thereby expanding the potential demand for the channel (Cheng and Liu, 2011). Proposition 3 (3) indicates the existence of an optimal KOL's increase-traffic power that minimizes the FPS's profit, meaning that the FPS will not always benefit from the KOL livestreaming. When the unit traffic cost is low, a stronger KOL's increase-traffic power enables the e-retailer to obtain greater profits. However, the signing fee obtained by the KOL cannot cover his livestreaming costs, resulting in a decrease in his profits. Therefore, it is necessary to establish a reasonable signing fee between the e-retailer and the KOL to achieve a win-win situation, which can also facilitate long-term cooperation between the two.

By analyzing the effect of the blockchain technology level y on the optimal decisions of APSC members, we have Proposition 3 as follows.

Proposition 3. *The change trends of the optimal decisions of APSC members with the blockchain technology level are:*

(1) $\frac{\partial w^{BS*}}{\partial y}=\frac{\partial w^{BK*}}{\partial y}<0$; $\frac{\partial p_d^{BS*}}{\partial y}=\frac{\partial p_d^{BK*}}{\partial y}<0$; $\frac{\partial p_r^{BS*}}{\partial y}>0$; $\frac{\partial p_r^{BK*}}{\partial y}<0$; $\frac{\partial e_e^{BS*}}{\partial y}>0$; $\frac{\partial e_k^{BK*}}{\partial y}=0$.

(2) $\frac{\partial D_r^{BK*}}{\partial y}>\frac{\partial D_r^{BS*}}{\partial y}>0$; $\frac{\partial D_d^{BS*}}{\partial y}=\frac{\partial D_d^{BK*}}{\partial y}>0$.

(3) If $a_1 < a < 1$, then $\frac{\partial \pi_s^{BS*}}{\partial y} > 0$; if $\gamma > \gamma_{10}$, then $\frac{\partial \pi_s^{BK*}}{\partial y} > 0$; if $a_2 < a < 1$, then $\frac{\partial \pi_e^{BS*}}{\partial y} > 0$; if $\gamma > \gamma_9$, then $\frac{\partial \pi_e^{BK*}}{\partial y} > 0$; $\frac{\partial \pi_k^{BK*}}{\partial y} > 0$.

Proposition 3(1) indicates that a higher blockchain technology level will increase the retail price and the e-retailer's livestreaming effort but will lower the wholesale price and direct sales price. The reasons behind this result are as follows. A higher blockchain technology level can reduce the loss rate of fresh products, leading to an increase in the actual quantity of fresh products transported to the e-retailer and consumers. Therefore, the FPS has the motivation to reduce the wholesale price and direct sales price. For the e-retailer, it hopes to promote blockchain-based fresh products to attract consumers who require high freshness of agricultural products. Therefore, it will simultaneously increase the livestreaming effort and retail price to seek greater profits. For the KOL, he does not need to pay any related blockchain costs, so he maintains the same level of livestreaming effort. Proposition 3(2) suggests that the demands for both channels, whether the e-retailer or the KOL goes livestreaming, increase with the blockchain technology level. Blockchain can ensure the supply of high-quality agricultural products, improve the transparency and stability of the supply chain system, and create a safe and reliable consumption environment for consumers to increase their purchases. (Tang and Veelenturf, 2019). For example, according to a survey conducted by CEIBS and JD.com, the sales of fresh products that use both blockchain and livestreaming functions have increased by 77.6% (Liu et al., 2022b). Proposition 3 (3) indicates that the relationship between the profits of the FPS and the e-retailer and the blockchain technology level depends on the potential demand and the KOL's increase-traffic power. Only with more potential consumers and traffic can the FPS and the e-retailer feel that investing in blockchain technology is worthwhile. Otherwise, the cost of investing in blockchain is greater than the benefits it brings, and a higher blockchain technology level will lower their profits. The KOL doesn't have to pay any blockchain costs, and investing in blockchain technology attracts more consumers in the e-retailing channel, so he always benefits from a higher blockchain technology level.

5.2. *Optimal pricing and sales strategies of APSC members*

In this section, by comparing the equilibrium solutions in the four models NS, BS, NK, and BK, we can derive the following conclusions.

First, we compare the optimal prices in the two channels, and we can obtain Proposition 4.

Proposition 4. *The optimal wholesale price, direct sales price, retail price, and livestreaming effort in the different four models have the following relationship:*

(1) If $f > f_1$, then $w^{BK*} < w^{BS*} < w^{NK*} < w^{NS*}$, otherwise $w^{BK*} < w^{NK*} < w^{BS*} < w^{NS*}$.

(2) $p_d^{BS*} = p_d^{BK*} < p_d^{NS*} = p_d^{NK*}$.

(3) $$\begin{cases} p_r^{BK*} < p_r^{NK*} < p_r^{NS*} < p_r^{BS*} & 0 < \gamma < \tilde{\gamma}_1 \\ p_r^{BK*} < p_r^{NS*} < p_r^{NK*} < p_r^{BS*} & \tilde{\gamma}_1 < \gamma < \min\{\tilde{\gamma}_2, \tilde{\gamma}_3\} \\ p_r^{NS*} < p_r^{BK*} < p_r^{NK*} < p_r^{BS*} & \tilde{\gamma}_2 < \tilde{\gamma}_3 \text{ and } \tilde{\gamma}_2 < \gamma < \tilde{\gamma}_3 \\ p_r^{BK*} < p_r^{NS*} < p_r^{BS*} < p_r^{NK*} & \tilde{\gamma}_3 < \tilde{\gamma}_2 \text{ and } \tilde{\gamma}_3 < \gamma < \tilde{\gamma}_2 \\ p_r^{NS*} < p_r^{BK*} < p_r^{BS*} < p_r^{NK*} & \max\{\tilde{\gamma}_2, \tilde{\gamma}_3\} < \gamma < \tilde{\gamma}_4 \\ p_r^{NS*} < p_r^{BS*} < p_r^{BK*} < p_r^{NK*} & \gamma > \tilde{\gamma}_4 \end{cases}.$$

(4) $e_e^{NS*} < e_e^{BS*}$; $e_k^{NK*} = e_k^{BK*}$.

Proposition 4 (1) and (2) indicate that the wholesale price and direct sales price with investing in blockchain are always lower than the wholesale price and direct sales price without investing in blockchain, which is different from the conclusion of Liu et al. (2022b), Niu et al. (2021a), and Liang and Xiao (2023). They believe that blockchain users must increase wholesale prices due to the increasing costs. However, in this paper, blockchain significantly reduces the loss rate of fresh products, and the FPS benefits more from investing in blockchain than its costs. Therefore, it has the motivation to lower the wholesale price and direct sales price to maintain the stability of the APSC system. The wholesale price with KOL livestreaming is always lower than the wholesale price with e-retailer livestreaming. This is because the KOL has stronger bargaining power and marketing ability than the e-retailer. The FPS is willing to offer the KOL a lower wholesale price in order to increase sales and expand product popularity.

Proposition 4 (3) indicates that when the KOL's increase-traffic power is strong enough, the retail price with KOL livestreaming is the highest; otherwise, the retail price with KOL livestreaming is the lowest. On the one hand, a stronger KOL's increase-traffic power can bring more potential demands, which motivates the e-retailer to increase the retail price to make greater profits. On the other hand, a stronger KOL's increase-traffic power means that the e-retailer needs to pay higher signing fees, and cost considerations make it must increase the retail price. When the e-retailer goes livestreaming, the retail price with investing in blockchain is always higher than that without investing in blockchain, while the opposite is true when the KOL goes livestreaming ($p_r^{BS*} > p_r^{NS*}$, $p_r^{BK*} < p_r^{NK*}$). This is because the FPS offers a lower wholesale price to the KOL but a higher wholesale price to the retailer, resulting in a double marginalization effect that leads to a higher retail price with e-retailer livestreaming.

Proposition 4 (4) suggests that investing in blockchain improves the e-retailer's livestreaming effort, while the KOL is unaffected. Obviously, higher pricing will motivate the e-retailer to increase its livestreaming effort to compensate for the related blockchain costs. The lower pricing does not reduce the KOL's livestreaming efforts, as he does not pay any blockchain costs and he needs to maintain a strong increase-traffic power; otherwise, the e-retailer would rather go livestreaming by itself. In order to describe in detail the impact of KOL's increase-traffic power on the retail price, we consult the literature (Gong et al., 2022; Yan et al., 2022) and the actual situation of enterprises and set the basic values of the parameters as $m = 0.02$, $k = 0.2$, $y = 0.7$, $\rho = 0.3$, $\beta_r = 0.8$, $\beta_d = 0.5$, $c = 0.2$, $f = 0.02$, and $F = 0.01$. We take $a \in [0.2, 0.8]$ as the independent variable and observe the relationship between the optimal retail prices in the four models, as shown in Fig. 1.

Fig. 1 shows that a higher potential demand will increase the thresholds of KOL's increase-traffic power, and as the potential demand increases, the gap between each threshold continues to narrow. When the potential demand is high, the e-retailer has to hire a more influential streamer to raise the retail price. When the potential demand is low, the thresholds of KOL's increase-traffic power are less than 1, the e-retailer can easily increase the retail price in this case. We can clearly observe that the retail price with KOL livestreaming will increase with the increase of the KOL's increase-traffic power, which also verifies the conclusion in Proposition 2.

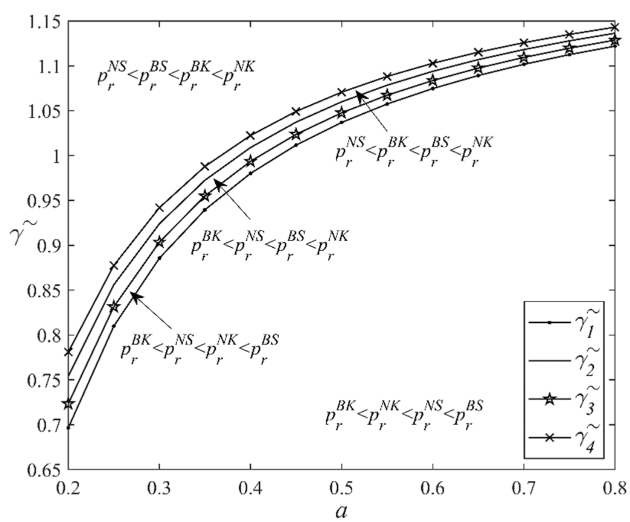


Fig. 1. The relationship among retail prices in the four models

Second, we compare the equilibrium demands of the direct channel and e-retailing channel in the four models to explore whether investing in blockchain and introducing KOL live streaming can stimulate consumer demand for fresh products. The conclusion is shown in Proposition 5.

Proposition 5. *The demands of the two channels in the four models have the following relationship:*

(1) $D_d^{NS*} = D_d^{NK*} < D_d^{BS*} = D_d^{BK*}$.

(2) $$\begin{cases} D_r^{NK*} < D_r^{BK*} < D_r^{NS*} < D_r^{BS*} & 0 < \gamma < \tilde{\gamma}_5 \\ D_r^{NK*} < D_r^{NS*} < D_r^{BK*} < D_r^{BS*} & \tilde{\gamma}_5 < \gamma < \min\{\tilde{\gamma}_6, \tilde{\gamma}_7\} \\ D_r^{NS*} < D_r^{NK*} < D_r^{BK*} < D_r^{BS*} & \tilde{\gamma}_6 < \tilde{\gamma}_7 \text{ and } \tilde{\gamma}_6 < \gamma < \tilde{\gamma}_7 \\ D_r^{NK*} < D_r^{NS*} < D_r^{BS*} < D_r^{BK*} & \tilde{\gamma}_7 < \tilde{\gamma}_6 \text{ and } \tilde{\gamma}_7 < \gamma < \tilde{\gamma}_6 \\ D_r^{NS*} < D_r^{NK*} < D_r^{BS*} < D_r^{BK*} & \max\{\tilde{\gamma}_6, \tilde{\gamma}_7\} < \gamma < \tilde{\gamma}_8 \\ D_r^{NS*} < D_r^{BS*} < D_r^{NK*} < D_r^{BK*} & \gamma > \tilde{\gamma}_8 \end{cases}$$

Proposition 5 (1) indicates that investment in blockchain leads to greater sales in the direct channel, which reflects the classic interaction between price and demand in the market, i.e., lower pricing leads to higher sales. When the FPS faces the situation where the e-retailer introduces KOL livestreaming to increase sales of the retail channel, it can control the sales of the direct channel by adjusting the price to promote fresh products in a targeted manner.

Proposition 5 (2) shows that investing in blockchain technology can always increase the sales of fresh products in the e-retailing channel ($D_r^{BK*} > D_r^{NK*}$, $D_r^{BS*} > D_r^{NS*}$). Combined with Proposition 5 (1), we can find that sales in both channels increase after investing in the blockchain, which means that investment in the blockchain can effectively attract consumers to buy more fresh products. For demand-driven enterprises, they should invest in blockchain technology to quickly increase sales and seize market share. When the KOL's increase-traffic power is strong enough, the sales in the e-retailing channel with KOL livestreaming are the highest, otherwise, the sales in the e-retailing channel with e-retailer livestreaming are the highest. For the e-retailer, when the KOL's increase-traffic power is strong, it should introduce the KOL livestreaming; otherwise, it should go livestreaming by itself. For consumers, their choices are no longer constrained by the price, and even higher prices for livestreaming may make them rush to purchase. This is because streamers rely on their reputation to endorse the brand or quality of livestreaming products, which greatly saves consumers the hassle of trying and comparing prices in physical stores. In addition, livestreaming goods are usually fast-moving consumer goods such as cosmetics and snacks, and consumers are usually not sensitive to their prices, which can easily lead to impulsive consumption under the guidance of streamers. For example, under the praise and recommendation of Li Jiaqi, the Chinese beauty brand "Huaxizi" leapt to become the top-selling beauty brand at Tmall's "618" shopping carnival in 2021.

Keeping the above basic parameters unchanged, in order to describe in detail, the impact of KOL's increase-traffic power on the demand of the e-retailing channel, we take $a \in [0.2, 0.8]$ as the independent variable to observe the relationship among demands of retail channels in the four models, as shown in Fig. 2.

Fig. 2 shows that a higher potential demand will increase the thresholds of KOL's increase-traffic power, and as the potential demand increases, the gap between each threshold continues to narrow. That is to say, when the potential demand is high, the e-retailer has to hire a more influential streamer to increase sales. When the potential demand is low, the thresholds of KOL's increase-traffic power are low, and choosing to introduce KOL livestreaming is the most efficient way to increase sales in this case. We can clearly observe from Fig. 2 that the sales with KOL livestreaming in the e-retailing channel increase with the improvement of the KOL's increase-traffic power, which also verifies the conclusion in Proposition 2. In addition, we can observe that thresholds of demand in the e-retailing channel are greater than thresholds of retail price, which means that e-retailer can raise the retail price while selling more fresh products by introducing KOL livestreaming.

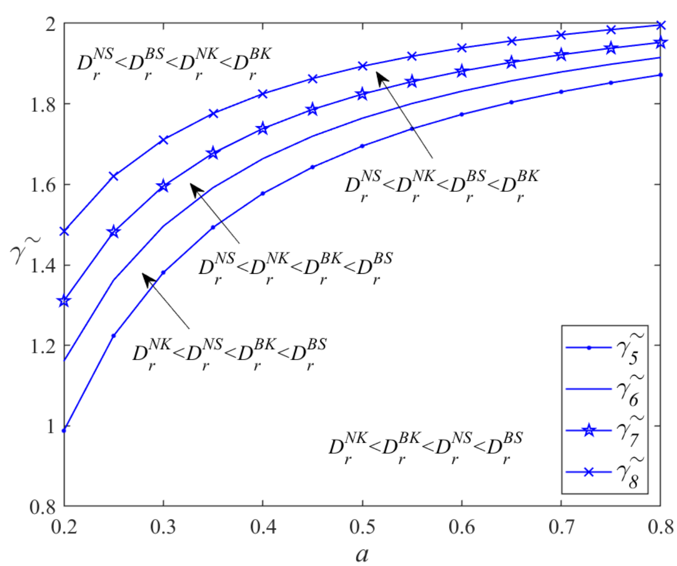


Fig. 2. The relationship among demands of the e-retailing channel in the four models

5.3. Optimal operation strategy for the APSC

In this section, we derive the conditions for the FPS to invest in blockchain and the e-retailer to introduce KOL livestreaming by comparing the optimal profits of APSC members. In addition, we explore the impact of APSC members' strategic choices on other members.

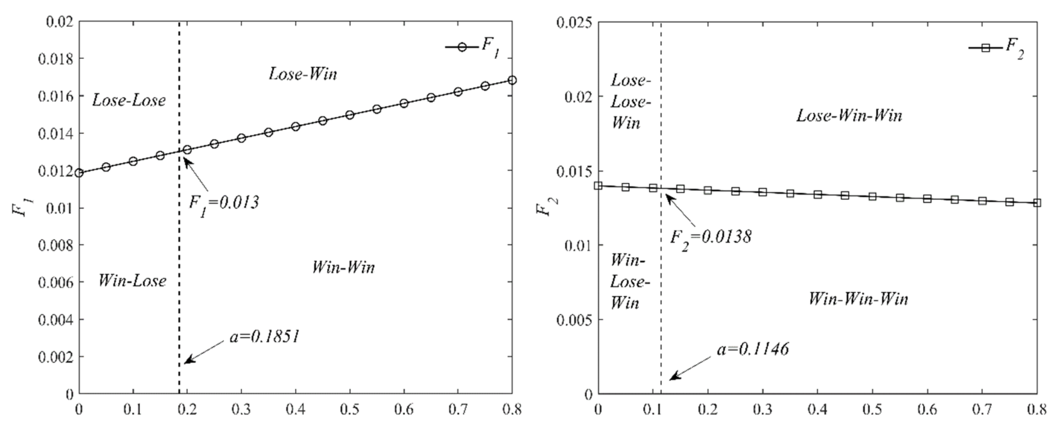
Proposition 6. *The impact of investing in blockchain on the optimal profits of APSC members is as follows:*
(1) If $F < F_1$, then $\pi_s^{BS*} > \pi_s^{NS*}$; if $F < F_2$, then $\pi_s^{BK*} > \pi_s^{NK*}$.

(2) If $a_3 < a < 1$, then $\pi_e^{BS*} > \pi_e^{NS*}$; if $a_4 < a < 1$, then $\pi_e^{BK*} > \pi_e^{NK*}$.
(3) $\pi_k^{BK*} > \pi_k^{NK*}$.

Proposition 6 (1) indicates that the FPS will invest in blockchain technology only when the blockchain fixed fee is less than a certain threshold. This result is intuitive, as the excessive blockchain fee compresses the FPS's profit margin. For example, for small and medium-sized enterprises, the cost of building an information sharing platform is too high, but they can choose to spend less money to join a consortium blockchain platform such as Antchain, which can also realize the traceability and information sharing of fresh products. Proposition 6 (2) indicates that investment in blockchain is beneficial for the e-retailer only when the potential demand of the e-retailing channel is higher than a certain threshold. From Proposition 4, we know that the retail price in the model BS is higher than that in the model NS. If the potential demand for the e-retailing channel is too low, then consumers will shift to the lower priced direct channel for purchases, and the price-off promotions will only lower the e-retailer's profit. Proposition 6 (3) indicates that KOL always benefits from investment in blockchain, and there is a free-riding behavior in the APSC. This is because when KOL goes livestreaming, the sales of the e-retailing channel with blockchain are always greater than those without blockchain, and he does not need to pay any blockchain costs to obtain more commissions. Next, we analyze the impact of investing in blockchain on APSC members through numerical simulation. Keeping the above basic parameters unchanged, we calculate that $F_1 = 0.013$, $F_2 = 0.0138$, $a_3 = 0.1851$, and $a_4 = 0.1146$. Taking $a \in [0.2, 0.8]$ as the independent variable, Fig. 3 shows the optimal strategies of investment in blockchain in the APSC.

Fig. 3 (a) shows that when the e-retailer goes livestreaming by itself, a higher potential demand of the e-retailing channel will increase the threshold of blockchain fixed fee, which means that as the potential demand of the e-retailing channel increases, the FPS can gain greater profits by investing in blockchain. When $a > 0.1851$ and $F < 0.013$, investing in blockchain is a win-win situation for both the FPS and the e-retailer. For the FPS, he needs to control the blockchain fixed cost and it is unwise to invest in blockchain when the cost is too high. For the e-retailer, it benefits from the investment in blockchain in most cases, and it should increase potential demand by increasing livestreaming promotion and advertising to incentivize the FPS to invest in blockchain and improve APSC performance.

It can be seen from Fig. 3 (b) that compared with the e-retailer livestreaming, the threshold of potential demand is reduced, while the threshold of blockchain fixed cost is increased with the KOL livestreaming. When $a > 0.1146$ and $F < 0.0138$, investing in blockchain is a win-win situation for both the FPS and the e-retailer, compared to the case of e-retailer livestreaming, their win-win conditions are more relaxed. Unlike Fig. 3 (a), when the KOL goes livestreaming, a higher potential demand of the e-retailing channel will lower the blockchain cost threshold, which means that as the potential demand of the e-retailing channel increases, the profit of the FPS declines after investing in blockchain. In this case, the introduction of influential KOLs by the e-retailer will hinder the FPS from investing in blockchain. This is because the KOL always benefits from investing in blockchain, and he does not need to pay any costs, which harms the interests of the FPS. Therefore, KOL should share appropriate blockchain costs to incentivize its investment in blockchain technology, thereby improving the APSC performance.



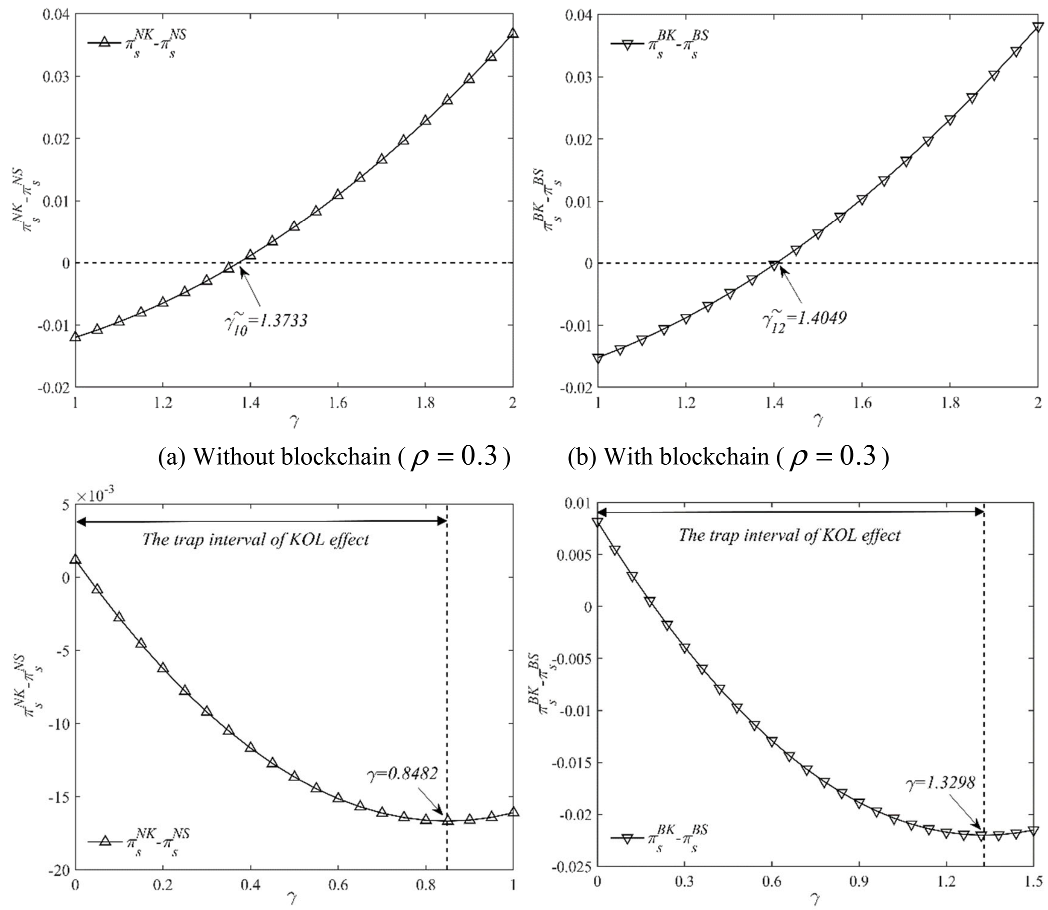
(a) E-retailer livestreaming (b) KOL livestreaming

Fig. 3. Optimal strategies of investment blockchain for APSC members

Proposition 7. *The impact of the introduction of KOL livestreaming on the optimal profits of APSC members is as follows:*
(1) If $\gamma > \tilde{\gamma}_{10}$ or if $\rho_1 < \rho < 1$ and $0 < \gamma < \tilde{\gamma}_9$, then $\pi_s^{NK*} > \pi_s^{NS*}$; If $\gamma > \tilde{\gamma}_{12}$ or if $\rho_2 < \rho < 1$ and $0 < \gamma < \tilde{\gamma}_{11}$, then $\pi_s^{BK*} > \pi_s^{BS*}$.
(2) If $0 < m < m_5$, then $\pi_e^{NK*} > \pi_e^{NS*}$; if $0 < m < m_6$, then $\pi_e^{BK*} > \pi_e^{BS*}$.
Proposition 7 (1) shows that the impact of introducing KOL livestreaming on the FPS's profit depends on the commission rate

and KOL's increase-traffic power. The strong KOL effect increases the demand of the e-retailing channel, which compensates for the FPS's loss due to the lower wholesale price. When the commission rate is too high and the KOL's increase-traffic is weak, the FPS can also obtain more profits from KOL livestreaming. This is since a high commission rate forces the e-retailer to raise the retail price, and the weak KOL effect cannot attract consumers to purchase expensive goods. In this case, consumers will shift to the direct channel for purchases, and the incremental profits obtained by the FPS from the direct channel will compensate for the losses of the e-retailing channel. Proposition 7 (2) indicates that the e-retailer will introduce KOL livestreaming only when the unit traffic cost is below a certain threshold. This result is intuitive, as the excessive signing fee can cause some of the e-retailer's profit to be captured by the KOL. Moreover, the excessive signing fee does not motivate the KOL to put in huger live streaming efforts ($\frac{\partial e_k^{NK*}}{\partial m} = \frac{\partial e_k^{BK*}}{\partial m} = 0$), so when the unit traffic cost is too high, the e-retailer would rather go livestreaming on its own.

We set $a = 0.4$ and keep the other parameters unchanged. Under the above parameter settings, we calculate that $\tilde{\gamma}_{10} = 1.3733$ and $\tilde{\gamma}_{12} = 1.4049$. We take $\gamma \in [1,2]$ as the independent variable and explore the impact of introducing KOL livestreaming on the FPS, as shown in Fig. 4.



(a) Without blockchain ($\rho = 0.3$) (b) With blockchain ($\rho = 0.3$)

(c) Without blockchain ($\rho = 0.65$) (d) With blockchain ($\rho = 0.85$)

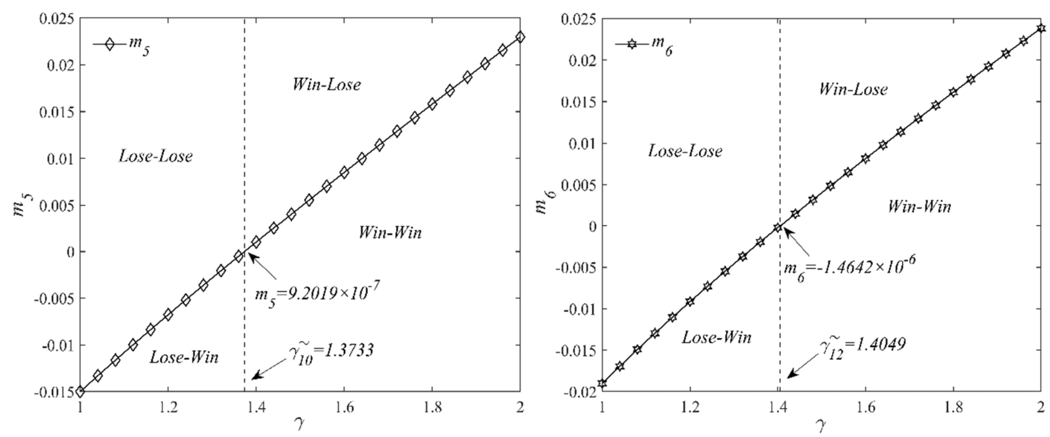
Fig. 4. The impact of introducing KOL livestreaming on the FPS's profit

Figs. 4 (a) and (b) indicate that when the KOL's increase-traffic power is strong enough, a higher KOL's increase-traffic power will enable the FPS to gain more benefits. We can observe that when the FPS does not invest in blockchain, it will profit from the introduction of KOL livestreaming only if $\gamma > 1.3733$; when the FPS invests in blockchain, it will profit from the introduction of KOL livestreaming only if $\gamma > 1.4049$. That is to say, the introduction of KOL is not always beneficial for the FPS, which depends on the KOL's increase-traffic power. In addition, the threshold has increased after investing in blockchain, which means that the e-retailer needs to hire a more influential streamer to incentivize the FPS to invest in blockchain.

From Proposition 7, we have concluded that introducing KOL may not always be beneficial for the FPS, which depends on two factors: the commission rate and KOL's increase-traffic power. Next, let's analyze another situation. We raise the commission rate, and we calculate that $\rho_1 = 0.625$ and $\rho_2 = 0.7942$ based on the above parameters. Therefore, we set $\rho_1 = 0.65$ and $\rho_2 = 0.85$, and Figs. 4 (c) and (d) show the impact of the KOL's increase-traffic power on the FPS's profit under a high commission rate.

From Figs. 4 (c) and (d), we find an interesting phenomenon that when the commission rate is too high, the FPS's profit shows a downward and then upward trend as the KOL's increase-traffic power increases. When the KOL's increase-traffic is weak enough, as shown in Figs. 4 (c) and (d) where $\gamma < 0.8482$ and $\gamma < 1.3298$, it becomes a negative driving force that further damages the FPS's profit. We refer to this interval as "The trap interval of KOL traffic", and the enhancement of the KOL's increase-traffic power within this interval will result in increasing losses for the FPS. The occurrence of this situation is mainly attributed to the commission rate. When the commission rate is high and the KOL's increase-traffic power is weak, the KOL captures a portion of the profits of the FPS and the e-retailer but fails to discover enough potential customers for them. When the commission rate is low, both the e-retailer and the FPS can retain most of their profits, allowing them to benefit from the enhancement of KOL's increase-traffic power. In summary, when the commission rate is too high, the KOL effect can be a negative driving force for the FPS. Therefore, the FPS should negotiate the commission rate with the e-retailer or collaborate with it to hire a more influential streamer.

Finally, we analyze the impact of introducing KOL livestreaming on APSC members through numerical simulation, as shown in Fig. 5. We set $\rho = 0.3$, take $\gamma \in [1, 2]$ as the independent variable, and calculate that $m_5 = 9.2019 \times 10^{-7}$ and $m_6 = -1.4642 \times 10^{-6}$. Fig. 5 shows that a higher KOL's increase-traffic power will increase the unit traffic cost. This result is intuitive, hiring a more influential streamer usually requires paying him more expensive signing fees. The high signing fee allows the KOL to earn a stable income, even if live sales are not significant, he will not lose much. In other words, the high signing fee shifts the risk of live sales to the e-retailer, compressing its profit margin, and the e-retailer is more inclined to go livestreaming on its own in this case. From Fig. 5, ittheres a win-win situation in that both the FPS and the e-retailer benefit from the introduction of KOL livestreaming when the unit traffic cost is small and the KOL's increase-traffic power is strong. For the e-retailer, hiring an influential and affordable streamer is a challenge. Therefore, the FPS should share a portion of the signing fee to incentivize the e-retailer to introduce a more influential streamer, thereby improving the APSC performance.



(a) Without blockchain (b) With blockchain

Fig. 5. Optimal strategies of introduction KOL livestreaming for APSC members

6. Extensions

In order to enrich related studies and verify the robustness of models, we extend the models to further discuss the impact of the spillover effect, consumer surplus, social welfare, and KOL's social responsibility.

6.1. Traffic spillover effect

From the above conclusion, we can conclude that neither e-retailer livestreaming nor KOL livestreaming affects the price and demand of the direct channel. In fact, many direct sales suppliers have realized the threat of livestreaming e-commerce to direct channels, and they will use the influence of streamers to increase the potential demand for direct sales channels. For example, some of the best-selling books on Dangdang.com will be labeled "recommended by streamers" to enhance marketing. Moreover, the research has found that KOL may have a subsequent impact on non-livestreaming channels, which is referred to as the spillover effect (Fan et al., 2022). Therefore, in this section, we consider the spillover effect based on the original models, assuming that the degree of spillover effect with KOL livestreaming is λ, $0 \le \lambda \le 1$. So, the demand functions for the e-retailing channel and direct channel with KOL livestreaming are: $\hat{D}_r = \gamma a - \beta_r p_r + e_k$ and $\hat{D}_d = 1 - a - \beta_d p_d + \lambda \gamma a$. Solving by the backward induction, the optimal results of the models NK and BK considering the traffic spillover effect are as follows: $\hat{w}^{NK*} = w^{NK*}$, $\hat{p}_d^{NK*} = \frac{(1-a+a\lambda\gamma)(1-k)+c\beta_d}{2\beta_d(1-k)}$, $\hat{p}_r^{NK*} = p_r^{NK*}$,

$\hat{e}_K^{NK*} = e_K^{NK*}$, $\hat{D}_d^{NK*} = \frac{(1-k)(1-a+a\lambda\gamma)-c\beta_d}{2(1-k)}$, $\hat{D}_r^{NK*} = D_r^{NK*}$,

$\hat{\pi}_s^{NK*} = \frac{[(1-a+a\lambda\gamma)(1-k)-c\beta_d]^2}{4\beta_d(1-k)^2} + \frac{\beta_r[2a\gamma(1-k)(1-\rho)-c(2\beta_r-\rho)]^2}{8(1-k)^2(1-\rho)(2\beta_r-\rho)^2}$, $\hat{\pi}_e^{NK*} = \pi_e^{NK*}$, and $\hat{\pi}_k^{NK*} = \pi_k^{NK*}$; $\hat{w}^{BK*} = w^{BK*}$,

$\hat{p}_d^{BK*} = \frac{(1-a+a\lambda\gamma)(1-k+ky)+c\beta_d}{2\beta_d(1-k+ky)}$, $\hat{p}_r^{BK*} = p_r^{BK*}$, $\hat{e}_K^{BK*} = e_K^{BK*}$, $\hat{D}_d^{BK*} = \frac{(1-k+ky)(1-a+a\lambda\gamma)-c\beta_d}{2(1-k+ky)}$, $\hat{D}_r^{BK*} = D_r^{BK*}$,

$\pi_s^{BK*} = \frac{[(1-a+a\lambda\gamma)(1-k+ky)-c\beta_d]^2}{4\beta_d(1-k+ky)^2} + \frac{\beta_r[2a\gamma(1-k+ky)(1-\rho)-c(2\beta_r-\rho)]^2}{8(1-k+ky)^2(1-\rho)(2\beta_r-\rho)^2} - F$, $\hat{\pi}_e^{BK*} = \pi_e^{BK*}$, and $\hat{\pi}_k^{BK*} = \pi_k^{BK*}$. The spillover effect only affects the optimal results of the price and demand of the direct channel, and the FPS's profit, while other results remain unchanged. Therefore, in this section, we will only analyze these three results. By comparing the optimal results in the four models considering spillover effects, we have Proposition 8.

Proposition 8. *The optimal results considering the spillover effect have the following relationship:*

(1) If $\lambda_1 < \lambda \le 1$, then $\hat{p}_d^{NK*} > \hat{p}_d^{BK*} > p_d^{NS*} > p_d^{BS*}$, otherwise $\hat{p}_d^{NK*} > p_d^{NS*} > \hat{p}_d^{BK*} > p_d^{BS*}$.

(2) If $\lambda_1 < \lambda \le 1$, then $\hat{D}_d^{BK*} > \hat{D}_d^{NK*} > D_d^{BS*} > D_d^{NS*}$, otherwise $\hat{D}_d^{BK*} > D_d^{BS*} > \hat{D}_d^{NK*} > D_d^{NS*}$.

(3) If $\gamma \ge \max\{\hat{\gamma}_2, 0\}$ or if $0 \le \lambda < \lambda_2$, $\rho_1 < \rho < 1$, and $0 < \gamma < \hat{\gamma}_1$, then $\hat{\pi}_s^{NK*} > \pi_s^{NS*}$; if $\gamma \ge \max\{\hat{\gamma}_4, 0\}$ or if $0 \le \lambda < \lambda_3$, $\rho_2 < \rho < 1$, and $0 < \gamma < \hat{\gamma}_3$, then $\hat{\pi}_s^{BK*} > \pi_s^{BS*}$.

Propositions 8 (1) and (2) indicate that when the degree of spillover effect exceeds a certain threshold, the price and demand of the direct channel with KOL livestreaming are both the highest. This is because the higher degree of spillover effect means that there are more potential consumers in the direct channel. The existence of the spillover effect increases consumers' awareness of fresh products in the direct channel, leading to the homogenization of services between the two channels. This attracts consumers who missed the livestreaming or the opportunity to rush to purchase livestreaming products to purchase through the direct channel. Therefore, the FPS will raise the direct sales price to gain more profits. Proposition 8 (3) indicates that the FPS's profit depends on the KOL's increase-traffic power, traffic spillover effect, and commission rate. In the first case, when the KOL's increased-traffic power is strong enough, it leads to an increase in sales for both channels, bringing more revenue to the FPS. In the second case, a high commission rate and weak KOL's increased-traffic power mean that introducing KOL is not worthwhile for the e-retailer. And it must raise the retail price to make up for losses. Consumers who did not enjoy discounts from livestreaming will shift to the direct channel to find substitutes, leading to an increase in sales for the direct channel. In this case, the FPS can benefit from the direct channel.

6.2. Consumer surplus and social welfare

Consumers enjoy purchasing goods through livestreaming. So, does livestreaming increase consumer surplus? How to balance the profitability and social responsibility of enterprises? To answer the above questions, we derive the social welfare and consumer surplus in the four models. According to Xu et al. (2023a) and Niu et al. (2021a), consumer surplus (CS) and social welfare (SW) in the four models can be formulated that $CS^i = \int_{p_d}^{\max\{p_d\}} D_d^i dp_d + \int_{p_r}^{\max\{p_r\}} D_r^i dp_r = \frac{D_d^{i\,2}}{2\beta_d} + \frac{D_r^{i2}}{2\beta_r}$ and $SW^i = \pi_s^i + \pi_e^i + \pi_k^i + CS^i$.

Substituting the optimal results in the four models into the above equations, we have Theorem 5.

Theorem 5. *The consumer surplus and social welfare in the four models are as follows:*

$$CS^{BK} = \frac{\beta_r[2a\gamma(1-k+ky)(1-\rho)-c(2\beta_r-\rho)]^2}{32(1-k+ky)^2(1-\rho)^2(2\beta_r-\rho)^2} + \frac{[(1-k+ky)(1-a)-c\beta_d]^2}{8\beta_d(1-k+ky)^2}$$

$$CS^{BS} = \frac{\beta_r[a(1-k+ky)-c\beta_r]^2}{8(1-k+ky)^2(2\beta_r-1)^2} + \frac{[(1-k+ky)(1-a)-c\beta_d]^2}{8\beta_d(1-k+ky)^2}$$

$$CS^{NK} = \frac{\beta_r[2a\gamma(1-k)(1-\rho)-c(2\beta_r-\rho)]^2}{32(1-k)^2(1-\rho)^2(2\beta_r-\rho)^2} + \frac{[(1-k)(1-a)-c\beta_d]^2}{8\beta_d(1-k)^2}$$

$$CS^{NS}=\frac{\beta_r[a(1-k)-c\beta_r]^2}{8(1-k)^2(2\beta_r-1)^2}+\frac{[(1-k)(1-a)-c\beta_d]^2}{8\beta_d(1-k)^2}$$
$$SW^i=\pi_s^i+\pi_e^i+\pi_k^i+CS^i$$

By comparing consumer surplus in the four models, we have Proposition 9.

Proposition 9. *The consumer surplus in the four models has the following relationship:*
(1) If $\gamma>\hat{\gamma}_6$, or if $0<\rho<1/2\beta_r$, $c_1<c<c_2$, and $0<\gamma<\hat{\gamma}_5$, or if $1/2\beta_r<\rho<1$, $c>c_2$, and $0<\gamma<\hat{\gamma}_5$, then $CS^{NK}>CS^{NS}$; if $\gamma>\hat{\gamma}_8$, or if $0<\rho<1/2\beta_r$, $c_3<c<c_4$, and $0<\gamma<\hat{\gamma}_7$, or if $1/2\beta_r<\rho<1$, $c>c_4$, and $0<\gamma<\hat{\gamma}_7$, then $CS^{BK}>CS^{BS}$.
(2) If $0<c<c_5$, then $CS^{BS}>CS^{NS}$; If $0<c<c_6$, then $CS^{BK}>CS^{NK}$.

Proposition 9 shows that the size of consumer surplus depends on the KOL's increase-traffic power, commission rate, and unit cost. The KOL with strong increase-traffic power can sell goods faster, resulting in higher sales in the e-retailing channel and an increase in consumer surplus. And when the commission rate is low and the unit cost keeps a reasonable range, or when the commission rate and the unit cost are very high, even if the KOL's increase-traffic is low, the introduction of KOL livestreaming can also increase consumer surplus. In conclusion, in most cases, the introduction of KOL livestreaming can increase consumer surplus. Proposition 9 (2) shows that when the unit cost is low, investing in blockchain technology can increase consumer surplus. Blockchain can quickly trace all the links of fresh products in circulation, increasing consumers' purchasing trust. Therefore, investing in blockchain will increase sales in both channels, thereby increasing consumer surplus. The higher unit cost will increase the price of fresh products. In this case, consumers pay more attention to the price factor, and investing in blockchain cannot increase their utility.

Due to the complexity of the equations for social welfare, we use numerical simulation to analyze the social welfare in the four models. We take and as the independent variable and keep the other parameters unchanged. Fig. 6 shows the impact of unit cost and KOL's increased-traffic power on social welfare in the four models.

Fig. 6 shows that a higher unit cost will reduce social welfare in the four models. When the unit cost exceeds a certain threshold, the social welfare with investment in blockchain is greater; otherwise, the social welfare without investment in blockchain is greater. The intuition behind this result is that when the unit cost is low, the benefits that APSC members gain from investing in blockchain are much smaller than the related blockchain cost. But the higher unit cost makes investing in blockchain reduce more losses of fresh products in circulation, leading to more benefits for APSC members from investing in blockchain. Therefore, for fresh products with higher unit costs, such as cherries and strawberries, the government should grant subsidies to FPSs to encourage them to invest in blockchain. From Fig. 6, we can also conclude that the introduction of KOL livestreaming will increase social welfare only when the KOL's increased-traffic power exceeds a certain threshold. Social welfare will increase with the enhancement of KOL's increased-traffic power, but it is not significant. This is because a stronger KOL's increased-traffic power will increase the KOL's profit, but the e-retailer needs to pay him more money for this, resulting in an increase and decrease in the profits of both the e-retailer and the KOL. Therefore, social welfare mainly depends on the size of consumer surplus. So, under what circumstances will the KOL care about consumer surplus? To answer this question, we next analyze KOL's social responsibility.

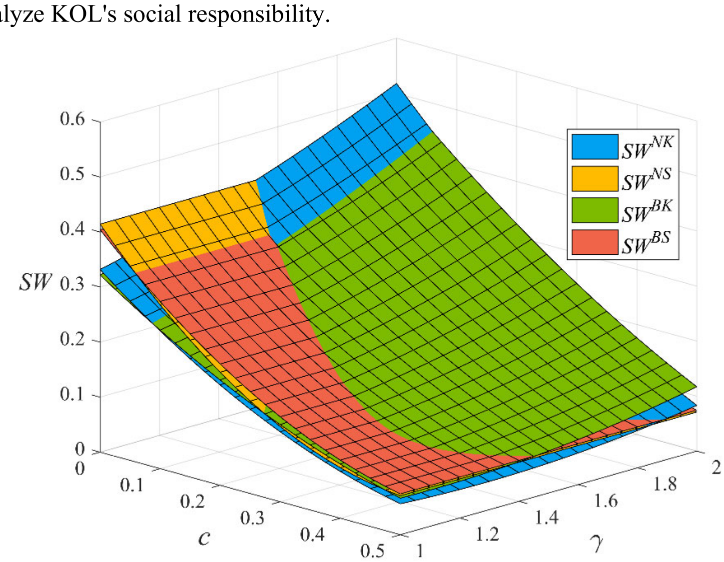


Fig. 6. Impact of unit cost and KOL's increase-traffic power on social welfare

6.3. KOL's social responsibility

Nowadays, consumers are increasingly inclined to purchase products from socially responsible companies. Proactively taking on social responsibility can enhance a company's image and achieve greater profits (Ageron et al., 2012). For example, Oriental Selection helped farmers sell agricultural products through livestreaming in Yunnan, which brought 105 million yuan in sales revenue to the local area. The number of fans usually determines the sales revenue of streams, so they also need to maintain relationships with fans and strive to improve their purchasing utility. Referring to Sinayi and Rasti-Barzoki (2018), we use $V_k^i = \pi_k^i + \varphi CS^i$ to represent the KOL's social responsibility, where $\varphi \geq 0$ is the level of KOL's social responsibility. By comparing the KOL's social responsibility with and without investing in blockchain, we have Proposition 10.

Proposition 10. If $\rho_3 < \rho < 1$ or if $0 < \rho < \rho_3$ and $0 < c < c_7$, then $V_k^{BK} > V_k^{NK}$.

Proposition 10 shows that when the commission rate is high or when the commission rate and the unit cost are low, investing in blockchain can improve KOL's social responsibility. The reason behind this result is that a higher commission rate motivates the KOL to better go livestreaming, and investing in blockchain reduces the retail price and increases sales, thereby increasing KOL's social responsibility. When the unit cost is low, investing in blockchain can increase consumer surplus, thus increasing KOL's social responsibility.

Additionally, we notice that for more influential streamers, investing in blockchain is more effective in enhancing their social responsibility ($\frac{\partial(V_k^{BK} - V_k^{NK})}{\partial \gamma} > 0$). This is since top streamers sell hundreds of products per livestreaming, and they are unable to accurately understand the information and authenticity of each product, which can have serious repercussions in the event of product quality problems. For example, top streamer Xin Ba was fined 900,000 yuan for selling fake bird's nest products (Pandaily, 2020). The use of blockchain can help streamers strictly control all aspects of product circulation and reduce losses, thereby effectively enhancing their social responsibility.

7. Conclusions

The rapid development of e-commerce and network communication technology has made livestreaming a mainstream shopping method, and the KOL effect drives consumers to be willing to pay more for fresh products recommended by streamers. Agricultural products inevitably suffer quantity losses during transportation due to spoilage, improper storage, and information asymmetry. The decentralized, transparent, and tamper proof characteristics of blockchain enable the accelerated circulation of fresh products to reduce losses, enhance consumer trust in purchasing, and stimulate their purchasing. Based on these contexts, we consider the quantity loss of fresh products and explore the blockchain investment strategy of the FPS and the livestreaming broadcast strategy of the e-retailer in the APSC using a game theory method. We summarize the conclusions of this paper and provide some useful management insights for APSC members.

The results show the following: (1) Investing in blockchain can stimulate consumers to purchase fresher products in both channels. When the KOL's increase-traffic power exceeds a certain threshold, the introduction of KOL livestreaming will increase the retail price and sales for the e-retailing channel. Investing in blockchain can increase the e-retailer's livestreaming effort, but it cannot increase the KOL's livestreaming effort. (2) The FPS will invest in blockchain technology only when the blockchain fixed fee is less than a certain threshold. The FPS subsidizes the unit verification fee to the e-retailer in the form of a lower wholesale price. There is a win-win situation where both the FPS and the e-retailer can benefit from investing in blockchain, while the KOL always benefits from investing in blockchain, thereby there is a free-riding behavior in the APSC. (3) The e-retailer will introduce KOL livestreaming only when the unit traffic cost is less than a certain threshold, otherwise, it will go livestreaming on its own. Interestingly, when the commission rate is very high and the KOL's increase-traffic power is weak enough, the KOL effect will become a negative driving force to further damage the FPS's profit. Nevertheless, there is still a win-win situation where the FPS and the e-retailer can benefit from introducing KOL livestreaming.

In the extended model, we verify the robustness of theoretical models and obtained some new conclusions. The results show the following: (1) When the degree of traffic spillover effect exceeds a certain threshold, the price and sales with KOL livestreaming in the direct channel are the highest. After considering the spillover effect, in most cases, introducing KOL livestreaming can bring more profits to the FPS. (2) The size of consumer surplus in the four models depends on the combined effect of the KOL's increase-traffic power, commission rate, and unit cost. In most cases, investing in blockchain and introducing KOL livestreaming can improve consumer surplus and social welfare. (3) When the commission rate is high or when the commission rate and unit cost are low, investing in blockchain can enhance KOL's social responsibility.

Based on the above conclusions, we provide some management insights for enterprises in the APSC that want to invest in blockchain and introduce KOL livestreaming. The FPS should balance the costs and benefits of investment in blockchain and reasonably control related blockchain costs. For example, although private blockchains have higher efficiency and better confidentiality, they often bring higher costs. For some small and medium-sized enterprises, a better choice is to join a consortium blockchain platform to realize the traceability of fresh products. In most cases, investing in blockchain is beneficial for the e-retailer, so it should share some related blockchain costs proactively, which can achieve long-term stable cooperation between both parties and improve the overall APSC performance. In order to achieve information sharing, facilitate regulation, and improve overall social welfare, the government can implement subsidies for high-cost fresh products to encourage fresh product information to be actively uploaded to the blockchain. The high signing fee shifts most of the livestreaming risks to the e-retailer, hindering the introduction of KOL livestreaming. Therefore, government departments should regulate the behavior of streamers and curb sky-high signing fees. To avoid falling into "The trap interval of KOL effect", the FPS and e-retailer can collaborate to hire a more influential streamer and each bears a portion of the signing fee, which is beneficial for both parties.

Our research can be expanded in various ways in the future. Firstly, in subsequent work, we can consider the government as one of the members of the APSC and study the effect of government subsidies on the optimal decision of the APSC. Secondly, we have concluded that consumers may purchase more expensive fresh products from KOL livestreaming, which may lead to some consumers returning products due to impulsive purchases. Therefore, we can consider consumers' return behavior and e-retailers' strategies for providing return-freight insurance. Finally fresh products both face quantity and quality losses. We can further study the operation decision making of APSC considering double losses.

Data Availability

The data used to support the findings of this study are open in the paper and available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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References

Ageron, B., Gunasekaran, A., Spalanzani, A. (2012). Sustainable supply management: An empirical study. *International Journal of Production Economics*, *140*(1), 168-182.

Ahmed, S., & Broek, N.T. (2017). Blockchain could boost food security. *Nature*, *550*(7674), 43-43.

Behnke, K., & Janssen, M.F.W.H.A. (2020). Boundary conditions for traceability in food supply chains using blockchain technology. *International Journal of Information Management*, *52*, 101969.

Bigliardi, B., & Galanakis, C.(2020). Innovation management and sustainability in the food industry: concepts and models, in: Galanakis, C. (Ed.), *The Interaction of Food Industry and Environment. Academic Press, 315-340*.

BJNEWS (2023). Spend 200,000 yuan to live with goods in 3 months turnover of 278 yuan, rely on the celebrity is not as good as relying on the quality products. *https://www.bjnews.com.cn/detail/1679219729169011.html.*

Cai, J., Wohn, D.Y., Mittal, A., Sureshbabu, D.(2018). Utilitarian and Hedonic Motivations for Live Streaming Shopping. *Proceedings of the 2018 ACM International Conference on Interactive Experiences for TV and Online Video. Association for Computing Machinery, SEOUL, Republic of Korea*, 81–88.

Caro, M.P., Ali, M.S., Vecchio, M., & Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation, 2018 IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany), *Tuscany*, Italy, 1-4.

Chen, C.-C., & Lin, Y.-C. (2018). What drives live-stream usage intention? The perspectives of flow, entertainment, social interaction, and endorsement. *Telematics and Informatics*, *35*(1), 293-303.

Cheng, H.K., & Liu, Y. (2011). Optimal Software Free Trial Strategy: The Impact of Network Externalities and Consumer Uncertainty. *Information Systems Research*, *23*(2), 488-504.

Chen, J.& Pan, S.(2017). Research on supply chain management of agricultural products based on RFID technology. *Agro Food Industry Hi-Tech*, *28*(3), 959-964.

CNNIC(2023). The 51st statistical report on China's internet development. https://cnnic.cn/NMediaFile/2023/0322/MAIN16794576367190GBA2HA1KQ.

Di Francesco Maesa, D., & Mori, P. (2020). Blockchain 3.0 applications survey. *Journal of Parallel and Distributed Computing, 138*, 99-114.

Dutta, P., Choi, T.-M., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: Applications,

challenges and research opportunities. *Transportation Research Part E: Logistics and Transportation Review*, *142*, 102067.
Fan, T., Wang, L., & Song, Y.(2022). Impact of live commerce spillover effect on supply chain decisions. *Industrial Management & Data Systems*, *122*(4), 1109-1127.
Feng, H., Wang, X., Duan, Y., Zhang, J., & Zhang, X. (2020). Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges. *Journal of Cleaner Production*, 260, 121031.
Fu, H., Zhao, C., Cheng, C., & Ma, H.(2020). Blockchain-based agri-food supply chain management: case study in China. *International Food and Agribusiness Management Review*, *23*(5), 667-679.
Gad, A.G., Mosa, D.T., Abualigah, L., & Abohany, A.A. (2022). Emerging Trends in Blockchain Technology and Applications: A Review and Outlook. *Journal of King Saud University - Computer and Information Sciences*, *34*(9), 6719-6742.
Gong, H., Zhao, M., Ren, J., & Hao, Z. (2022). Live streaming strategy under multi-channel sales of the online retailer. *Electronic Commerce Research and Applications*, *55*, 101184.
Guo, L., Hu, X., Lu, J., & Ma, L. (2021). Effects of customer trust on engagement in live streaming commerce: mediating role of swift guanxi. *Internet Research*, *31*(5), 1718-1744.
Helo, P., & Hao, Y. (2019). Blockchains in operations and supply chains: A model and reference implementation. *Computers & Industrial Engineering*, *136*, 242-251.
Iimedia (2022). 2022 China Fresh E-commerce Operation Big Data and Development Prospect Research Report. *https://www.iimedia.cn/c400/84894.html.*
Ji, G., Fu, T., & Li, S.(2023). Optimal selling format considering price discount strategy in live-streaming commerce. *European Journal of Operational Research*, *309*(2), 529-544.
Ji, G., Zhou, S., Lai, K.-H., Tan, K.H., & Kumar, A. (2022). Timing of blockchain adoption in a supply chain with competing manufacturers. *International Journal of Production Economics*, *247*, 108430.
Jiang, X., Guangkuo, G., & Xuezheng, Y. (2023). Evolutionary game analysis on live streaming commerce considering brand awareness and anchor influence. *Kybernetes*, *52*(12), 6467-6493.
Kshetri, N.(2019). Blockchain and the Economics of Food Safety. *IT Professional* ,21 (3), 63-66.
Liang, X., & Xiao, J. (2023). Blockchain-based dual-channel supply chain pricing decision and online channel selection strategy. Chinese *Journal of Management Science* ,35 (5), 29-38.
Liao, M., Fang, J., Han, L., Wen, L., Zheng, Q., Xia, G. (2023). Boosting eCommerce sales with livestreaming in B2B marketplace: A perspective on live streamers' competencies. *Journal of Business Research*, 167, 114167.
Lin, Z., Li, Y., & Chen M. (2023). Research on Live Broadcast Marketing Strategy in Dual-Channel Supply Chain. *Journal of Systems Science and Mathematical Sciences*. https://doi.org/10.12341/jssms22732
Liu, S., Hua, G., Cheng, T.C.E., & Choi, T.M. (2022a). Optimal pricing and quality decisions in supply chains with consumers' anticipated regret and online celebrity retailers. *IEEE Transactions on Engineering Management* ,1-15.
Liu, S., Hua, G., Kang, Y., Edwin Cheng, T.C., & Xu, Y. (2022b). What value does blockchain bring to the imported fresh food supply chain? *Transportation Research Part E: Logistics and Transportation Review*, *165*, 102859.
Liu, Y., Ma, D., Hu, J., & Zhang, Z.(2021). Sales mode selection of fresh food supply chain based on blockchain technology under different channel competition. *Computers & Industrial Engineering*, *162*, 107730.
Meng, L., Duan, S., Zhao, Y., Lü, K., & Chen, S.(2021). The impact of online celebrity in livestreaming E-commerce on purchase intention from the perspective of emotional contagion. *Journal of Retailing and Consumer Services*, *63*, 102733.
Nayal, K., Raut, R. D., Narkhede, B. E., Priyadarshinee, P., Panchal, G. B., & Gedam, V. V. (2023). Antecedents for blockchain technology-enabled sustainable agriculture supply chain. *Annals of operations research*, *327*(1), 293-337.
Niu, B., Dong, J., & Liu, Y., (2021a). Incentive alignment for blockchain adoption in medicine supply chains. *Transportation Research Part E: Logistics and Transportation Review,* 152, 102276.
Niu, B., Mu, Z., Cao, B., & Gao, J. (2021b). Should multinational firms implement blockchain to provide quality verification? *Transportation Research Part E: Logistics and Transportation Review*, *145*, 102121.
Niu, B., Yu, X., Li, Q., & Wang, Y. (2023). Gains and Losses of Key Opinion Leaders' Product Promotion in Livestream E-commerce. *Omega*, *117*, 102846.
Pandaily, (2020). Top Chinese Livestreamer Fined $138,000 for Selling Fake Bird's Nest Products. *https://pandaily.com/top-chinese-livestreamer-fined-138000-for-selling-fake-birds-nest-products/*.
Pan, R., Feng, J., & Zhao, Z. (2022). Fly with the wings of live-stream selling—Channel strategies with/without switching demand. *Production and Operations Management*, *31*(9), 3387-3399.
Park, H.J., & Lin, L.M. (2020). The effects of match-ups on the consumer attitudes toward internet celebrities and their live streaming contents in the context of product endorsement. *Journal of Retailing and Consumer Services*, *52*, 101934.
Parker, C., Ramdas, K., & Savva, N. (2016). Is IT Enough? Evidence from a Natural Experiment in India's Agriculture Markets. *Management Science*, *62*(9), 2481-2503.
Peng, X., Zhao, Z., Wang, X., Li, H., Xu, J., & Zhang, X.(2023). A review on blockchain smart contracts in the agri-food industry: Current state, application challenges and future trends. *Computers and Electronics in Agriculture*, *208*, 107776.
Salah, K., Nizamuddin, N., Jayaraman, R., Omar, M.,(2019). Blockchain-Based Soybean Traceability in Agricultural Supply Chain. *IEEE Access*, *7*, 73295-73305.
Sinayi, M., & Rasti-Barzoki, M.,(2018). A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention. *Journal of Cleaner Production*, *196*, 1443-1458.
Song, M.-X., & Yang Morgan, X. (2019). Leveraging core capabilities and environmental dynamism for food traceability and firm performance in a food supply chain: A moderated mediation model. *Journal of Integrative Agriculture*, *18*(8),

1820-1837.
Sun, Y., Shao, X., Li, X., Guo, Y., & Nie, K. (2019). How live streaming influences purchase intentions in social commerce: An IT affordance perspective. *Electronic Commerce Research and Applications*, *37*, 100886.
Tang, C.S., & Veelenturf, L.P. (2019). The strategic role of logistics in the industry 4.0 era. *Transportation Research Part E: Logistics and Transportation Review*, *129*, 1-11.
Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. *2016 13th International Conference on Service Systems and Service Management (ICSSSM)*, 1-6.
Tong, X., Chen, Y., Zhou, S., & Yang, S. (2022). How background visual complexity influences purchase intention in live streaming: The mediating role of emotion and the moderating role of gender. *Journal of Retailing and Consumer Services*, *67*, 103031.
Tönnissen, S., & Teuteberg, F. (2020). Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies. *International Journal of Information Management*, *52*, 101953.
Tortajada, C., & Lim, N.S.W. (2021). Food Security and COVID-19: Impacts and Resilience in Singapore. *Frontiers in Sustainable Food Systems*, *5*, 740780
Vangipuram, S.L.T., Mohanty, S.P., Kougianos, E., & Ray, C.(2022). agroString: Visibility and Provenance through a Private Blockchain Platform for Agricultural Dispense towards Consumers. *Sensors*, *22*(21), 8227.
Wongkitrungrueng, A., & Assarut, N. (2020). The role of live streaming in building consumer trust and engagement with social commerce sellers. *Journal of Business Research*, *117*, 543-556.
Wu, X.-Y., Fan, Z.-P., & Cao, B.-B. (2023). An analysis of strategies for adopting blockchain technology in the fresh product supply chain. *International Journal of Production Research*, *61*(11), 3717-3734.
Xiong, H., Chen, J., Yan, H., & Guo, H.(2023). Pricing and coordination of live e-commerce dual-channel supply chain considering the characteristics of anchors. *Journal of Industrial Engineering and Engineering Managemen*, *37*(04), 188-195.
Xu, X., & Choi, T.-M. (2021). Supply chain operations with online platforms under the cap-and-trade regulation: Impacts of using blockchain technology. *Transportation Research Part E: Logistics and Transportation Review*, *155*, 102491.
Xu, X., Yan, L., Choi, T.-M., & Cheng, T.C.E. (2023a). When Is It Wise to Use Blockchain for Platform Operations with Remanufacturing? *European Journal of Operational Research*, *309*(3), 1073-1090.
Xu, Y., Wang, J., Cao, K.(2023b). Interaction between joining platform blockchain technology and channel encroachment for fresh agricultural product firms. *International Transactions in Operational Research*.
Yan, B., Chen, X., Cai, C., & Guan, S.(2020). Supply chain coordination of fresh agricultural products based on consumer behavior. *Computers & Operations Research*, *123*, 105038.
Yan, B., Liu, Y., & Fan, J.(2022). Two-echelon fresh product supply chain with different transportation modes. *Annals of Operations Research*.
Ye, F., Liu, S., Li, Y., Zhan, Y., Cai, Z., & Kumar, A. (2022). Early Adopter or Follower? The Strategic Equilibrium of Blockchain Technology Adoption Strategy for Competing Agri-Food Supply Chains. *IEEE Transactions on Engineering Management*, 1-15.
Zhang, M., Qin, F., Wang, G.A., & Luo, C. (2020). The impact of live video streaming on online purchase intention. *The Service Industries Journal*, *40*(9-10), 656-681.
Zhang, S., Guo, D., & Li, X. (2023a). The rhythm of shopping: How background music placement in live streaming commerce affects consumer purchase intention. *Journal of Retailing and Consumer Services*, *75*, 103487.
Zhang, T., Dong, P., Chen, X., & Gong, Y. (2023b). The impacts of blockchain adoption on a dual-channel supply chain with risk-averse members. *Omega*, *114*, 102747.
Zhang, T., & Tang, Z. (2023). Should manufacturers open live streaming shopping channels? *Journal of Retailing and Consumer Services*, *71*, 103229.
Zhang, T., Tang, Z., & Han, Z. (2022a). Optimal online channel structure for multinational firms considering live streaming shopping. *Electronic Commerce Research and Applications*, *56*, 101198.
Zhang, X., Chen, H., & Liu, Z. (2022b). Operation strategy in an E-commerce platform supply chain: whether and how to introduce live streaming services? *International Transactions in Operational Research*. https://doi.org/10.1016/j.elerap.2023.101348
Zhao, G., Liu, S., Lopez, C., Lu, H., Elgueta, S., Chen, H., & Boshkoska, B.M. (2019). Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions. *Computers in Industry*, *109*, 83-99.
Zhao, Z., & Cheng, Y.(2022). Two-Stage Decision Model of Fresh Agricultural Products Supply Chain Based on Option Contract. *IEEE Access*, *10*, 119777-119795.
Zhou, J., Zhou, J., Ding, Y., & Wang, H. (2019). The magic of danmaku: A social interaction perspective of gift sending on live streaming platforms. *Electronic Commerce Research and Applications*, *34*, 100815.