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# A study of dual-channel supply chain pricing decisions considering consumer privacy concerns in the context of blockchain

**Xiang Yang Ren[a], Jia lin Tian[a] and Li min Wang[a*]**

[a]*School of Management Engineering and Business; Hebei University of Engineering, Handan, Hebei 056038, the P. R. China*
[b]*Industrial technical college of Santa Maria, Production Engineering post-graduation program, Avenue Roraima 1000, building 5, 97105-900 Santa Maria, Brazil*

**C H R O N I C L E**

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**A B S T R A C T**

Blockchain technology is introduced into the dual-channel supply chain system of online direct marketing and offline traditional retailing to solve the problem of opaque product sources and information asymmetry while also considering consumers' privacy concerns to increase their willingness to buy and improve enterprises' profitability. Based on the introduction of blockchain technology, the paper considers consumers' privacy concerns, uses the manufacturer-dominated Stackelberg game model to solve the equilibrium, and compares and analyzes the optimal pricing decisions and profits of supply chain members in different models before and after the introduction of blockchain technology. It is shown that when blockchain is not adopted, the rise in consumer sensitivity to false appraisal results leads to lower prices, and demand and pricing increase with the probability of the product being genuine; when blockchain is adopted, the increase in privacy concern costs will lead to lower demand and prices. Under a given condition, introducing blockchain technology can enhance the profits of all parties in the supply chain.



## 1. Introduction

Owing to the swift advancement of Internet technology in recent years, consumers have been asking for real-time, convenience, and diversified shopping has been growing. Online shopping has significantly influenced daily life in the country and has been preferred by several consumers (Chen et al., 2020). In the context of the continuous growth of the proportion of online shopping, more and more suppliers choose to open online direct sales channels based on offline channels, and this trend has brought significant competitive pressure on traditional retail channels (Chen et al., 2018). However, product information transparency is a key factor influencing consumers' purchasing decisions in both digital and physical channels (Xu et al., 2021). Manufacturers must meet consumers' desire for product traceability, they need to effectively mitigate channel conflicts while enhancing their profits and address consumers' demands for traceability due to questioning the authenticity of products. In recent years, under the dual-channel model, especially in the online channel, problems such as difficulty in authentication, mixing of real and fake products, and difficulty defending rights after buying fake products have occurred frequently. Negative news about product counterfeiting has weakened consumers' willingness to buy and hindered upward price adjustments, thus further compressing the profits of manufacturers and retailers and reducing market share, which is detrimental to the survival and growth of enterprises. For example, between 2013 and 2014, former Hermes employees and executives took advantage of their positions to steal core technology, produce imitation bags with trimmings and sell them at nearly half price, making a profit of more than 2 million euros, which has caused a huge negative impact on the brand's image; the French luxury brand Chanel had a large-scale perfume counterfeiting incident, and the substitute buyers, e-commerce platforms, and even shopping mall counters were all subjected to complaints from consumers about buying fake products at the Genuine price to buy fake goods, leading to a decline in consumer trust, which in turn affects brand sales. According to the OECD, the total value of counterfeit products in 2019 reached $464 billion, accounting for 2.5% of world trade. However, most enterprises lack openness and transparency in procurement, production, sales, and distribution, making it difficult to effectively monitor, resulting in the opacity of key product information becoming the norm (Saberi et al., 2019). According to the China

* Corresponding author Tel: (+86)13031450596
E-mail 2217206339@qq.com (L.M. Wang)
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Consumers' Association's analysis of complaints in the first half of 2024, product quality issues accounted for 21.07%, up 2.03% from 2023. This lack of transparency further reduces consumer trust in products and seriously affects the interests of various channels. The lack of transparency in information is an important issue that manufacturers must address when selling.

Given the above issues, manufacturers are beginning to focus on blockchain technology to address current challenges and market demands. Blockchain technology is a distributed ledger with the characteristics of decentralization, openness and transparency, and tamper-proof information, which provides a potential solution to solve the problems of opaque product information and data falsification (Hastig et al., 2020). The blockchain system may effectively integrate supply chain enterprises within a unified framework, and manufacturers can realize real-time information sharing and open transparency in all aspects of procurement, production, sales, and distribution, ensuring that every product distribution process is traceable, thus enhancing consumer trust in the products (Hsiao et al., 2022). In addition, applying blockchain technology can also effectively reduce channel conflicts caused by information asymmetry, maintain corporate reputation, and increase market share. Blockchain technology is widely used in the supply chain, substantially improving product information transparency (Saberi et al., 2019b). For example, luxury goods manufacturer LV uses blockchain technology to achieve product traceability and authenticity verification. LVMH, ConsenSys, and Microsoft jointly launched the AURA blockchain platform based on Ether and Microsoft Azure cloud services to track the supply chain of luxury goods to combat counterfeiting. However, there are obvious limitations in applying the traditional Bitcoin blockchain in specific environments (Sheng et al., 2020). For instance, the transparency and openness of blockchain improve data traceability and security, it also poses the potential risk of leaking sensitive information. Since blockchain technology requires all participants to share information, this highly transparent feature enhances trust while making private data easily exposed in the public domain. As the scope of application of blockchain technology continues to expand, the risk of consumers' private information leakage has become more apparent. For example, when applying blockchain technology, some enterprises usually require users to register their digital identities and provide personal information, including name, mobile number, address for email, credit card details, home phone number, and residential address. This process raises users' concerns about data storage, use, and protection (Li et al., 2020). While the transparency of blockchain is seen as a benefit, this feature also means that by having only one address, multiple addresses associated with it can be tracked. Consumers are thus concerned that this sensitive data may be misused, sold, or suffer privacy damage due to data leakage, eroding trust in companies and blockchain platforms. In addition, if the blockchain system is hacked, information leakage will be even more risky.

Based on the current state of development of e-tailing channels and the riskiness of blockchain technology, more and more e-commerce platforms are considering whether to use blockchain technology effectively to reduce costs and promote economic growth. This study focuses on the positive effects of the inherent traceability properties of blockchain technology while considering the impact of factors such as consumer privacy concerns on dual-channel supply chain pricing and exposes the following issues:

RQ (1): How does blockchain technology affect dual-channel supply chain pricing decisions?
RQ (2): How do important factors like consumer privacy affect dual-channel blockchain choice equilibrium strategies?

Therefore, this study mainly adopts the Stackelberg model method to study the dual-channel supply chain decision-making dilemma, explore the influence of blockchain technology, consumer privacy concerns, and other factors on supply chain decisions, and provide strategic suggestions for promoting the implementation of blockchain technology within the dual-channel supply chain.

## 2. Literature Review

### *2.1 Cutting-edge research on competition issues and pricing strategies within dual-channel supply chains*

Before the rise of e-commerce, the supply chain structure was relatively simple. There was a relative lack of industrial resources and limited manufacturing capacity, and firms relied mainly on the traditional single channel, whereby manufacturers delivered their products to consumers through wholesalers or retailers. Consumers mainly purchased products through brick-and-mortar stores, and the core tasks of supply chain management focused on traditional issues such as optimizing inventory, logistics, and production planning. In this model, manufacturers and retailers have a clear partnership but face price control and inventory optimization challenges. However, with the diversification of market demand and the increase in production capacity, the single-channel model has gradually revealed its limitations in adapting to the diversified needs of consumers. However, the rise of e-commerce has completely broken the physical boundaries of the traditional supply chain and built a new bridge between manufacturers and consumers. In the early stage of e-commerce development, Chiang et al. (2003) studied how e-commerce drives manufacturers to redesign the traditional channel structure through direct sales channels to assess consumer acceptance of online sales, laying a theoretical foundation for developing dual-channel supply chains. With the in-depth application of Internet technology, many enterprises have actively expanded online channels, and manufacturers have gradually recognized the importance of omnichannel services, which has led to the formation of a dual-channel model that meets the diverse needs of consumers (Karimabadi et al., 2020; Liu et al., 2016). However, there is inevitable competition among both online and offline channels, which brings new challenges to dual-channel management.Both domestically and internationally, researchers have undertaken comprehensive analyses of price and service competition inside dual channels to investigate the phenomenon of dual-channel competition further. Zhou et al. (2022) developed a price competition model featuring two rival supply chains and determined that the manufacturer's decision is influenced by bargaining power, product quality, and the expenses associated with quality enhancement. He noted that sales volume rises while sales price declines when both manufacturers opt to negotiate. On the other hand, Nair et al. (2022) analyzed the optimal price and profit under three centralized operation scenarios, emphasizing that the leader's optimal price is always greater than or equal to the follower's in sequential games, while the market price is lowest in synchronous pricing scenarios. He et al. (2020) examined the issue of price rivalry within a dual-channel supply chain by evaluating the information symmetry regarding the pricing and services of both digital and physical channels. Subsequently, DL et al. (2022) extended the research model and found that information asymmetry has a significant impact on suppliers' channel decisions in a market environment with high demand volatility. To further explore the impact of information asymmetry, Liu et al. (2024) proposed a coordination mechanism to encourage information sharing among supply chain parties, but the results showed that asymmetric information exacerbates the bias of optimal decisions among supply chain members. Information sharing is usually beneficial to manufacturers, while it may hurt retailers. To comprehend the dynamic mechanism of service competition in a dual-channel environment, Yanfei et al. (2023) focused on the fair concern behavior and consumer preferences of physical retailers in a dual-channel system and constructed a game model of service competition, which analyzed in depth the impact of service competition strategies on consumer choices in different fair concern situations. Furthermore, some researchers have conducted an in-depth examination of the pricing tactics employed by dual-channel supply chains (Pakdel Mehrabani et al., 2021; Rong et al., 2022; Wang et al.,2022). Specifically, Dai et al. (2019) investigated the impact of dual-channel competition and coordination on pricing by modeling a hybrid dual-channel supply chain, evaluating the pricing strategies of producers and retailers under different competition and coordination methods, and their effect on the performance of the supply chain. To thoroughly examine the influence of consumer expectations on merchants' pricing strategies, (Du et al.,2019) examined the influence of consumer uncertainty on online and offline channels on consumer expectations and investigated retailers' optimal pricing strategies under inventory constraints. Sun et al. (2020) constructed a pricing decision model with dual-channel retailers and traditional retailers as leaders and explored pricing strategies under this model, revealing the importance of the competitive market environment and consumer demand characteristics for revenue maximization. From the perspective of retailer pricing, Yang et al. (2022) investigated how changes in platform commission ratio, rights structure, and consumer multichannel preference effect supply chain participants' pricing strategies and channel selections across three dual-channel structure models, highlighting its complexity and dynamics. From the perspective of consumers, Liu et al. (2022) examined the effect of consumer overconfidence on demand, pricing decisions, and profits and constructed a research framework for dual-channel supply chains, revealing how overconfidence leads to the overestimation of product value by consumers, which in turn affects price-setting strategies.

### *2.2 Current Research Status of Blockchain Technology in Supply Chain*

Blockchain technology has been increasingly used in supply chain management in recent years. The blockchain concept was first proposed by Nakamoto et al. (2008), and with the rise of Bitcoin, it triggered the attention of academics and various organizations. Since then, blockchain technology has rapidly expanded into several fields, and Manzoor et al. (2022) state that blockchain technology has disruptive potential and wide application prospects within the realm of supply chain management. Blockchain technology can enhance the openness and traceability of the supply chain, increasing participant trust and reducing transaction costs. Kshetri (2018a) and Chang et al. (2018) examined the impact of blockchain technology on supply chain management via a stochastic model, and the results showed that blockchain could optimize production, ordering, pricing, and inventory decisions. Its decentralized nature makes information sharing more efficient and secure, thus optimizing the supply chain process. Some other scholars have also studied the specific application of blockchain in the supply chain. Cao et al. (2022) pointed out that blockchain technology significantly changes enterprises' business models, continuously promotes technological innovation, and plays a key role in industrial restructuring. Blockchain, being a decentralized ledger system, significantly enhances the transparency and accessibility of information (Baharmand et al., 2021; Bai et al., 2020). The blockchain system can seamlessly unite diverse corporate organizations within the supply chain to achieve mutual supervision and benefit sharing. Allen et al. (2019) and Kshetri (2018) indicated that blockchain also diminishes the trade cost of producing and coordinating credible information inside the supply chain. In addition, blockchain technology can significantly reduce the risk of fraud. Jiang and Chen (2021) and Shen et al. (2022) show that blockchain adoption improves product traceability and transparency and provides consumers with more reliable purchase guarantees, thus effectively curbing counterfeiting. Ji et al. (2022) finds that manufacturers introducing blockchain technology are more likely to make significant profits, suggesting that its information transparency and traceability advantages will change the strategic choices and benefit distribution of all entities along the supply chain. Despite the many advantages of information transparency in applying blockchain technology, its potential negative impacts cannot be ignored. Transparency may raise the risk of privacy breaches, where consumers' personal data and transaction information are publicly recorded on the blockchain, exposing them to the threat of information misuse. Leakage of privacy may affect consumers' purchasing decisions and brand loyalty and raise concerns about privacy issues, which may reduce the effectiveness of blockchain (Pun et al., 2021; Zhang et al., 2022). Therefore, privacy protection must be emphasized while advancing blockchain technology to ensure sustainability and social acceptance. With the increased probability of counterfeiting branded products such as luxury goods, the adoption of blockchain technology has become an effort to solve the problem at the source. Many studies have proposed that blockchain technology possesses the potential for application in the supply chain's traceability system. These studies have important academic value and support enterprises' decisions in practice. However, there are still some limitations to research on blockchain technology:

(1) Existing research on dual-channel competition has not yet fully explored the impact of information asymmetry on consumer channel choice behavior. The opacity of product information may increase consumers' distrust of online channels, thus affecting their decision-making process. Therefore, this factor can provide a more comprehensive understanding of consumer behavior patterns in a dual-channel environment and provide a more in-depth perspective for related theoretical studies.

(2) Current research mainly discusses blockchain's advantages in supply chain management and less deeply explores its negative impacts on the decision-making of each member of the supply chain. For example, blockchain's openness and transparency may lead to the leakage of important information (Cai et al., 2021; Liu et al., 2022). By exploring these factors, feasible solution strategies and policy recommendations can be provided to decision-makers. Given this, this paper assumes that offline traditional retail channels and online network channels choose whether to adopt blockchain. It explores the optimal pricing model under the two joint blockchain strategies and analyzes the equilibrium blockchain adoption strategy in the dual-channel supply chain by comparing model profits. The study's results can provide practical references for applying blockchain in dual-channel supply chains.

## 3. Model description and assumptions

### *3.1 Description of the model*

The paper posits a dual-tier supply chain comprising manufacturers and merchants. Manufacturers are the principal actors in this chain, while merchants are the subordinate participants, adhering to the Stackelberg model. The vendor adheres to the game. Both parties maintain absolute rationality and consider maximizing their interests. Assume the manufacturer produces only one product within a manufacturer-led dual-channel supply chain. First of all, the dual-channel is categorized into two modes: network direct sales and retail distribution, using a pricing model devoid of blockchain technology developed and analyzed by Stackelberg game equilibrium. Second, the pricing decision model, post-introduction of blockchain technology, is formulated and resolved to utilize the Stackelberg game equilibrium. A comparative analysis of pricing and profit within the supply chain model, both before and after the implementation of blockchain technology, is undertaken to examine the impact of blockchain technology, consumer privacy concerns, and other variables on the supply chain's pricing decisions. This research analyzes an authentic dual-channel supply chain comprising a manufacturer and a retailer. Fig. 1 depicts the fundamental model of the supply chain.

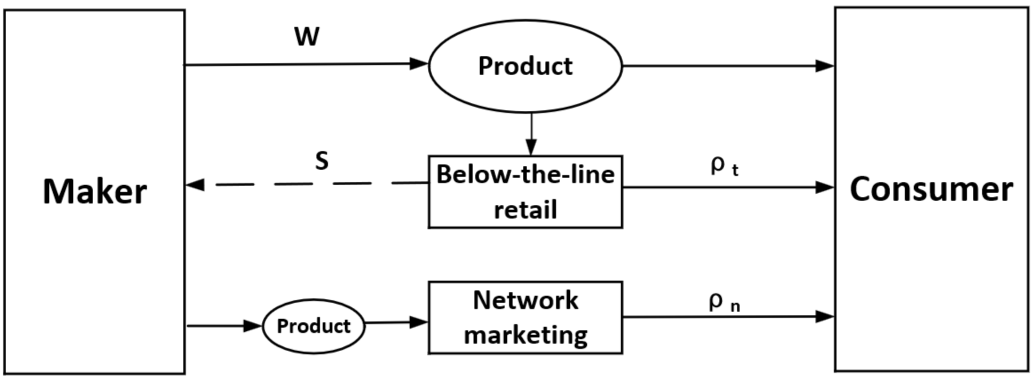



**Fig. 1.** Product Dual Channel Supply Chain Sales Model

### *3.2 Basic assumptions and notation*

This section describes the basic assumptions and the main notations proposed to solve the problem and make the description and analysis of the model more concise.

(1) Manufacturers, traditional retailers, and e-tailers maintain neutral behavior toward risk.
(2) For simplification, assume that the manufacturer's unit production cost is negligible.
(3) The testing and evaluation of products after production takes time. When blockchain technology is not adopted, the time for testing and evaluation is $T$, while after blockchain technology is adopted, the time for testing and evaluation is shortened to $t$, and $T > t$.

See Table 1 for specific symbols and their meanings.

**Table 1**
Explanation of parameters and symbols

| parameters | Description of symbols |
|---|---|
| $A$ | Potential demand for the product in the market |
| $F$ | Market share of retail by offline retailers |
| $1\text{-}f$ | Market share of manufacturers' direct online sales |
| $\rho_d^{NS}$ | E-tail price |
| $\rho_r^{NS}$ | Traditional retail prices |
| $\Omega$ | denotes the cross-elasticity price coefficient between the dual channels (0 < ω < 1) |
| $\delta$ | Sensitivity coefficients for testing false probabilities |
| $\beta$ | Sensitivity factor for time needed for product testing and evaluation |
| $\gamma$ | Fixed one-time fee for manufacturers to introduce blockchain technology |
| $s$ | Unit verification fees paid by traditional retailers to manufacturers under blockchain technology |
| $\lambda$ | Consumers will bear the cost of privacy breaches |
| $C$ | C denotes the direct selling cost per unit of product sales in the manufacturer's direct selling channel |
| $m$ | The probability that the product is true |
| $1\text{-}m$ | The probability that the product is false (must be true with blockchain) |

## 4. Dual-channel structural model without blockchain technology

### *4.1 Supply Chain Decision Modeling Considering Consumer Privacy without Blockchain Technology*

In the supply chain distribution system comprising manufacturers and retailers, manufacturers are the primary entities, while retailers are the subordinate participants. Manufacturers sell part of their products directly to consumers through online sales platforms, while the other part is provided to offline retailers for sale through the brick-and-mortar model. Single-channel demand is influenced not solely by the price of this channel; the same product price competition exists and is therefore also affected by the price of other channels of cross-influence; the market demand is randomized, and there are other uncertainties in the influence of the factors. In this dual-channel supply chain, the manufacturer or maker first wholesales to the retailer at wholesale price $w^{NS}$ , and the retailer subsequently sells out at the offline retail price $\rho_t^{NS}$ , while the producer retails straight to the consumer at the website's direct selling price $\rho_n^{NS}$ . The market demand encountered by the conventional retail channel and the internet sales channel is as follows:

$$D_t^{NS} = fa - \rho_t^{NS} + \omega\rho_n^{NS} - \delta T - \beta(1-m) \tag{1}$$
$$D_n^{NS} = (1-f)a - \rho_n^{NS} + \omega\rho_t^{NS} - \delta T - \beta(1-m) \tag{2}$$

The manufacturer-driven dual-channel supply chain pricing model has a two-stage Stackelberg model between the manufacturer and the merchant. The manufacturer first determines the wholesale pricing for the retail channel $w^{NS}$ in comparison to the direct online price $\rho_n^{NS}$ , and subsequently establishes the offline retail price $\rho_t^{NS}$ according to the product's wholesale rate $w^{NS}$ . The aggregate revenue function for the manufacturer and retailer inside this dual-channel model is:

$$\Pi_M^{NS} = w^{NS} D_t^{NS} + (\rho_n^{NS} - C) D_n^{NS} \tag{3}$$
$$\Pi_R^{NS} = (\rho_t^{NS} - w)\, D_t^{NS} \tag{4}$$

The model is solved by inverse induction method, using $\Pi_R^{NS}$ to $\rho_t^{NS}$ for the second order partial derivatives, since $\frac{\partial^2 \Pi_R^{NS}}{\partial^2 \rho_t^{NS}} < 0$, that is to say, indicating that there is the existence of a great value of $\rho_t^{NS}$ for the first order partial derivatives and solve for it, and the obtained $\rho_t^{NS}$ is substituted into the equation (2), and can be obtained by solving the solution of $\frac{\partial \Pi_M^{NS}}{\partial w^{NS}} = 0$ and $\frac{\partial \Pi_M^{NS}}{\partial \rho_n^{NS}} =$ 0 in conjunction with each other:

$$\begin{cases} \rho_n^{NS*} = \dfrac{\beta - a - C + T_1\delta + af - \beta m + \beta\omega + C\omega^2 + T\delta\omega - af\omega - \beta m\omega}{2\left(\omega^2 - 1\right)} \\ w^{NS*} = \dfrac{\beta + T_1\delta - af - \beta m - a\omega + \beta\omega + T\delta\omega + af\omega - \beta m\omega}{2\left(\omega^2 - 1\right)} \end{cases} \tag{5}$$

The solution can be obtained by substituting back the obtained $w^{NS*}$ and $\rho_n^{NS*}$:

$$\rho_t^{NS*} = \frac{C\omega(\omega^2-1)-3(af+\beta m-T\delta-\beta)+2\omega(\beta-a)-\beta\omega^2+\omega(T\delta-\beta m)(2-\omega)+af\omega(2+\omega)}{4\left(\omega^2-1\right)} \tag{6}$$

Substituting the obtained $w^{NS*}$, $\rho_n^{NS*}$ and $\rho_t^{NS*}$ into Eq. (3) and Eq. (4) respectively gives $\Pi_M^{NS*}$ and $\Pi_R^{NS*}$ as:

$$\Pi_M^{NS*} = \frac{\begin{aligned} &C^2(\omega^4-3\omega^2+2)+CT\gamma(-2\omega^3-4\omega^2+2\omega+4)+Caf(2\omega^3-4\omega^2-2\omega+4) \\ &+Ca(4\omega^2-4)+C\beta m(2\omega^3+4\omega^2-2\omega-4)+C\beta(-2\omega^3-4\omega^2+2\omega+4) \\ &+T^2\gamma^2(\omega^2+4\omega+3)+Taf\gamma(-2\omega^2+2)+Ta\gamma(-4\omega-4)+T\beta\gamma m(-2\omega^2-8\omega-6) \\ &+T\beta\gamma(2\omega^2+8\omega+6)+a^2f^2(\omega^2-4\omega+3)+2a^2+a\beta fm(2\omega^2-2) \\ &+a\beta f(-2\omega^2+2)+4a\beta m\omega+4a\beta m-4a\beta\omega-4a\beta+\beta^2m^2(\omega^2+4\omega+3) \\ &-2\beta^2m\omega(\omega+4)-6\beta^2m+\beta^2\omega(\omega+4)+3\beta^2 \end{aligned}}{8(1-\omega^2)} \tag{7}$$

$$\Pi_R^{NS*} = \frac{\left(C\omega-\beta-T\delta+af+\beta m\right)^2}{16} \tag{8}$$

*4.2 Analysis of Supply Chain Decision-Making Models without Using Blockchain Technology*

**Proposition 1:** In a dual-channel supply chain model that takes into account consumers' privacy concerns, the sensitivity coefficients of consumers to the probability of a false test result $\delta$ are negatively correlated with the manufacturer's retail price, the direct selling price on the Internet, and the merchant's retail price, respectively. In two distinct dual-channel models, the first-order partial derivatives of the ideal wholesale price and the optimal retail price for the sensitivity coefficient of consumers regarding the likelihood of false test results are derived, revealing how consumers' trust in the product affects price fluctuations:

① $\frac{\partial \rho_n^{NS*}}{\partial \beta} = \frac{\partial w^{NS*}}{\partial \beta} < 0$ ② $\frac{\partial \rho_t^{NS*}}{\partial \beta} < 0$

**Proof:** The first order partial derivative $\delta$ concerning 0< $\omega$< 1 is obtained for the optimal wholesale price, optimal retail price, and optimal direct selling price of the product:

① $\frac{\partial \rho_n^{NS*}}{\partial \delta} = \frac{\partial w^{NS*}}{\partial \delta} = \frac{1-m}{2(\omega-1)} < 0$, ($0<m<1$, $0<\omega<1$)

② $\frac{\partial \rho_t^{NS*}}{\partial \delta} = \frac{m\omega-3m-\omega+3}{4\left(\omega-1\right)} < 0$, ($0<m<1$, $0<\omega<1$)

Proposition 1 suggests that the larger the sensitivity coefficient $\delta$ of consumers to the probability of the test result being false, the lower the willingness to pay for the product, which creates some obstacles for retailers to increase their prices. This will simultaneously decrease the manufacturer's wholesale price, the network directly selling price, and the retailer's retail price, diminishing earnings for both the producer and the retailer. For consumers, the authenticity of the product cannot be guaranteed. Not only will it increase the cost of identification, but at the same time, bringing consumers a sense of bad consumer experience will hurt the price increase, and consumer spending intentions will also decline.

**Proposition 2:** In a dual-channel supply chain model that accounts for consumer privacy concerns, m ($0<m<1$) exhibits a positive correlation with the manufacturer's completely price, the website's direct sales price, and the retailer's retail pricing, respectively. For two distinct dual-channel models, compute the first-order partial derivations of the probability that the optimal wholesale and retail prices of the product are accurate at the time of the blockchain, as well as the variation in the influence of this probability on the product's price:

① $\frac{\partial \rho_n^{NS*}}{\partial m} = \frac{\partial w^{NS*}}{\partial m} > 0$ ② $\frac{\partial \rho_t^{NS*}}{\partial m} > 0$

**Proof:** Determine the first-order partial derivative form for the optimal wholesale, retail, and direct selling prices of the product, and 0< $\omega$< 1 is obtained:

① $\frac{\partial \rho_n^{NS*}}{\partial m} = \frac{\partial w^{NS*}}{\partial m} = \frac{-\beta}{2(\omega-1)}$ >0, (0< $\omega$ <1)

② $\frac{\partial \rho_t^{NS*}}{\partial m} = \frac{\beta(\omega-3)}{4(\omega-1)}$ >0, (0< $\omega$ <1)

Proposition 2 suggests that the greater the probability m(0 < m < 1) that a product is genuine without a blockchain, the higher the willingness to pay for the product. When consumers purchase products without clear authenticity identification, they usually purchase them based on their subjective judgment. The greater the consumer's willingness to spend, the bigger the demand for the goods via the conventional retail channel. To generate higher profits, retailers tend to increase the retail price of their products, which in turn pushes up overall profits. At the same time, manufacturers adjust their wholesale prices to enhance their profitability. However, when a manufacturer opens a direct sales channel to attract more consumers, it usually sells its products directly to consumers at a relatively low price, thus creating a competitive price advantage and further expanding its market share.

## 5 Dual-channel structural model using blockchain technology

### *5.1 Supply chain model construction with the introduction of blockchain technology*

To address the issue of consumers verifying product authenticity, the manufacturer integrates blockchain technology into the dual-channel supply chain, establishing a blockchain-based dual-channel supply chain that considers consumers' privacy concerns. This ensures the veracity of the product's authenticity verification. Furthermore, it allows for the assessment of market demand for both the conventional retail and e-commerce sales channels following the implementation of blockchain technology:

$$D_t^{WS} = fa - \rho_t^{WS} + \omega\rho_n^{WS} - \delta t - \lambda \tag{9}$$

$$D_n^{WS} = (1-f)a - \rho_n^{WS} + \omega\rho_t^{WS} - \delta t - \lambda \tag{10}$$

To solve the dual-channel supply chain model, WS, with the introduction of blockchain technology, $\Pi_M^{WS}$ denotes the manufacturer's profit, $\Pi_R^{WS}$ the retailer's profit, and the profit functions of the manufacturer and the retailer, respectively:

$$\Pi_M^{WS} = (w^{WS} + s)D_t^{WS} + \rho_n^{WS} D_n^{WS} - \gamma \tag{11}$$

$$\Pi_R^{WS} = (\rho_t^{WS} - w^{WS} - s)\, D_t^{WS} \tag{12}$$

The model is solved by the inverse induction method by taking the second-order partial derivatives of $\Pi_R^{WS}$ to $\rho_t^{WS}$ concerning, and since $\frac{\partial^2 \Pi_R^{WS}}{\partial^2 \rho_t^{WS}}$ <0, that is to say, it indicates the existence of a great value, the first-order partial derivatives are taken $\rho_t^{WS}$ concerning and solved, and the obtained $\rho_t^{WS}$ is substituted into Eq. (10), and the solution is obtained by solving the problem for the conjunction of $\frac{\partial \Pi_M^{WS}}{\partial w^{WS}}$ and $\frac{\partial \Pi_M^{WS}}{\partial \rho_n^{WS}}$ =0:

$$\begin{cases} w^{WS}* = \dfrac{\lambda + 2s + \lambda\omega - af - a\omega + \delta t - 2\omega^2 s + af\omega + \delta\omega t}{2(\omega^2 - 1)} \\ \rho_n^{WS}* = \dfrac{\lambda - a + \lambda\omega + af + \delta t - af\omega + \delta\omega t}{2(\omega^2 - 1)} \end{cases} \tag{13}$$

The solution can be obtained by substituting back the obtained $w^{WS*}$ and $\rho_n^{WS*}$ :

$$\rho_t^{WS}* = \frac{3\lambda + 2\lambda\omega - 3af - 2a\omega + 3\delta t - \lambda\omega^2 - \delta\omega^2 t + 2af\omega + 2\delta\omega t + af\omega^2}{4(\omega^2 - 1)} \tag{14}$$

Substituting the obtained $w^{WS*}$ , $\rho_n^{WS*}$ and $\rho_t^{WS*}$ information into Eq. (11) and Eq. (12) respectively give $\Pi_M^{WS*}$ and $\Pi_R^{WS*}$ as:

$$\Pi_M^{WS*} = -\frac{\begin{array}{l}\lambda^2\omega^2 + 4\lambda^2\omega + 3\lambda^2 - 2\lambda a f\omega^2 + 2\lambda a f - 4\lambda a\omega - 4\lambda a + 2\lambda\delta\omega^2 t + 8\lambda\delta\omega t \\ +6\lambda\delta t + a^2 f^2\omega^2 - 4a^2 f^2\omega + 3a^2 f^2 + 4a^2 f\omega - 4a^2 f + 2a^2 - 2af\delta\omega^2 t \\ +2af\delta t - 4a\delta\omega t - 4a\delta t + \delta^2\omega^2 t^2 + 4\delta^2\omega t^2 + 3\delta^2 t^2 + 8y\omega^2 - 8y\end{array}}{8\left(\omega^2 - 1\right)} \tag{15}$$

$$\Pi_R^{WS*} = \frac{\left(\lambda - af + \delta T_2\right)^2}{16} \tag{16}$$

*5.2 Supply Chain Decision Modeling with the Introduction of Blockchain Technology and Consideration of Consumer Privacy*

**Proposition 3:** In two distinct dual-channel models incorporating blockchain technology, the influence of consumers' privacy concern costs on product price variations as:

① $\frac{\partial \rho_n^{WS*}}{\partial \lambda} = \frac{\partial w^{WS*}}{\partial \lambda} < 0$ ② $\frac{\partial \rho_t^{WS*}}{\partial \lambda} < 0$

**Proof:** Determine the first-order partial derivative for λ for the optimal wholesale pricing, optimal retail price, and optimal direct selling price of the product, given that $0 < \omega < 1$:

① $\frac{\partial \rho_n^{WS*}}{\partial \lambda} = \frac{\partial w^{WS*}}{\partial \lambda} = \frac{1}{2(\omega - 1)} < 0$

② $\frac{\partial \rho_t^{WS*}}{\partial \lambda} = \frac{-\omega^2 + 2\omega + 3}{4\left(\omega^2 - 1\right)} = \frac{3 - \omega}{4(\omega - 1)} < 0$

**Proposition 3 suggests that** the cost of consumer privacy concerns is negatively related to supply chain operations, with both selling price and demand decreasing as the cost increases. The cost of privacy concerns reflects how much consumers value their privacy and security. The more consumers care about protecting their privacy and the more they worry about privacy breaches, the higher the cost of privacy breaches (i.e., the higher the cost of), which leads to a decrease in the perceived value of the product, a rise in the psychological burden, and a decrease in willingness to pay. This reduced willingness to pay forces retailers to attract consumers by lowering retail prices to remain competitive. At the same time, manufacturers need to reduce wholesale prices, which in turn cuts R&D costs. The equilibrium strategy of the dual-channel blockchain is closely related to the consumers' trust in the original product and the consumers' privacy concern cost λ.

**Proposition 4:**

① $\delta < \frac{\lambda + \beta m - \beta - 2\omega s + 2s}{t - T}$ then, $w^{WS*} > w^{NS*}$;

② $\delta < \frac{C(1-\omega) + \lambda + \beta m - \beta}{T - t}$ then, $\rho_n^{WS*} > \rho_n^{NS*}$;

③ $\delta < \frac{C\omega - C\omega^2 - \lambda\omega + 3\lambda - \beta m\omega + 3\beta m + \beta\omega - 3\beta}{T\omega - 3T - \omega t + 3t}$ then, $\rho_t^{WS*} > \rho_t^{NS*}$;

④ $\beta < \frac{\lambda - T\delta + \delta t - 2\omega s + 2s}{m - 1}$ then, $w^{WS*} > w^{NS*}$;

⑤ $\beta < \frac{C - C\omega + \lambda - T\delta + \delta t}{m - 1}$ then, $\rho_n^{WS*} > \rho_n^{NS*}$;

⑥ $\beta < \frac{C\omega^2 - C\omega + \lambda\omega - 3\lambda - T\delta\omega + 3T\delta + \delta\omega t - 3\delta t}{m\omega - 3m - \omega + 3}$ then, $\rho_t^{WS*} > \rho_t^{NS*}$;

**Proof:** subtracting the wholesale prices before and after the introduction of blockchain technology yields:

$w^{WS*} - w^{NS*} = \frac{\lambda + 2s + \lambda\omega + \delta t - 2\omega^2 s + \delta\omega t - \beta - T\delta + \beta m - \beta\omega - T\delta\omega + \beta m\omega}{2\left(\omega^2 - 1\right)}$; let $w^{WS*} - w^{NS*} > 0$, then

$\delta < \dfrac{\lambda + \beta m - \beta - 2\omega s + 2s}{t - T}$; similarly, let $\rho_n^{WS*} - \rho_n^{NS*} > 0$, let $\rho_t^{WS*} - \rho_t^{NS*} > 0$, $\Pi_M^{WS*} - \Pi_M^{NS*} > 0$, $\Pi_R^{WS*} - \Pi_R^{NS*} > 0$, and β ditto.

**Proposition 4 suggests that** retailers invest in blockchain technology to increase profits without jeopardizing manufacturers' profits. Therefore, the research will focus on the critical conditions under which retailers introduce blockchain technology to maximize the profits of all parties. When δ and β are below a particular threshold, adopting blockchain technology reduces wholesale prices, online direct sales prices, and traditional retail prices compared to not using blockchain technology. Conversely, when δ and β exceed that threshold, the abovementioned prices and profits will be higher with the adoption of blockchain technology than they would have been without it. Specifically, when δ and β exceed that threshold, consumers value the inspection time of the product and care more about the time required for inspection and the authenticity of the inspection results, and consumers would rather pay a higher price for more reliable and prompt service. At this point, the consumer's concern for privacy can be offset. In this case, companies' introduction of blockchain technology can help increase consumer satisfaction, which in turn can significantly increase the profits of retailers and manufacturers.

## 6. Quantitative simulation analysis

To validate the accuracy of the aforementioned inference, the parameters mentioned above are assigned values so that a=100, f=0.5, ω=0.5, C=10, s=10, δ=0.6, T=2, t=1, β=0.4, m=0.75, γ=1000, and λ=10; the subsequent numerical simulation study evaluates the price decisions of each participant in a dual-channel supply chain, considering the impact of various parameters. The pricing decisions of members, associated profit comparisons, and outcomes are as follows. When other data are constant and β ∈ (0,5), substituting Eq. (5), Eq. (6), Eq. (13), and Eq. (14) yields the results shown in Fig. 2.

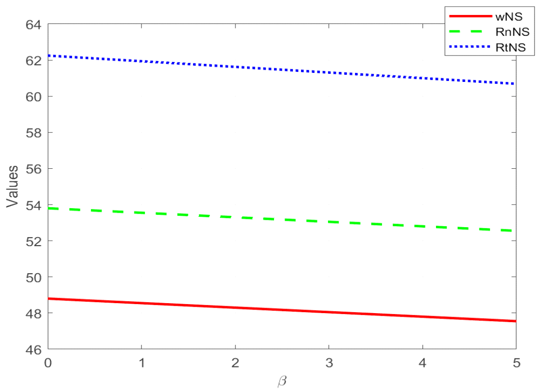



**Fig. 2.** Schematic representation of pricing in the model as a function of β

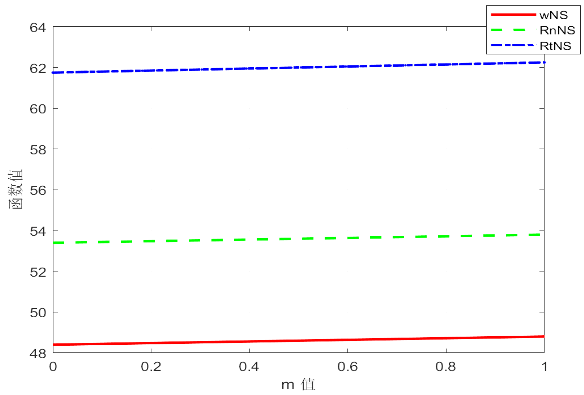



**Fig. 3.** Schematic representation of the variation of pricing with m in the model

Fig. 2 illustrates that as the coefficient of consumer sensitivity for the time needed for product inspection and evaluation ranges from 0 to 5, the wholesale price, offline retail price, and the pricing for internet direct sales all diminish with an increase in the coefficient of consumer sensitivity to the likelihood of erroneous product inspection results, corroborating the findings from Proposition 1. When the other data are unchanged and m ∈ (0,1), substituting Eq. (5), Eq. (6), Eq. (13), and Eq. (14) yields the results shown in Fig. 3. As seen in Fig. 3, when consumers' sensitivity coefficient to the probability of the product test result being false varies between 0 and 1, the wholesale price, offline retail price, and the pricing for internet direct sales all increase as consumers' sensitivity coefficient to the likelihood of erroneous product test results rises, which is in line with the conclusion obtained from Proposition 2. When the other data are unchanged and λ ∈ (0,50), substituting Eq. (5), Eq. (6), Eq. (13), and Eq. (14) yields the results shown in Fig. 4.

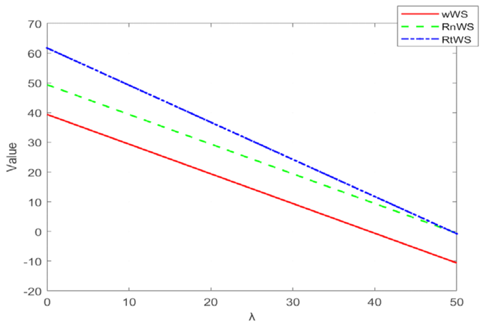
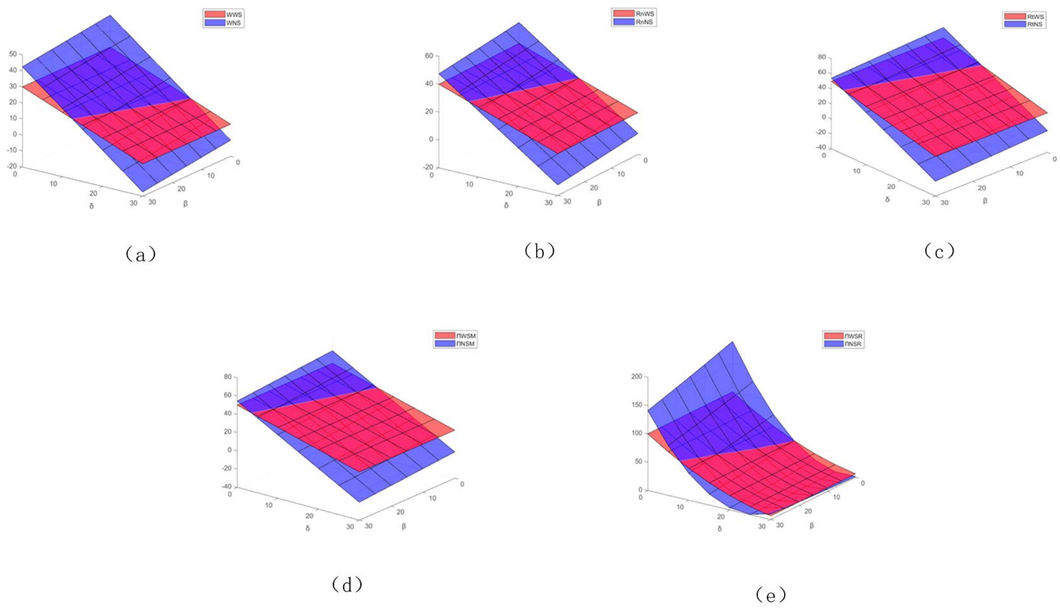



**Fig. 4.** Schematic representation of the variation of pricing with λ in the model

As seen in Fig. 4, when the cost that consumers will suffer from privacy breaches varies between 0 and 50, wholesale prices, offline retail prices, and the pricing for internet direct sales all decrease as the cost that consumers will suffer from privacy breaches increases, consistent with the conclusion obtained from Proposition 3.



(a) (b) (c) (d) (e)

**Fig. 5.** The information of the best wholesale price

From Fig. 5, the best wholesale price for manufacturers and the optimal retail price for retailers diminish with escalation δ and β, irrespective of the adoption of blockchain technology. The decrease in product pricing is more significant in the absence of blockchain technology. This indicates that when these two parameters increase, the cost pressure among members in the supply chain also increases, leading to a conservative pricing strategy. In addition, the implementation of blockchain technology is accompanied by additional costs, so the product pricing increases accordingly, and the following relationship exists: $w^{WS*} > w^{NS*}$, $\rho_n^{WS*} > \rho_n^{NS*}$, $\rho_t^{WS*} > \rho_t^{NS*}$, $\Pi_M^{WS*} > \Pi_M^{NS*}$, $\Pi_R^{WS*} > \Pi_R^{NS*}$ .Specifically, the optimal wholesale price of the manufacturer, the optimal retail price of the direct sales channel, and the optimal retail price of the offline retailer are all higher than the corresponding prices without blockchain technology, which is consistent with the conclusion of Proposition 4.

## 7. Conclusion

This research examines the alterations in two-channel models pre- and post-implementation of blockchain technology, focusing on the price issue inside a dual-channel supply chain. The research introduces key parameters such as the cost of consumer privacy concerns, the sensitivity coefficient regarding the duration necessary for product inspection and evaluation, and the probability of product authenticity and explores the pricing decisions in different models with and without blockchain technology in a manufacturer-driven context. Studies have shown that in the absence of blockchain adoption, manufacturers' wholesale prices, straight direct prices, and retailers' retail prices decline as consumer sensitivity to the likelihood of a false test result increases. Specifically, introducing blockchain technology provides an advantage only when the sensitivity coefficient of the product examination and evaluation time reaches a certain threshold with the sensitivity coefficient of the product authenticity result. At the same time, when consumers are more sensitive to product authenticity and the probability of authenticity grows, they demonstrate a greater willingness to pay elevated prices to ensure authenticity, resulting in increased demand in traditional retail channels and subsequent price escalation. When blockchain is adopted, the cost of privacy concerns becomes a factor, and as the cost of privacy concerns increases, selling prices and demand fall, and pricing decreases accordingly. Irrespective of the use of blockchain technology is adopted, as the parameters δ and β rise, the manufacturer's optimal wholesale price and the retailer's optimal retail price fall, and by a greater amount when blockchain is not adopted. By analyzing the above findings, the following management insights can be offered:

(1) To enhance the promotion of blockchain technology, it is necessary to pay attention to consumer privacy and security and the value of technology applications. Technically, the secrecy of consumer data should be safeguarded through mechanisms such as digital encryption; institutionally, the government ought to enhance the regulation and penalties for information leaking to mitigate customers' apprehensions about privacy breaches through the dual safeguards of technological and institutional frameworks.

(2) The application value of blockchain is mainly reflected in enhancing product trust and reducing the use cost. Enterprises should increase R&D investment in blockchain technology to enhance the transparency of each link in the supply chain and

realize product traceability so that consumers and regulators can conveniently trace the whole process of the products to guarantee quality and authenticity to enhance consumer trust. At the same time, the government should lead the establishment of a reasonable cost-sharing mechanism to help enterprises reduce application costs. In addition, priority should be given to promoting blockchain technology in industries where frequent counterfeits and consumer trust are low (e.g., luxury goods and branded apparel) to ensure product authenticity and enhance overall market trust.

(3) Blockchain can not only show certain advantages in improving logistics efficiency and safety in practical application, but its decentralized architecture can realize real-time sharing and synchronization of logistics information, reduce delays and errors caused by information asymmetry, and encryption algorithms and non-tampering characteristics provide security for logistics data. At the same time, blockchain can also break the data exclusivity situation so that the data can be safely shared and interacted with among multiple participants, stimulating the potential of data innovation. Given these salient features, modeling research can be conducted in the future to address its advantages to better utilize blockchain's role in various fields and promote sustainable economic and social development.

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**References**

Allen, D. W., Berg, C., Davidson, S., Novak, M., & Potts, J. (2019). International policy coordination for blockchain supply chains. *Asia & the Pacific Policy Studies*, *6*(3), 367-380
Baharmand, H., Maghsoudi, A., & Coppi, G. (2021). Exploring the application of blockchain to humanitarian supply chains: insights from Humanitarian Supply Blockchain pilot project. *International Journal of Operations & Production Management*, *41*(9), 1522-1543
Bai, C., & Sarkis, J. (2020). A supply chain transparency and sustainability technology appraisal model for blockchain technology. *International journal of production research*, *58*(7), 2142-2162
Cai, Y. J., Choi, T. M., & Zhang, J. (2021). Platform supported supply chain operations in the blockchain era: Supply contracting and moral hazards. *Decision Sciences*, *52*(4), 866-892
Cao, Y., Yi, C., Wan, G., Hu, H., Li, Q.,... Wang, S. (2022). An analysis on the role of blockchain-based platforms in agricultural supply chains. *Transportation Research Part E: Logistics and Transportation Review*, *163*, 102731
Chang, J., Katehakis, M. N., Melamed, B., & Shi, J. J. (2018). Blockchain design for supply chain management. *Available at SSRN 3295440*
Chen, J., Zhang, W., & Liu, Z. (2020). Joint pricing, services and quality decisions in a dual-channel supply chain. *RAIRO-Operations Research*, *54*(4), 1041-1056
Chen, L., Nan, G., & Li, M. (2018). Wholesale pricing or agency pricing on online retail platforms: The effects of customer loyalty. *International Journal of Electronic Commerce*, *22*(4), 576-608
Chiang, W. K., Chhajed, D., & Hess, J. D. (2003). Direct marketing, indirect profits: A strategic analysis of dual-channel supply-chain design. *Management science*, *49*(1), 1-20
D, L., S, W., & Jiajia, N. J. (2022). Impact of retailers' information sharing on suppliers' intrusion strategy under the perspective of diseconomies of scale. *Industrial Engineering*,*5* , 10-19
Dai, L., Wang, X., Liu, X., & Wei, L. (2019). Pricing Strategies in Dual-Channel Supply Chain with a Fair Caring Retailer. *Complexity*, *2019*(1), 1484372
Du, S., Wang, L., & Hu, L. (2019). Omnichannel management with consumer disappointment aversion. *International Journal of Production Economics*, *215*, 84-101
Hastig, G. M., & Sodhi, M. S. (2020). Blockchain for supply chain traceability: Business requirements and critical success factors. *Production and Operations Management*, *29*(4), 935-954
He, P., Wen, J., Ye, S., & Li, Z. (2020). Logistics service sharing and competition in a dual-channel e-commerce supply chain. *Computers & Industrial Engineering*, *149*, 106849
Hsiao, S., & Sung, W. (2022). Blockchain-based supply chain information sharing mechanism. *Ieee Access*, *10*, 78875-78886
Ji, G., Zhou, S., Lai, K., 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, J., & Chen, J. (2021). Managing the product-counterfeiting problem with a blockchain-supported e-commerce platform. *Sustainability*, *13*(11), 6016
Karimabadi, K., Arshadi-khamseh, A., & Naderi, B. (2020). Optimal pricing and remanufacturing decisions for a fuzzy dual-channel supply chain. *International Journal of Systems Science: Operations & Logistics*, *7*(3), 248-261
Kshetri, N. (2018). 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of information management*, *39*, 80-89
Li, X., Jiang, P., Chen, T., Luo, X., & Wen, Q. (2020). A survey on the security of blockchain systems. *Future generation computer systems*, *107*, 841-853
Liu, C., Lee, C., & Zhang, L. L. (2022). Pricing strategy in a dual-channel supply chain with overconfident consumers. *Computers & Industrial Engineering*, *172*, 108515

Liu, M., Cao, E., & Salifou, C. K. (2016). Pricing strategies of a dual-channel supply chain with risk aversion. *Transportation Research Part E: Logistics and Transportation Review*, *90*, 108-120

Liu, S., Hua, G., Kang, Y., Cheng, T. E., & Xu, Y. (2022). What value does blockchain bring to the imported fresh food supply chain? *Transportation Research Part E: Logistics and Transportation Review*, *165*, 102859

Liu, Y., Yan, B., & Chen, X. (2024). Decisions of dual-channel fresh agricultural product supply chains based on information sharing. *International Journal of Retail & Distribution Management*, *52*(9), 910-930.

Manzoor, R., Sahay, B. S., & Singh, S. K. (2022). Blockchain technology in supply chain management: an organizational theoretic overview and research agenda. *Annals of Operations Research*, 1-48

Nair, R. B., Abijith, K. P., Abraham, A., Kumar, K. R., & Sridharan, R. (2022). Prices and profits in centralized dual-channel supply chains under competition. *IFAC-PapersOnLine*, *55*(10), 2366-2371

Nakamoto, S., & Bitcoin, A. (2008). A peer-to-peer electronic cash system. *Bitcoin.–URL: https://bitcoin. org/bitcoin. pdf*, *4*(2), 15

Pakdel Mehrabani, R., & Seifi, A. (2021). The impact of customers' channel preference on pricing decisions in a dual channel supply chain with a dominant retailer. *Journal of Industrial and Production Engineering*, *38*(8), 599-617

Pun, H., Swaminathan, J. M., & Hou, P. (2021). Blockchain adoption for combating deceptive counterfeits. *Production and Operations Management*, *30*(4), 864-882

Rong, D., Zhao, Y., Han, C., Yang, M., & Liu, F. (2022). Research on dual channel supply chain decision making of new retailing enterprises considering service behavior in the era of big data. *Journal of Global Information Management (JGIM)*, *30*(9), 1-16

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International journal of production research*, *57*(7), 2117-2135.

Shen, B., Dong, C., & Minner, S. (2022). Combating copycats in the supply chain with permissioned blockchain technology. *Production and Operations Management*, *31*(1), 138-154

Sheng, H., Wang, S., Zhang, Y., Yu, D., Cheng, X., Lyu, W.,... Xiong, Z. (2020). Near-online tracking with co-occurrence constraints in blockchain-based edge computing. *IEEE Internet of Things Journal*, 8(4), 2193-2207

Sun, H. X., Li, X. F., & Zhou, Z. (2020). Pricing strategies of dual channel retailers and traditional retailers. *Journal of Chineese Management Science*, *28*, 104-111

Wang, T., Chen, Z., Govindan, K., & Chin, K. (2022). Manufacturer's selling mode choice in a platform-oriented dual channel supply chain. *Expert Systems with Applications*, *198*, 116842

Xu, X., Zeng, S., & He, Y. (2021). The impact of information disclosure on consumer purchase behavior on sharing economy platform Airbnb. *International Journal of Production Economics*, *231*, 107846

Yanfei, Z., & Yong, W. (2023). A study on platform supply chain service level decision-making considering physical retailers' fairness concerns under consumer channel preference. *Journal of Management Engineering*, 2023, 1-14

Yang, X., & Xu, M. Z. (2022). Channel Pricing Strategies and Channel Selection of Different Dual-Channel Retailers under Manufacturer Dominance. *Computer Integrated Manufacturing Systems*, *1*, 307-324

Zhang, Z., Ren, D., Lan, Y., & Yang, S. (2022). Price competition and blockchain adoption in retailing markets. *European Journal of Operational Research*, *300*(2), 647-660

Zhou, Y., Liu, J., & Wu, X. (2022). How to Implement the Wholesale Price Contract: Considering Competition between Supply Chains. *Journal of Systems Science and Systems Engineering*, *31*(2), 150-173