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BLOCKCHAIN ADOPTION AND PRICING STRATEGIES IN CROSS-BORDER E-COMMERCE SUPPLY CHAINS CONSIDERING COMPETITION AND CONSUMER TRUST

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Abstract. Cross-border e-commerce has shifted product sales from traditional offline retail to a dual-channel model combining an offline retailer and a cross-border e-commerce platform, intensifying competition between channels and raising issues of incomplete consumer trust in product quality. We develop a game model where an overseas manufacturer distributes products through both channels while competing with a competitive manufacturer. With varying consumer trust in product quality across multiple channels, we investigate the overseas manufacturer's blockchain adoption strategy and the value of blockchain. First, we find that when the overseas manufacturer's combined tax and shipping cost is high, blockchain adoption depends on a low blockchain cost. Otherwise, a moderate blockchain cost is necessary. Second, the offline retailer benefits from blockchain if and only if there is a high channel quality variation level, a high blockchain cost, or a low overseas manufacturer's combined tax and shipping cost, while the competitive manufacturer benefits if and only if the channel quality variation level is low and either the blockchain cost is high or the overseas manufacturer's combined tax and shipping cost is low. Finally, rising blockchain cost decreases the value of blockchain for the overseas manufacturer yet enhances it for the offline retailer and the competitive manufacturer. Interestingly, as the product quality variation level decreases, the value of blockchain for an offline retailer reduces under a high platform commission rate but increases otherwise. Our analysis provides insights into when the overseas manufacturer should adopt blockchain and the value of blockchain considering competition and consumer trust.

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1. Introduction

In the early stages of cross-border brand establishment, overseas manufacturers, due to informational disadvantages in domestic markets, did not establish direct sales channels but instead chose to wholesale products to offline retailers establishing domestic stores. This traditional sales model resulted in a double marginalization effect, leading to low overall supply chain efficiency [1]. Overseas manufacturers have the incentive to establish

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direct sales channels to mitigate double marginalization and counter competitor pressures, particularly through cross-border e-commerce platforms that provide such direct-to-consumer access. By leveraging these platforms, overseas manufacturers bypass offline retailers and deliver products directly to domestic consumers through international logistics. Consumers no longer need to visit offline stores to select products. Instead, they browse overseas products online, make payments digitally, and have items delivered to specified addresses via logistics which reduces the shopping cost. This user-friendly cross-border e-commerce model has earned broad consumer acceptance. In 2024, China's cross-border e-commerce sales totaled 2.63 trillion yuan, reflecting a 10.8% growth compared to 2023. Prada entered China in the 1990s, establishing numerous offline stores. In June 2019, JD.com announced a partnership with the Prada Group, with three of its brands – Prada, Miu Miu, and Car Shoe – joining JD.com during the "618" shopping festival. Miniso opened its first overseas store in Singapore in 2015, with offline stores laying a solid foundation for its international brand presence. Starting in 2019, Miniso expanded its presence on cross-border e-commerce platforms such as Shopee and Lazada while also facing competition from competitive manufacturers like Muji in international markets.

However, the introduction of cross-border e-commerce platform channel by overseas manufacturers has brought several challenges, which can be specifically categorized into three aspects. First, it increases the complexity of multi-channel management for overseas manufacturers. In terms of pricing, overseas manufacturers need to set both wholesale prices for offline retailers and retail prices for cross-border e-commerce platforms. Regarding product allocation, overseas manufacturers need to decide quantities distributed to offline retailers and cross-border e-commerce platforms, rather than supplying all products exclusively to offline retailers [2, 3]. Second, the cross-border e-commerce platform channel significantly reduces consumers' time and distance costs for shopping, while the offline store provides in-person services and product experiences. The coexistence of two channels with distinct characteristics and competitive manufacturer channel intensifies market competition [4]. Third, consumers exhibit lower trust in product quality through the cross-border e-commerce platform compared to the offline retailer channels. Consumers believe products through the offline retailer channel are authentic while they remain skeptical about the genuineness of products through the cross-border e-commerce platform channel due to frequent absence of origin certification even when products claim brand authorization [5, 6].

In recent years, blockchain technology has emerged as a vital tool for overseas manufacturers in addressing quality trust issues. Blockchain technology facilitates the immutable record of the entire product lifecycle, encompassing production, sales, warehousing, and transportation, while assigning a distinct digital identifier to each individual item. This capability empowers consumers to verify product authenticity conveniently, which in turn significantly enhances consumer trust [7]. For instance, New Zealand dairy manufacturer Anchor has collaborated with the Provenance blockchain platform to establish end-to-end traceability from pasture to processing and cross-border logistics.[1] Leading luxury brands, including LVMH, Prada, and Cartier, have jointly established the Aura Blockchain Consortium.[2] Through this initiative, each luxury item is assigned a unique digital identity, enabling consumers to verify product provenance and authenticity in real time across global channels. The pharmaceutical company Merck Sharp & Dohme employs blockchain technology to track the cross-border production and distribution of its pharmaceuticals, thereby enhancing drug safety and integrity.[3] Swisse utilizes blockchain to trace goods from Australian production to China, allowing consumers to verify authenticity via QR codes.[4] Simultaneously, Tmall Global requires overseas brands to upload supply chain data onto Ant Chain.[5] The traceable identifiers thereby alleviate consumer concerns, which in turn helps maintain higher product prices in official channels. Koala's cross-border direct mail service utilizes blockchain to transparently show consumers a product's origin, journey, and destination, thereby enhancing information vis-

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[1] https://www.provenance.org/case-studies/anchor-milk?utm_source.

[2] https://www.pradagroup.com/en/news-media/press-releases-documents/2021/21-04-20-aura-blockchain-consortium.html.

[3] https://supplychaindigital.com/company-reports/msd-building-digital-superhighway.

[4] https://www.alibabagroup.com/news-and-resource.

[5] https://www.tmall.hk/.

ibility. However, the adoption of blockchain technology is not universal across all enterprises [6, 8]. On the one hand, the costs associated with blockchain implementation – such as investments in hardware and expenses related to data on boarding – pose a significant financial burden for small and medium-sized enterprises. On the other hand, when overseas manufacturers adopt blockchain technology, they can enhance the credibility of both their online products and those sold through offline retailers simultaneously, which may create a free-riding effect to some extent. High blockchain cost and the intensified market competition which is because blockchain enhances the consumer trust in the quality of overseas manufacturers' products distributed through different channels lead overseas manufacturers to carefully weigh the blockchain's pros and cons before deciding on its adoption [34–35, 41].

Based on this background, this paper focuses on the following research questions.

(1) In cross-border e-commerce supply chains, how does blockchain influence the pricing equilibrium and product demand of competing channels by enhancing consumer trust? How is the blockchain adoption strategy of the overseas manufacturer constrained by cost-related conditions?
(2) How does blockchain create "free rider" benefits for the offline retailer and competitive manufacturer that do not bear the implementation cost?
(3) How does blockchain value creation exhibit the dual characteristics of being "cost-sensitive" and "quality-dependent"? How do these dual characteristics explain the differentiated value impacts on various supply chain participants?

To address these questions, our paper considers a multi-channel competition scenario where an overseas manufacturer sells products through a cross-border e-commerce platform and an offline retailer channel, while a competitive manufacturer sells products in domestic offline stores. We analyze the overseas manufacturer's blockchain adoption strategy and value of blockchain.

First, under equilibrium conditions, blockchain adoption prompts the overseas manufacturer to raise the wholesale price and online retail price, driving the offline retailer to increase the retail price. The competitive manufacturer raises the retail price only if the blockchain cost is high. Post-adoption, demand for the overseas manufacturer's online product increases with low blockchain cost, while demand increases for both the offline retailer's and the competitive manufacturer's products only when the blockchain cost is high. In general, the overseas manufacturer adopts blockchain only when the blockchain cost is low. Zhao *et al.* (2024) on its adoption [25], who concluded that blockchain adoption in dual-channel supply chains is primarily influenced by blockchain implementation costs and platform commission rates, our study identifies cross-border tax and transportation costs as additional critical determinants in cross-border supply chain contexts. With the low overseas manufacturer's combined tax and shipping cost, adoption occurs only with moderate blockchain cost to avoid online retail price dropping below wholesale price or the competitive manufacturer existing the market under extremely low blockchain cost.

Second, blockchain intensifies competition but the offline retailer always benefits from blockchain when the channel quality variation level is high. This occurs because blockchain enhances consumer trust in offline retailer's product quality significantly more than in the overseas manufacturer's online product quality, rising demand for the offline retailer's product. Otherwise, it benefits only from high blockchain cost or the low overseas manufacturer's combined tax and shipping cost which correlates with relatively high blockchain cost. Interestingly, high blockchain cost alone doesn't guarantee the competitive manufacturer's benefits. It benefits if and only if the channel quality variation level is low and either the blockchain cost is high or the overseas manufacturer's combined tax and shipping cost is low. This occurs because under a high channel quality variation level blockchain always reduces demand for the competitive manufacturer's product and a low overseas manufacturer's combined tax and shipping cost correlates with relatively high blockchain cost.

Third, higher blockchain cost reduces value of blockchain for the overseas manufacturer while enhancing it for both the offline retailer and competitive manufacturer. This occurs because the overseas manufacturer's online product experiencing significantly greater retail price increases compared to other products, increasing demands for both the offline retailer's and competitive manufacturer's products. Generally, blockchain creates less value for the offline retailer but more value for the competitive manufacturer as the product quality variation level decreases. However, under a low platform commission rate, the reduced product quality variation level enhances value of blockchain for the offline retailer. This occurs because demand decreases in the product quality variation level and impact of blockchain on demand regardless of the product quality variation level.

This paper is organized as follows. Section 2 reviews the foundational literature spanning three critical areas: channel encroachment, cross-border e-commerce, and blockchain. In Section 3, we describe a Stackelberg game model involving an overseas manufacturer, an offline retailer, a competitive manufacturer, a cross-border e-commerce platform, and consumers. Section 4 establishes the market equilibrium, conducting comparative analysis of pricing and demand dynamics across adoption scenarios. We further evaluate blockchain adoption incentives, assess its impact on the offline retailer and competitive manufacturer, and identify key value-determining parameters. We provide two extensions in Section 5 regarding the consumer's online shopping cost and the blockchain cost-sharing mechanism. We present conclusions, managerial implications, limitations, and directions for future research in Section 6.

2. Literature review

Our work engages with three distinct but complementary bodies of scholarship: (1) channel encroachment under quality uncertainty, (2) supply chain management under cross-border e-commerce, (3) blockchain-enhanced consumer trust in product quality.

First, our study is related to prior research on channel encroachment under product quality uncertainty. Some scholars have studied channel encroachment under deterministic quality conditions: Chen *et al.* [9] examined manufacturer encroachment considering consumer quality trust, retailer risk-aversion behavior, and the manufacturer's private cost information; Chen *et al.* [10] explored how manufacturers utilize online channels to influence retailers' decisions regarding discount stores when consumers have the same level of trust in product quality across online and offline channels, considering both offline and online channels. In contrast, this study extends the above research context to cross-border e-commerce settings. Other scholars have studied channel encroachment under quality uncertainty: Wu *et al.* [11] found that downstream firms' entry into the market can enhance quality transparency and does not necessarily harm traditional retailers; Qiu *et al.* [12] showed that manufacturers adopt virtual showrooms to help consumers evaluate products when experience cost is at a moderate level and consumers are sensitive to physical store visit costs, while we consider in our extension the impact of consumers' online shopping costs on the overseas manufacturer's blockchain adoption decision; Zhang *et al.* [13] analyzed how manufacturers differentiate channel quality based on production costs and consumer quality sensitivity; Nire *et al.* [14] studied brand quality selection and profitability in new markets under consumer quality evaluation influenced by existing products, whereas we examine how the ability of offline retailers and competitive manufacturers – who cannot make blockchain adoption decisions – to benefit from blockchain is influenced by channel quality variation. Du *et al.* [15] linked the quality of remanufactured and compatible products to consumer types. Notably, this study explores channel encroachment under quality uncertainty in the cross-border e-commerce context, thereby extending this research stream to more complex and globally relevant scenarios.

Second, existing research has conducted in-depth investigations into supply chain management in cross-border e-commerce. Specifically, some scholars focus on logistics mode management: Ren *et al.* [16] developed an optimal logistics capacity allocation model under different service demands; Niu *et al.* [17] established the relationship between bonded warehouses and direct shipping channels with supply chain disruption; Zhang *et al.* [18] analyzed logistics mode selection from the perspectives of cost and inventory risk. Additionally, significant contributions have been made in the field of channel management: Shi *et al.* [19] focused on a brand's entry decision of whether to explore overseas markets or remain in the domestic market, with the optimal choice influenced by tax rules. However, we primarily study how the overseas manufacturer's blockchain adoption decision is affected by the interplay between blockchain cost and the overseas manufacturer's direct shipping and tax costs, offering a more comprehensive consideration. Siqin *et al.* [20] pointed out that channel integration strategies between mobile applications and websites depend on e-commerce operators' operational models; Hua *et al.* [21] investigated vertical integration strategies between integrated logistics service providers and platforms, exploring the impact of channel power and logistics cost performance on the choice of integration mode, focusing on integration decisions within logistics service supply chains. In contrast, under the established dual-channel distribution structure of the overseas manufacturer, this study incorporates channel quality variation and horizontal product competition into a unified framework, revealing the interactive mechanism through which blockchain affects consumer trust and the interests of various supply chain parties in cross-border e-commerce. Few studies have focused on channel competition in cross-border e-commerce: Niu *et al.* [6] explored the application of blockchain technology for quality verification in a co-opetitive cross-border supply chain, but only considered online and offline competition of the same product without accounting for substitute product competition, whereas we incorporate a domestic competitive manufacturer, thereby revealing the strategic interaction between horizontal competition and blockchain adoption.

Last, our paper is related to prior studies on blockchain-enhanced consumer trust in product quality. This study is related to the literature on blockchain technology for enhancing consumer trust in product quality [47,51]. Specifically, early research focuses on traditional supply chains. For example, Chang *et al.* [22] studied the equilibrium strategies of blockchain adoption and online sales channels, while Hu *et al.* [23] revealed differences in blockchain adoption strategies in agricultural supply chains. However, existing studies are mostly based on traditional contexts, whereas platform supply chains face more complex challenges due to the characteristics of online operation models and differences in regulatory environments, thus warranting a dedicated investigation. Choi *et al.* [24] examined information disclosure strategies based on the premise that product information disclosure via blockchain is crucial for attracting customers, while Zhao *et al.* [25] focused on a dual-channel e-commerce platform supply chain consisting of a manufacturer, a reselling platform, and an agency platform, finding that commission rates influence the manufacturer's adoption decision.They only considered platform trust enhancement, whereas we consider blockchain covers both channels, allowing offline retail to free-ride on adoption. Currently, a few studies on blockchain in platform supply chains have been further refined to the context of cross-border e-commerce platforms. Niu *et al.* [6] assumed blockchain completely eliminates channel quality variation between the e-commerce platform and the retail division, representing an idealized state; in reality, blockchain's ability to eliminate consumer distrust is limited. Moreover, they ignored substitution competition and focused only on channel quality variation. In response, this study considers that blockchain enhances consumer trust in both channels by the same proportion based on their initial levels, but online trust remains lower than offline after adoption, capturing consumers' heterogeneous trust in cross-border markets. Additionally, we introduce a competitive manufacturer and incorporate channel quality variation and product quality variation as dual dimensions, more realistically characterizing competitive dynamics and systematically revealing blockchain's interactive mechanism, providing a more comprehensive theoretical perspective.

3. Model

We consider a supply chain where an overseas manufacturer M distributes its products to domestic consumers through an offline retailer R and a cross-border e-commerce platform P channel, competing with a competitive manufacturer T establishing a domestic offline store simultaneously (see Fig. 1). We assume that the overseas manufacturer decides whether to adopt blockchain and analyze two scenarios with versus without blockchain adoption.

3.1. Without blockchain

Suppose consumers purchasing offline products are uniformly and heterogeneously distributed along a Hotelling line between 0 and 1, $x \in \{0, 1\}$, with a consumer's offline shopping cost t per unit distance [10]. The offline retailer and the competitive manufacturer are located at $x = 0$ and $x = 1$ respectively. Consumers purchase online products through a cross-border e-commerce platform channel with online shopping cost h_{o} per unit product. Every consumer can only purchase one product. There is a difference in consumer trust in quality of products across multiple channels. In contrast to the assumptions made by Chen *et al.* [10] and Chang

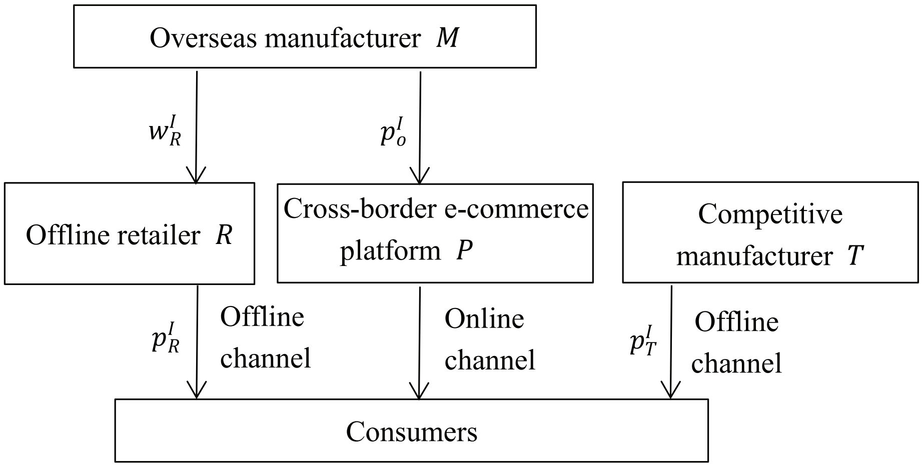

FIGURE 1. Supply chain structure.

et al. [22], who posited that consumers' perceptions of product quality are consistent across different channels, this study integrates a crucial factor derived from real-world consumption contexts. When purchasing through online channels, consumers often develop significant distrust due to the inability to physically inspect products [26]. Specifically, the consumer has v trust in offline retailer's product quality, while the consumer has δv trust in competitive manufacturer's product quality and has γv trust in overseas manufacturer's online product quality, where δ indicates the product quality variation level and γ indicates the channel quality variation level. We assume $0 < \gamma < 1$ and $0 < \delta < 1$. We define the scenario without blockchain as Scenario N. Consequently, the utility of a consumer who locates at x to buy a product through the offline retailer channel at price p_R^N is

$$U_R^N = v - p_R^N - tx. \tag{1}$$

The utility of a consumer who locates at x to buy a product through the competitive manufacturer channel at price p_T^N is

$$U_T^N = \delta v - p_T^N - t(1-x). \tag{2}$$

The utility of a consumer to buy a product through the cross-border e-commerce platform channel at price p_O^N is

$$U_o^N = \gamma v - p_o^N - h_o. \tag{3}$$

In Figure 2, $x_R^N = \frac{h_o + p_o^N - p_R^N + v - \gamma v}{t}$ is derived by setting $U_o^N = U_R^N$. The marginal consumers who locate at x_R^N are indifferent between shopping through the offline retailer and cross-border e-commerce platform channel. $x_T^N = \frac{p_T + t + \gamma v - v\delta - p_o - h_o}{t}$ is derived by setting $U_o^N = U_T^N$. The marginal consumers who locate at x_T^N are indifferent between shopping through the competitive manufacturer and cross-border e-commerce platform channel. Consequently, the demands for the offline retailer's product, the competitive manufacturer's online product, and the overseas manufacturer's online product are, respectively,

$$d_R^N = x_R^N \tag{4}$$
$$d_T^N = 1 - x_T^N \tag{5}$$
$$d_o^N = x_T^N - x_R^N. \tag{6}$$

The overseas manufacturer pays the cross-border e-commerce platform a commission rate $\alpha \in (0, 1/2)$ for every unit of product fulfilled [39]. The overseas manufacturer sets wholesale price w_R^N per unit product through

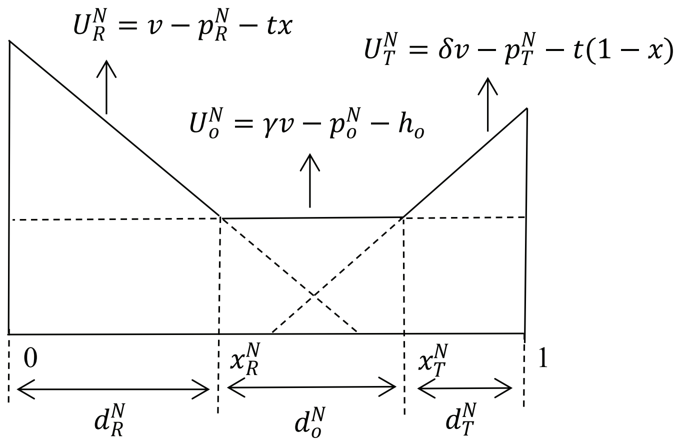

FIGURE 2. Consumer's utility and demand without blockchain.

the offline retailer channel and bears the tax and shipping cost c of unit product through the cross-border e-commerce platform channel. Then, the profit functions of the overseas manufacturer, the offline retailer, the competitive manufacturer, and the cross-border e-commerce platform are, respectively,

$$\pi_M^N = (1-\alpha)p_o^N d_o^N - cd_o^N + w_R^N d_R^N \tag{7}$$
$$\pi_R^N = (p_R^N - w_R^N)d_R^N \tag{8}$$
$$\pi_T^N = p_T^N d_T^N \tag{9}$$
$$\pi_P^N = \alpha p_o^N d_o^N. \tag{10}$$

3.2. With blockchain

Consumers often distrust products sold through online channels due to the absence of in-person services and physical product experiences, which ultimately diminishes their purchase intention. Blockchain technology, characterized by its immutability and transparency, records detailed product information across stages such as production, packaging, and transportation. By enabling consumers to access this information via a traceability system, it enhances their purchase intention [27–30]. Therefore, the overseas manufacturer has an incentive to adopt blockchain technology to record product information [31]. Meanwhile, the adoption of blockchain technology by the overseas manufacturer enhances consumers' purchase intention in offline channels. For instance, both the luxury brand Louis Vuitton and the Dutch firm Decanter have adopted blockchain technology to provide traceability information, thereby enhancing consumer trust in the products and increasing purchase intention [32].

The overseas manufacturer adopting blockchain significantly increases consumer trust in quality of products produced by the overseas manufacturer by ρ [49]. Consumer trust in quality varies across three product categories sold through different channels. The consumer has δv trust in competitive manufacturer's product quality, while the consumer has $v(1+\rho)$ trust in offline retailer's product quality and has $\gamma v(1+\rho)$ trust in overseas manufacturer's online product quality. We define the scenario with blockchain as Scenario B. Consequently, the utility of a consumer who locates at x to buy a product through the offline retailer channel at price p_R^B is

$$U_R^B = v(1+\rho) - p_R^B - tx. \tag{11}$$

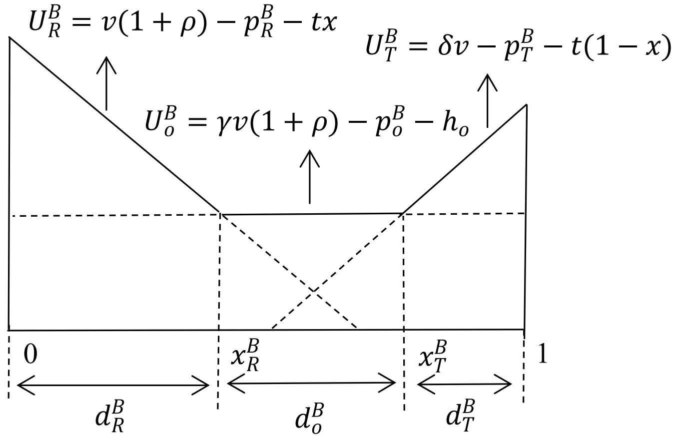

FIGURE 3. Consumer's utility and demand with blockchain.

The utility of a consumer who locates at x to buy a product through the competitive manufacturer channel at price p_T^B is

$$U_T^B = \delta v - p_T^B - t(1-x). \tag{12}$$

The utility of a consumer to buy a product through the cross-border e-commerce platform channel at price p_o^B is

$$U_o^B = \gamma v(1+\rho) - p_o^B - h_o. \tag{13}$$

In Figure 3, $x_R^B = \frac{h_o + p_o^B - p_R^B + v(1-\gamma)(1+\rho)}{t}$ is derived by setting $U_o^B = U_R^B$. The marginal consumers who locate at x_R^B are indifferent between shopping through the offline retailer and cross-border e-commerce platform channel. $x_T^B = \frac{p_T^B + t - p_o^B + v(\gamma - \delta + \gamma\rho) - h_o}{t}$ is derived by setting $U_o^B = U_T^B$. The marginal consumers who locate at x_T^B are indifferent between shopping through the competitive manufacturer and cross-border e-commerce platform channel. Consequently, the demands for the offline retailer's product, the overseas manufacturer's online product, and the overseas manufacturer's online product are, respectively,

$$d_R^B = x_R^B \tag{14}$$
$$d_T^B = 1 - x_T^B \tag{15}$$
$$d_o^B = x_T^B - x_R^B. \tag{16}$$

The overseas manufacturer bears the blockchain cost c_B per unit product [33]. Then, the profit functions of the overseas manufacturer, the offline retailer, the competitive manufacturer, and the cross-border e-commerce platform are, respectively,

$$\pi_M^B = (1-\alpha)p_o^B d_o^B - c d_o^B + w_R^B d_R^B - c_B\left(d_R^B + d_o^B\right) \tag{17}$$
$$\pi_R^B = \left(p_R^B - w_R^B\right)d_R^B \tag{18}$$
$$\pi_T^B = p_T^B d_T^B \tag{19}$$
$$\pi_P^B = \alpha p_o^B d_o^B. \tag{20}$$

The game sequence is as follows. At the first stage, the overseas manufacturer decides whether to adopt blockchain. At the second stage, the overseas manufacturer sets its wholesale price. Then, the offline retailer

TABLE 1. Definitions of notations.

Notation	Definition	Feasibility
Parameters		
v	Consumer trust in offline retailer's product quality	$v \in \{0,1\}$
γ	Channel quality variation level	$\gamma \in \{0,1\}$
δ	Product quality variation level	$\delta \in \{0,1\}$
ρ	Promotion rate of consumer trust in product quality caused by blockchain	$\rho \in \{0,1\}$
h_o	Consumer's online shopping cost	$h_o \in \{0,1\}$
t	Consumer's offline shopping cost	$t \in \{0,1\}$
c	Overseas manufacturer's combined tax and shipping cost	$c \in \{0,1\}$
α	Cross-border e-commerce platform commission rate	$\alpha \in \{0,1/2\}$
c_B	Blockchain cost	$c_B \in \{0,1\}$
Decision variables		
w_R^I	Overseas manufacturer's wholesale price	$w_R^I \geq 0$
p_R^I	Offline retailer's retail price	$p_R^I \geq 0$
p_o^I	Overseas manufacturer's online retail price	$p_o^I \geq 0$
p_T^I	Competitive manufacturer's retail price	$p_T^I \geq 0$
Calculated values		
U_R^I, d_R^I	Utility and demand for the offline retailer's product	$U_R^I, d_R^I \geq 0$
U_o^I, d_o^I	Utility and demand for the overseas manufacturer's online product	$U_o^I, d_o^I \geq 0$
U_T^I, d_T^I	Utility and demand for the competitive manufacturer's product	$U_T^I, d_T^I \geq 0$
π_M^I	Overseas manufacturer's profit	$\pi_M^I \geq 0$
π_R^I	Offline retailer's profit	$\pi_R^I \geq 0$
π_T^I	Competitive manufacturer's profit	$\pi_T^I \geq 0$
π_P^I	Cross-border e-commerce platform's profit	$\pi_P^I \geq 0$

Note: Superscript I represents the scenario where $I \in \{N, B\}$.

and the competitive manufacturer set their retail prices simultaneously. Finally, the overseas manufacturer sets the online retail price of products through the cross-border e-commerce platform. The definitions of notations are summarized in Table 1. We generalize the superscript notation to I, where I is in $\{N, B\}$.

4. ANALYSIS

This section presents our core model analysis. We begin by characterizing equilibrium outcomes under both scenarios, then systematically compare equilibrium prices, demands, and profits. Detailed proofs and threshold conditions appear in the Appendix.

Using backward induction to solve the subgames yields optimal decisions. For analytical simplicity, we assume that production costs of all products are zero and define $v = 1$ and $h_o = 0$. We start with the benchmark scenario without blockchain. Appendix A proves the existence of a unique equilibrium in this game. In this equilibrium solution, w_R^{N*} represents the overseas manufacturer's optimal wholesale price, while the vectors $(p_R^{N*},\ p_T^{N*},\ p_o^{N*})$ and $(d_R^{N*},\ d_T^{N*},\ d_o^{N*})$ characterize equilibrium retail prices and corresponding market demands across the three distribution channels, including the cross-border e-commerce platform, offline retailer, and competitive manufacturer channel. The profit vectors $(\pi_M^{N*},\ \pi_R^{N*},\ \pi_T^{N*}, \pi_P^{N*})$ quantify economic returns for all supply chain participants, comprising the overseas manufacturer, offline retailer, cross-border e-commerce platform, and competitive manufacturer. Then, for the scenario with blockchain, this game also has a unique equilibrium. The equilibrium solution specifies w_R^{B*} as the overseas manufacturer's wholesale price, with $(p_R^{B*},\ p_T^{B*},\ p_o^{B*})$ representing retail prices and $(d_R^{B*},\ d_T^{B*},\ d_o^{B*})$ reflecting corresponding demands across the three distribution channels, while $(\pi_M^{B*},\ \pi_R^{B*},\ \pi_T^{B*},\ \pi_P^{B*})$ captures the profit distribution among all supply chain participants. To guarantee that demands are positive and the market is completely covered for each scenario, some conditions need to be satisfied[6]:

First, the overseas manufacturer's combined tax and shipping cost should be mediate in Scenario N, *i.e.*, $\max\{c_1, c_2\} < c < \max\{c_3, c_4, c_5\}$. Second, the blockchain cost should not be too high in Scenario B, *i.e.*, $\max\{0, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4\}$.

We show comparisons of the equilibrium prices in two scenarios in Lemma 4.1.

Lemma 4.1. *Comparing equilibrium pricing with and without blockchain:*

(a) $w_R^{B*} > w_R^{N*}$, $p_o^{B*} > p_o^{N*}$, $p_R^{B*} > p_R^{N*}$.
(b) *There exists a threshold* c_B^5 *such that* $p_T^{B*} \le p_T^{N*}$ *if* $0 < c_B \le c_B^5$ *and* $p_T^{B*} \ge p_T^{N*}$ *if* $c_B > c_B^5$.
(c) $\frac{\partial c_B^5}{\partial \alpha} < 0$.

Lemma 4.1 shows that after the adoption of blockchain technology, increased consumer trust enables the overseas manufacturer to raise the wholesale price and the online retail price, while prompting the offline retailer to increase the offline retail price. The main reason lies in: on the one hand, blockchain technology enhances consumers' trust in overseas products, increasing market demand, thereby exerting upward pressure on the retail price. On the other hand, the overseas manufacturer will raise its offline wholesale and online retail prices to cover the blockchain cost [31]. Intuitively, facing the competitive edge of overseas products, the local competitive manufacturer would lower the product price to maintain market attractiveness. However, Lemma 4.1 reveals an intriguing conclusion: when the blockchain cost exceeds a specific threshold c_B^5, the competitive manufacturer will not only refrain from reducing the retail price but will increase it. The reason is that if the blockchain cost is high, the online and offline prices of overseas products will increase significantly, pushing up the overall price of the market. The competitive manufacturer has no need to respond to competition by cutting prices but will follow suit with price increases, thus boosting profits without a significant decline in sales. If the blockchain cost is low, the rise in the price of the overseas manufacturer's products on the two channels is limited, and price competition remains dominant. To avoid further loss of market share, the competitive manufacturer has proactively reduced prices, sacrificing unit profits to maintain its demand and attract price-sensitive consumers. Compared to the study by Niu *et al.* [31], Niu *et al.*'s findings suggest that when overseas suppliers adopt blockchain, the cross-border e-commerce platform may increase the purchase price of local products, aiming to distribute part of the blockchain implementation cost and incentivize local suppliers to expand production. This paper, however, focuses on the competitive relationship between overseas and local markets in the same market, emphasizing the differentiated impact of the blockchain cost on pricing strategies in a competitive environment.

In addition, we find that the cross-border e-commerce platform commission rate is inversely proportional to the blockchain cost threshold that triggers price increases by the competitive manufacturer. The economic logic lies in the fact that the profit margin of the overseas manufacturer determines its resilience in price competition. A high cross-border e-commerce platform commission rate severely squeezes the profit margin of the overseas manufacturer. Once the blockchain cost exceeds a specific threshold, the overseas manufacturer will be forced to raise prices due to cost pressure, losing its price competitiveness. This leads to reduced competitive pressure from the domestic competitive manufacturer. Given that the overseas manufacturer loses its offensive capability even under low blockchain cost, the threshold for the domestic competitive manufacturer to raise prices is correspondingly lowered. Conversely, when the cross-border e-commerce platform commission rate is low, the overseas manufacturer enjoys greater profit margin flexibility. It can tolerate higher blockchain cost while still maintaining price competitiveness to suppress its rival [36, 43–44].

We show comparisons of the equilibrium demands in two scenarios in Lemma 4.2.

Lemma 4.2. *There exist thresholds* c_B^6 *and* c_B^7 *such that the comparison of the equilibrium demands with and without blockchain are that:*

[6]This assumption is aligned with the related document, such as Chen *et al.* [10] and Chang *et al.* [22]. In Appendix, we will demonstrate how the conditions are established.

(a) *When* $0 < c_B \leq \max\{0, c_B^6\}$, $d_o^{B*} \geq d_o^{N*}$. *Otherwise,* $d_o^{B*} < d_o^{N*}$.
(b) *When* $0 < c_B \leq \max\{0, c_B^7\}$, $d_R^{B*} \leq d_R^{N*}$. *Otherwise,* $d_R^{B*} > d_R^{N*}$.
(c) *When* $0 < c_B \leq c_B^5$, $d_T^{B*} \leq d_T^{N*}$. *Otherwise,* $d_T^{B*} > d_T^{N*}$.

For online channels, when the blockchain cost is low, the blockchain significantly enhances the trust level of the online channel, making its products more attractive. At this time, consumers have a high level of initial trust in online products, the marginal effect of improving the level of trust is more prominent, and online demand increases significantly compared to the case without blockchain. Under high blockchain cost, the price of the online product increases significantly, leading to a decrease in demand. For the offline retailer, the fluctuation of demand does not only depend on their own price adjustment, but more importantly, it is affected by how blockchain technology changes the competitive dynamics between online and offline channels. If the blockchain cost is high, the online channel will lose its advantage due to the greater increase in prices, and the offline retailer will gain demand growth in opposite direction with a smaller increase in prices. Especially, when the cross-border e-commerce platform commission rate is high or trust level of online channel is low, the advantages of online are insufficient, the introduction of blockchain can always increase the demand. If the blockchain cost is low and the online channel is attractive, it can lead to a decrease in demand for the offline retailer. Currently, for the competitive manufacturer, the application of blockchain strengthens the competitiveness of the overseas manufacturer and squeezes out the demand for competitive products to a certain extent. However, when the blockchain cost exceeds a certain threshold, the domestic manufacturer, despite the possibility of increasing its own price (see Lem. 4.1), will still attract price-sensitive consumers because of its significant price advantage compared to the foreign manufacturer's product, leading to an increase in demand in the opposite direction [37–38, 40, 42].

We obtain Proposition 4.1 by comparisons of profits of the overseas manufacturer with and without blockchain.

Proposition 4.1. *There exist thresholds* c_6 *and* c_7 *such that*

(a) *When* $c \geq \max\{c_6, c_7\}$, *blockchain adoption by the overseas manufacturer occurs exclusively under the condition that* $0 < c_B < \min\{c_B^3, c_B^4, c_B^8\}$.
(b) *When* $c < \max\{c_6, c_7\}$, *blockchain adoption by the overseas manufacturer occurs exclusively under the condition that* $\max\{c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$.

Proposition 4.1 reveals a non-monotonic relationship between the blockchain cost and the decision to adopt blockchain for the overseas manufacturer, which is different from the intuition that the lower the blockchain cost, the more likely it is to be adopted. The decision regions in Figure 4 can be further analyzed to reveal the reasons. In Figure 4, the blank area means that the overseas manufacturer decides not to adopt blockchain, and the shaded area means that the overseas manufacturer decides to adopt blockchain.

When $c \geq \max\{c_6, c_7\}$, the high overseas manufacturer's combined tax and shipping cost compresses the profit margin of the overseas manufacturer. Only if the blockchain cost is low will the overseas manufacturer adopt it. If the blockchain cost is high, the adoption of blockchain will not only fail to improve the profit situation, but will also exacerbate its profit loss, in case the overseas manufacturer will choose not to adopt blockchain. This finding aligns with the research conclusion of Chang *et al.* [22], which stated that when the blockchain cost is excessively high, this technology is not practically feasible for the overseas manufacturer. And when the overseas manufacturer's combined tax and shipping cost is low ($c < \max\{c_6, c_7\}$), blockchain adoption is optimal only when the blockchain cost falls within the moderate range (*i.e.*, $\max\{c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4, c_B^5\}$). If the blockchain cost is too low, the overseas manufacturer will over-reduce the online retail price, even below its wholesale price. Even if the competitive manufacturer raises the retail price to stimulate demand for strategic reasons, the phenomenon of market exclusion still exists. If the blockchain cost is too high, the overseas manufacturer will significantly increase the online retail price. On the one hand, the high retail price directly suppresses online demand, leading to a sharp decline in online profits. On the other hand, although the offline retailer gains some growth due to the diversion of online demand, the growth in the offline market is far less than that in the online market, and they cannot make up for their profit losses, and even market failure may occur, which violates market laws.

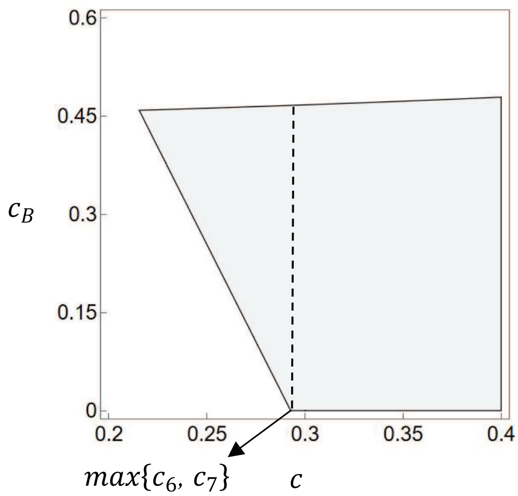

FIGURE 4. Optimal blockchain adoption strategy for the overseas manufacturer.

We obtain Proposition 4.2 by comparisons of profits of the offline retailer with and without blockchain if the overseas manufacturer adopts blockchain.

Proposition 4.2. *There exist thresholds c_6 and c_7 such that*

(a) *When $c \geq \max\{c_6, c_7\}$, blockchain adoption by the overseas manufacturer occurs exclusively under the condition that $0 < c_B < \min\{c_B^3, c_B^4, c_B^8\}$.*
(b) *When $c < \max\{c_6, c_7\}$, blockchain adoption by the overseas manufacturer occurs exclusively under the condition that $\max\{c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$.*

Under the condition that the overseas manufacturer adopts blockchain, the impact of blockchain technology on the profit of the offline retailer is not monotonic. This dependence is specifically mediated by the synergistic effect between the channel quality variation level and the blockchain cost, as shown in Figure 5.

When the channel quality variation level varies greatly ($i.e.$, $\gamma \leq \frac{60-53\alpha}{70-91\alpha+21\alpha^2}$), the offline retailer can always benefit from the blockchain. At this moment, consumers have low quality trust in online products. The application of blockchain enhances the quality trust of consumers in the online products of the overseas manufacturer ($\gamma\rho$) and enhances the quality trust of consumers in the product of the offline retailer (ρ). But the effect of enhancing trust in offline channels is relatively more significant than online, and the demand for offline products has grown more noticeably. The net increase in demand for offline products is enough to offset the negative effects of channel competition, so the offline retailer can always benefit from the application of blockchain.

When the channel quality variation level is small ($i.e.$, $\gamma > \frac{60-53\alpha}{70-91\alpha+21\alpha^2}$), the improvement of trust in online channels by blockchain is more pronounced, thus significantly intensifying channel competition, and the offline retailer may not necessarily benefit. At this point, the key to its profit change depends on the size of the blockchain cost. As shown in Figure 5, the offline retailer's profit increases significantly when $\max\{c_B^7, c_B^1, c_B^2\} < c_B < \min\{c_B^8, c_B^3, c_B^4\}$, otherwise, its profit is damaged. The main reason is that the proper blockchain cost will make the overseas manufacturer shift part of the cost to the online price, which will weaken the price competitiveness of online channels. By contrast, while the overseas manufacturer also passes on part of the cost through the wholesale price to the offline retailer, the retail price increases by a smaller margin. Due to the price difference, some consumers will shift from online to offline channels, leading to an increase in demand for the offline retailer's products. At the same time, the improvement of product trust brought by the blockchain has also created more demand for offline channels. Eventually, the offline retailer can benefit from blockchain applications.

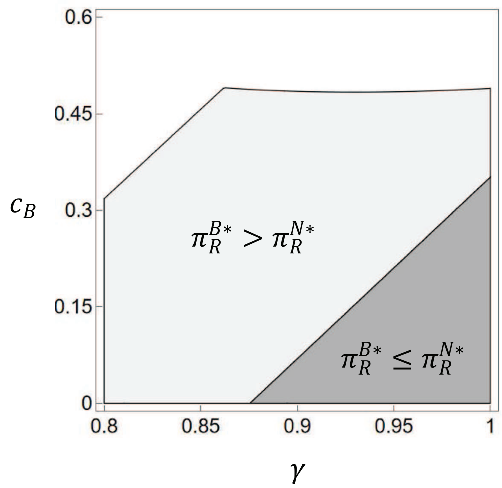

FIGURE 5. Benefits and losses of the offline retailer from blockchain.

This conclusion diverges from that of Chang *et al.* [22], who posited that a lower blockchain cost would not impact the offline retailer, a moderate cost would harm the offline retailer, and a higher cost would enable the offline retailer to increase profits. The primary reason for this discrepancy lies in the differences in channel quality and the mechanisms of the blockchain cost within the models. Particularly when there is a significant disparity in channel quality, the introduction of blockchain leads to a more pronounced enhancement of trust in offline channels, thereby altering the competitive landscape.

We establish Proposition 4.3 by analyzing the competitive manufacturer's profit differences between cases where the overseas manufacturer does or doesn't adopt blockchain.

Proposition 4.3. *When* $\max\{0, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$, *the overseas manufacturer adopts blockchain. In this case, the competitive manufacturer benefits from blockchain if and only if* $\gamma > \frac{10+18\alpha}{70-49\alpha-21\alpha^2}$ *and* $\max\{c_B^1, c_B^2, c_B^5\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$.

By Lemma 4.1, when the blockchain cost is higher than a specific threshold c_B^5, the overseas manufacturer increases their online and offline retail prices due to higher blockchain cost, which allows competitive manufacturer to follow suit. At the same time, Lemma 4.2 also further shows that while the competitive manufacturer is raising their prices, the demand for their products is increasing. Under the combined effect of price and demand, the competitive manufacturer can benefit from blockchain applications. However, it follows from Proposition 4.3 that the key premise for the competitive manufacturer to benefit from the blockchain is that the channel quality variation level is at a low and the blockchain cost is in the medium range (*i.e.*, $\max\{c_B^1, c_B^2, c_B^5\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$). When the channel quality variation level is high, the cost must be kept relatively low to prevent the overseas manufacturer's online products from existing in the market due to prohibitively high prices. In this equilibrium, the online retail price of the foreign manufacturer and the offline retail price of the retailer increase only slightly, resulting in a decrease in the demand for product of the competitive manufacturer after the adoption of the blockchain. Therefore, the profit of the competitive manufacturer will decrease after the adoption of blockchain. When the channel quality variation level is low, the difference between channels is more pronounced. Overseas manufacturers are also passing part of the cost on to product retail prices, and a significant increase in overseas product prices will make the products of the competitive manufacturer more attractive in terms of price. The competitive manufacturer, leveraging its price advantage, attracts price-sensitive consumers, thereby increasing demand for their products and achieving indirect benefits

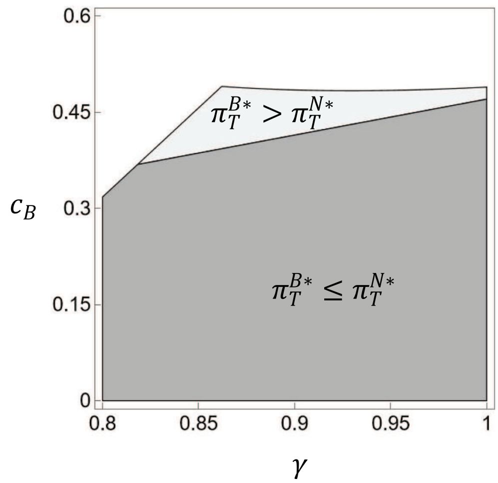

FIGURE 6. Benefits and losses of the competitive manufacturer from blockchain.

from blockchain. Figure 6 shows the impact of the channel quality variation level and the blockchain cost on whether the competitive manufacturer benefits from or is harmed by the blockchain.

We denote $(\Delta\pi_M, \Delta\pi_R, \Delta\pi_T)$ as three parties' profits after blockchain adoption minus profits before blockchain adoption. We show how the blockchain cost influences value of blockchain for the overseas manufacturer, the offline retailer and the competitive manufacturer in Proposition 4.4.

Proposition 4.4. *When* $\max\{0, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$, *the overseas manufacturer adopts blockchain. In this case, the following results are obtained:*

(a) $\frac{\partial(\Delta\pi_M)}{\partial c_B} < 0$.
(b) $\frac{\partial(\Delta\pi_R)}{\partial c_B} > 0$ *if the offline retailer benefits from blockchain, which holds under the conditions specified in Proposition 4.2.*
(c) $\frac{\partial(\Delta\pi_T)}{\partial c_B} > 0$ *if the competitive manufacturer benefits from blockchain, which holds under the conditions specified in Proposition 4.3.*

Figure 7 illustrates the impact of blockchain cost on blockchain value, with the horizontal axis denoting the cost and the vertical axis denoting the value. For the overseas manufacturer, a lower blockchain adoption cost enables the consumer trust premium generated by the technology to sufficiently offset the associated expenses, thereby yielding a positive net benefit. As the blockchain cost increases, the manufacturer's profit gains gradually diminish due to rising prices, exhibiting characteristics of diminishing marginal returns. Intuitively, for the offline retailer, rising blockchain cost would increase the wholesale price, thereby squeezing its profit margins. However, interestingly, as the blockchain cost increases, the offline retailer may benefit from blockchain technology. Specifically, when the blockchain cost is high, the increase in online prices set by the overseas manufacturer significantly outpaces that of offline retail prices, leading to a rise in demand for the offline retailer. Under certain conditions, the revenue generated from increased demand can offset the negative impact of price increases, resulting in net profit growth for the offline retailer. For the competitive manufacturer, when the blockchain cost drives up the prices of the overseas manufacturer's online and offline channels, its own similar products gain greater price competitiveness in the market, thereby increasing its market demand and profits.

We show how the product quality variation level influences value of blockchain for the offline retailer and the competitive manufacturer in Proposition 4.5.

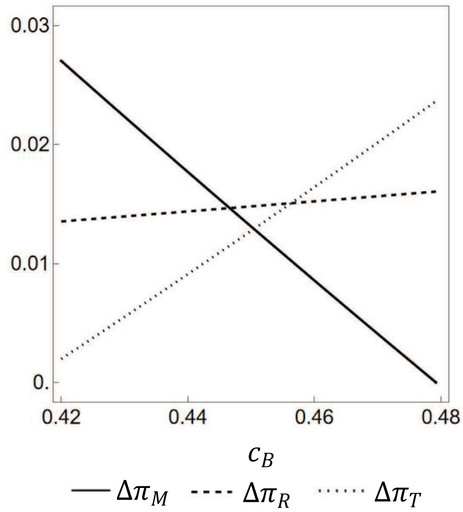

FIGURE 7. The impact of blockchain cost on blockchain value.

Proposition 4.5. *When* $\max\{0, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4, c_B^8\}$, *the overseas manufacturer adopts blockchain. In this case, the following results are obtained:*

(a) *There exists a critical threshold* α_1 *such that* $\frac{\partial(\Delta\pi_R)}{\partial\delta} < 0$ *if* $\alpha > \alpha_1$, *and* $\frac{\partial(\Delta\pi_R)}{\partial\delta} \geq 0$ *if* $\alpha \leq \alpha_1$, *provided that the offline retailer benefits from blockchain, which holds under the conditions specified in Proposition 4.2.*

(b) $\frac{\partial(\Delta\pi_T)}{\partial\delta} > 0$ *if the competitive manufacturer benefits from blockchain, which holds under the conditions specified in Proposition 4.3.*

The results in Proposition 4.5 represent the culmination of the model's analytical journey. Here, we formally introduce the cross-border e-commerce platform commission rate, a central governance mechanism in cross-border e-commerce, as an endogenous variable. While earlier propositions focused on structural parameters such as channel differentiation, blockchain cost, tax burden, and direct-shipping cost, this was not an oversight, but a deliberate modeling strategy necessitated by analytical complexity. The commission rate interacts nonlinearly with all parameters. Premature inclusion would have compromised tractability. Therefore, prior propositions established foundational equilibria, paving the way for analyzing the platform's strategic commission decision in Proposition 4.5. Specifically, blockchain adoption enhances consumer trust in the offline retailer's product quality valuation. As the product quality variation level decreases, the absolute trust-enhancing effect remains significant. However, its relative advantage compared to the competitive manufacturer's offering diminishes, reducing the blockchain's marginal benefit to the retailer. Critically, the cross-border e-commerce platform commission rate modulates this effect nonlinearly. When the cross-border e-commerce platform commission rate is high, the platform extracts a larger revenue share, weakening the retailer's ability to capitalize on demand growth. The high commission rate dampens pricing flexibility, causing the offline retailer's blockchain marginal benefit to turn negative as the quality variation level falls. Conversely, when the commission rate is low, the retailer retains more marginal revenue. A reduction in quality variation strengthens its competitive position. Due to intensified offline competition, the overseas manufacturer is motivated to lower its online retail price. Due to cost structures, the competitive manufacturer's price reduction magnitude is smaller than the offline retailer's price reduction magnitude. This asymmetric response drives higher demand toward the offline channel, amplifying the retailer's blockchain gains. The threshold α_1 represents the break-even point where the commission rate shifts from enabling to constraining offline retailer value creation. This boundary condition explains the non-monotonic relationship observed in the results. For the competitive manufacturer, the

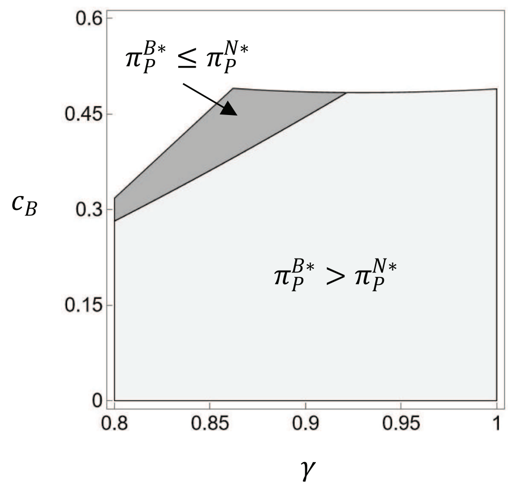

FIGURE 8. Benefits and losses of the cross-border e-commerce platform from blockchain.

reduction in quality variation level increases both demand and retail price in its channel. Hence, the competitive manufacturer benefits more from blockchain as product quality becomes lower. This analysis reveals that the commission rate is a key moderator in the value appropriation of blockchain technology. The offline retailer must evaluate blockchain adoption conditional on platform fee policies, as the technology's return on investment depends critically on the commission rate. Consequently, the cross-border e-commerce platform may strategically adjust commission rates to influence adoption incentives and boost overall system trust.

We obtain Observation 4.1 by comparisons of profits of the cross-border e-commerce platform with and without blockchain if the overseas manufacturer adopts blockchain.

Observation 4.1. Given the overseas manufacturer's blockchain adoption, the cross-border e-commerce platform may suffer losses from blockchain.

Figure 8 illustrates the net impact of the channel quality variation level and blockchain cost on the cross-border e-commerce platform. When the blockchain cost is high, the overseas manufacturer significantly increases the online price to offset the investment required for this technology. This price effect dampens demand in the online channel, thereby directly reducing the platform's commission income based on sales. Meanwhile, when the channel quality variation level is high, it indicates weak initial trust in the online channel. At this stage, blockchain technology offers limited improvement in trust in online product quality, which is insufficient to significantly stimulate consumer demand. Consequently, the platform cannot derive substantial benefits from its adoption. Conversely, in market environments where the channel quality variation level is minimal, blockchain technology can effectively enhance consumers' trust perception of online products. The resulting positive demand effect is generally sufficient to offset the negative impact caused by rising online prices, thereby allowing the platform to achieve net gains.

5. EXTENSION

5.1. Consumer's online shopping cost

In this section, we consider consumer's online shopping cost and define this scenario as Scenario H. When the overseas manufacturer adopts blockchain, we let w_R^{HB} denote the overseas manufacturer's equilibrium wholesale price, $(p_R^{HB}, p_T^{HB}, p_o^{HB})$ denote the equilibrium retail prices through three channels, and π_M^{HB} be profit of overseas manufacturer.

We show comparisons of the equilibrium prices and profits of the overseas manufacturer in Scenario H and Scenario B in Lemma 5.1.

Lemma 5.1. $w_R^{HB} > w_R^{B*}, \quad p_o^{HB} < p_o^{B*}, \quad p_R^{HB} > p_R^{B*}, \quad p_T^{HB} > p_T^{B*}, \quad \pi_M^{HB} < \pi_M^{B*}$.

Lemma 5.1 shows that the consumer utility for the overseas manufacturer's online product is lower when considering consumer's online shopping cost than when not, while the utilities for other products remain constant. After accounting for consumers' online shopping cost, the overseas manufacturer raises its wholesale price while reducing its online retail price, whereas the offline retailer and the competitive manufacturer both increase their retail prices. For the overseas manufacturer, reduction of profit through online channel exceeds increase of profit from wholesaling to the offline retailer resulting in an overall profit reduction.

We obtain Proposition 5.1 by comparisons of profits of the overseas manufacturer with and without blockchain.

Proposition 5.1. *There exist thresholds c_1^H, c_2^H, c_B^{H1}, c_B^{H2}, c_B^{H3}, c_B^{H4}, and c_B^{H5} such that:*

(a) *When $c \geq \max\{c_1^H, c_2^H\}$, $\pi_M^{HB*} > \pi_M^{HN*} \Leftrightarrow c_B < \min\{c_B^{H1}, c_B^{H2}, c_B^{H3}\}$.*
(b) *When $c < \max\{c_1^H, c_2^H\}$, $\pi_M^{HB*} > \pi_M^{HN*} \Leftrightarrow \max\{c_B^{H4}, c_B^{H5}\} < c_B < \min\{c_B^{H1}, c_B^{H2}, c_B^{H3}\}$.*

Proposition 5.1 indicates that when consumer's online shopping cost is considered, the influence of blockchain cost on the overseas manufacturer's blockchain adoption decisions aligns with the main model. When the overseas manufacturer's combined tax and shipping cost is high, the overseas manufacturer adopts blockchain only if the blockchain cost is low. However, when the overseas manufacturer's combined tax and shipping cost is low, the overseas manufacturer adopts blockchain only if the blockchain cost is moderate. The rationale is the same as that of Proposition 4.1.

5.2. The blockchain cost allocation

In this section, we examine a model where the blockchain cost is shared within each sales channel, denoted as Scenario S. Specifically, in the offline retailer channel, the blockchain cost is shared between the overseas manufacturer and the offline retailer. In the cross-border e-commerce platform channel, the blockchain cost is shared between the overseas manufacturer and the cross-border e-commerce platform. For both channels, the overseas manufacturer bears an identical rate, denoted as λ, of the blockchain cost. The expected profit functions of the overseas manufacturer, the offline retailer, the competitive manufacturer, and the cross-border marketplace in Scenario S are:

$$\pi_M^S = (1-\alpha)p_o^S d_o^S - c d_o^S + w_R^S d_R^S - \lambda c_B (d_R^S + d_o^S) \tag{21}$$
$$\pi_R^S = (p_R^S - w_R^S) d_R^S - (1-\lambda) c_B d_R^S \tag{22}$$
$$\pi_T^S = p_T^S d_T^S \tag{23}$$
$$\pi_P^S = \alpha p_o^S d_o^S - (1-\lambda) c_B d_o^S. \tag{24}$$

We obtain Observation 5.1 by comparisons of profits of the overseas manufacturer with and without blockchain considering blockchain cost-sharing rate.

Observation 5.1. Reducing the blockchain cost-sharing rate does not always make the overseas manufacturer less likely to adopt blockchain.

The horizontal axis of Figure 9 represents the blockchain cost-sharing rate, and the vertical axis represents the blockchain cost. The shaded area indicates the region where the overseas manufacturer adopts blockchain. A blockchain cost-sharing rate of 1 for the overseas manufacturer indicates the absence of cost sharing. Generally, the lower the blockchain cost-sharing rate for the overseas manufacturer, the more likely it is to adopt blockchain. However, Figure 9 reveals that when the blockchain cost-sharing rate is very low, the overseas manufacturer does not adopt blockchain. This is because when the overseas manufacturer bears very low blockchain cost, the offline

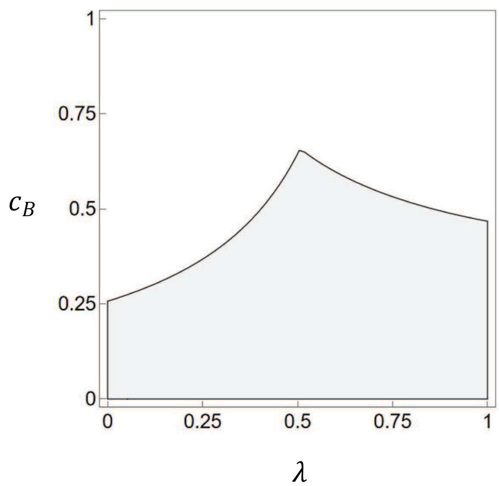

FIGURE 9. Optimal blockchain adoption strategy for the overseas manufacturer considering blockchain cost-sharing.

retailer and the cross-border e-commerce platform bear high blockchain cost, forcing them to significantly raise retail prices to compensate for the blockchain cost. This, in turn, severely reduces demand in both the offline retail channel and the cross-border e-commerce platform channel, leading to market failure. This reveals that simply lowering the blockchain cost-sharing rate to incentivize the overseas manufacturer to adopt blockchain is not always effective. It is essential to balance the distribution of benefits between upstream and downstream parties, avoiding a decline in market demand due to cost shifting to downstream channels.

6. Conclusion

Our analysis reveals that the overseas manufacturer utilizes both the cross-border e-commerce platform and the offline retailer as distribution channels, competing directly with the competitive manufacturer's product domestically. In the cross-border product market, consumers have lower trust in the quality of the online product compared to offline retailer's product which creates opportunities for blockchain enhancing consumer trust in product quality. We develop a game model to study when the overseas manufacturer will adopt blockchain and how blockchain will affect the offline retailer and the competitive manufacturer.

First, the blockchain cost reshapes the demand pattern across channels, while the overseas manufacturer's adoption decision exhibits a non-monotonic pattern. An increase in the blockchain cost raises product prices across all channels. When the blockchain cost is high, the demand for the overseas manufacturer's online product decreases, whereas the demand for the offline retailer's product and the competitive manufacturer's product increases, forming a demand transfer effect; conversely, the opposite trend emerges when the blockchain cost is low. When the overseas manufacturer's combined tax and shipping cost is high, the overseas manufacturer adopts blockchain only when the blockchain cost is low; otherwise, adoption occurs only when the blockchain cost is moderate. Second, blockchain technology generates a "free-riding" effect, enabling the offline retailer that does not bear the implementation cost to benefit, while the cross-border e-commerce platform may be harmed, and the competitive manufacturer's benefit is subject to strict constraints. For the offline retailer, when the channel quality variation is large, it always benefits from blockchain; otherwise, it benefits only when the blockchain cost is high. The competitive manufacturer's benefit condition is more restrictive: it benefits from blockchain only when the channel quality variation is small and the blockchain cost is high. Notably, the cross-border e-commerce platform may be harmed by blockchain adoption, further highlighting the asymmetric distribution of the value of blockchain among supply chain members. Third, the value of blockchain simultaneously exhibits dual characteristics of "cost sensitivity" and "quality dependence" accompanied by an asymmetric distribution effect. An increase in the blockchain cost reduces the value of blockchain for the overseas manufacturer but enhances the value of blockchain for the offline retailer and the competitive manufacturer, forming a reverse allocation mechanism. When the cross-border e-commerce platform commission rate is high, the platform's commission constrains pricing flexibility, and a decrease in the product quality variation instead weakens the offline retailer's benefit from blockchain; conversely, when the commission rate is low, the overseas manufacturer can lower its price to redirect demand to the offline channel, making the offline retailer's benefit increase as the product quality variation decreases. Extended analysis further reveals that consumer's online shopping cost has a limited impact on the main model's conclusions, and reducing the blockchain cost-sharing rate does not always increase the overseas manufacturer's adoption incentive, as adoption remains contingent on the interaction between the combined cost and competitive conditions. The above findings reveal the complex mechanism of blockchain from the perspective of multi-channel competition and quality uncertainty in cross-border e-commerce.

We have the following managerial insights that might be useful for supply chain members. For the overseas manufacturer, blockchain adoption is not always better with a lower cost. When the combined cost is high, adoption should be considered only when the blockchain cost is low; when the combined cost is low, a moderate blockchain cost is preferable, as an extremely low blockchain cost may trigger irrational market responses. Moreover, an increase in the blockchain cost erodes its own profitability while potentially benefiting channel partners and competitors. Thus, it must carefully evaluate how rising blockchain cost may diminish its own profit. For the offline retailer, blockchain technology presents a potential "free-riding" opportunity. When the channel quality variation is large, the retailer benefits from blockchain regardless of the blockchain cost; when the channel quality variation is small, it benefits only when the blockchain cost is high. Therefore, the offline retailer should monitor the overseas manufacturer's blockchain adoption and leverage the trust spillover effect in markets with significant channel quality variation or high blockchain cost to enhance its market share. For the competitive manufacturer, benefiting from blockchain requires strict conditions. It captures the value spillover only when the channel quality variation is small and the blockchain cost is high. Thus, it should closely monitor these factors and, when conditions are favorable, adjust its pricing strategy to absorb demand that shifts away from the online channel following blockchain adoption. For the cross-border e-commerce platform, blockchain adoption is not necessarily beneficial. The platform may suffer from pricing constraints and demand shifts induced by an increase in the blockchain cost. It should pay attention to how its commission rate affects the distribution of the value of blockchain: when the commission rate is high, a decrease in the product quality variation instead weakens the offline retailer's benefit, which may further affect platform ecosystem efficiency. The platform may adjust its commission structure or negotiate cost-sharing mechanisms with the manufacturer to mitigate negative impacts and achieve a win-win outcome. In summary, the value of blockchain in cross-border e-commerce supply chains is highly contingent and asymmetrically distributed. Each participant should formulate differentiated strategies based on its specific role, the prevailing cost environment, and the structure of market competition.

To conclude, we examine the study's limitations and propose areas for future exploration. First, while our study primarily examines blockchain's impact on multi-channel competition, the proposed framework incorporates an overseas manufacturer, an offline retailer, a competitive manufacturer, and consumers as the core components of the cross-border e-commerce supply chain. While existing analyses typically focus on the simplified supply chain structure, real-world supply chains often involve more complex networks. Future research should explore the value of blockchain in more complex competitive environments involving multiple manufacturers and retailers. Second, we assume that only the overseas manufacturer can decide whether to adopt blockchain. Future research could further investigate scenarios involving multiple parties voluntarily adopting blockchain technology, such as adoption by domestic manufacturers or offline retailers. Furthermore, considering real-world cross-border supply chain contexts, it would be valuable to examine how lower blockchain implementation costs for local manufacturers may influence their adoption incentives and alter competitive dynamics.

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Appendix A.

We first present Lemmas A.1 and A.2 that solve the equilibrium of the two scenarios without and with blockchain.

Lemma A.1. *For the scenario without blockchain, there exists a unique equilibrium, in which the three parties' decisions follow:*

$$w_R^{N*} = \frac{126c\alpha + 7t(\alpha-1)(21\alpha-50) + 3(\alpha-1)(21\alpha(2\gamma-\delta-1) + 50(\delta-1))}{300 - 300\alpha - 63\alpha^2}, \tag{A.1}$$

$$p_R^{N*} = \frac{21t(115-21\alpha)\alpha - 10(177+217t) - 210c(4+3\alpha) + 3(280\gamma + 310\delta) - 5(14\gamma - 83 + 698)}{21(100\alpha - 100 + 21\alpha^2)}, \tag{A.2}$$

$$p_T^{N*} = \frac{4(231t\alpha - 10(3+28t) - 54\alpha - 21c(10+3\alpha) - 21(\alpha-1)(10+3\alpha)\gamma + 3(-60 + \alpha(67+21\alpha)\delta))}{21(100\alpha - 100 + 21\alpha^2)}, \tag{A.3}$$

$$p_o^{N*} = \frac{10(3+28t) + 3(18\alpha - 77t\alpha + 7c(10+3\alpha) + 30\gamma - 51\alpha\gamma + (33\alpha - 40)\delta)}{300 - 300\alpha - 63\alpha^2}. \tag{A.4}$$

Proof of Lemma A.1. Given the overseas manufacturer's wholesale price, offline retailer's retail price, and competitive manufacturer's retail price, the overseas manufacturer's best response in online retail price can be obtained as p_o^{N*}. Substituting them into $\pi_R^N = (p_R^N - w_R^N)d_R^N$ and $\pi_T^N = p_T^N d_T^N$, we have the profit functions of offline retailer with respect to p_R^N and the profit functions of competitive manufacturer with respect to p_T^N. Since

$$\frac{\partial^2 \pi_R^N}{\partial^2 p_R^N} < 0 \quad \text{and} \quad \frac{\partial^2 \pi_T^N}{\partial^2 p_T^N} < 0, \tag{A.5}$$

π_R^N is a concave quadratic function of p_R^N and π_T^N is a concave quadratic function of p_T^N. By solving first-order conditions,

$$\frac{\partial \pi_R^N}{\partial p_R^N} = 0 \quad \text{and} \quad \frac{\partial \pi_T^N}{\partial p_T^N} = 0, \tag{A.6}$$

we obtain the unique equilibrium retail prices. Substituting p_R^{N*} and p_T^{N*} into p_o^{N*}, and then substituting p_o^{N*} into

$$\pi_M^N = (1-\alpha)p_o^N d_o^N - cd_o^N + w_R^N d_R^N, \tag{A.7}$$

we can obtain the profit function of overseas manufacturer. Since

$$\frac{\partial^2 \pi_M^N}{\partial^2 w_R^N} < 0, \tag{A.8}$$

π_M^N is a concave quadratic function of w_R^N. By solving first-order condition $\frac{\partial \pi_M^N}{\partial w_R^N} = 0$, we can obtain the unique equilibrium wholesale price w_R^{N*}. Substituting w_R^{N*} into p_o^{N*}, p_R^{N*}, and p_T^{N*}, we can obtain three retail prices through three channels. □

Lemma A.2. *For the scenario with blockchain, there exist unique best responses of the three parties in the subgame that follow:*

$$w_R^{B*} = \frac{\begin{array}{c}3c_B(29\alpha-50) - 7t(\alpha-1)(21\alpha-50) - 3(42c\alpha + (\alpha-1)(50\delta - 50(1+\rho) \\ -21\alpha(1+\delta+\rho-2\gamma(1+\rho))))\end{array}}{300\alpha + 63\alpha^2 - 300}, \tag{A.9}$$

$$p_R^{B*} = \frac{1}{21(100\alpha - 100 + 21\alpha^2)}\begin{bmatrix} -10(177+217t) + 2415t\alpha - 441t\alpha^2 - 210c(4+3\alpha) \\ +45c_B(5\alpha-26) + 21\alpha^2(7+3\delta+7\rho-10\gamma(1+\rho)) \\ -5\alpha(69\delta - 83(1+\rho) + 14\gamma(1+\rho)) \\ +10(31\delta - 59\rho + 28\gamma(1+\rho)) \end{bmatrix}, \tag{A.10}$$

$$p_T^{B*} = \frac{\begin{array}{c}4(30+280t+54\alpha-231t\alpha) + 9c_B(20+\alpha) + 21c(10+3\alpha) \\ -210\gamma + 147\alpha\gamma + 63\alpha^2\gamma + 180\delta - 201\alpha\delta - 63\alpha^2\delta \\ +3(10+18\alpha-70\gamma+7\alpha(7+3\alpha)\gamma)\rho\end{array}}{21(100-100\alpha-21\alpha^2)}, \tag{A.11}$$

$$p_o^{B*} = \frac{\begin{array}{c}30+280t+54\alpha-231t\alpha+9c_B(20+\alpha)+21c(10+3\alpha) \\ +90\gamma - 153\alpha\gamma - 120\delta + 99\alpha\delta + 3(10+18\alpha+30\gamma-51\alpha\gamma)\rho\end{array}}{300-300\alpha-63\alpha^2}. \tag{A.12}$$

Proof of Lemma A.2. Given the overseas manufacturer's wholesale price, offline retailer's retail price, and competitive manufacturer's retail price, the overseas manufacturer's best response in online retail price can be obtained as p_o^{B*}. Substituting them into $\pi_R^B = (p_R^B - w_R^B)d_R^B$ and $\pi_T^B = p_T^B d_T^B$, we have the profit function of offline retailer with respect to p_R^B and the profit function of competitive manufacturer with respect to p_T^B. Since $\frac{\partial^2 \pi_R^B}{\partial^2 p_R^B} < 0$ and $\frac{\partial^2 \pi_T^B}{\partial^2 p_T^B} < 0$, π_R^B is a concave quadratic function of p_R^B and π_T^B is a concave quadratic function of p_T^B. By solving first-order conditions, $\frac{\partial \pi_R^B}{\partial p_R^B} = 0$ and $\frac{\partial \pi_T^B}{\partial p_T^B} = 0$, we obtain the unique equilibrium retail prices.

Substituting p_R^{B*} and p_T^{B*} into p_o^{B*}, and then substituting p_o^{B*} into $\pi_M^B = (1-\alpha)p_o^B d_o^B - cd_o^B + w_R^B d_R^B - c_B(d_R^B + d_o^B)$, we can obtain the profit functions of overseas manufacturer. Since $\frac{\partial^2 \pi_M^B}{\partial^2 w_R^B} < 0$, π_M^B is a concave quadratic function of w_R^B. By solving first-order condition $\frac{\partial \pi_M^B}{\partial w_R^B} = 0$, we can obtain the unique equilibrium wholesale price w_R^{B*}. Substituting w_R^{B*} into p_o^{B*}, p_R^{B*}, and p_T^{B*}, we can obtain three retail prices through three channels. □

Lemma A.3. *For the scenario without blockchain, the feasibility conditions are as follows:*

$$\max\{c_1, c_2\} < c < \max\{c_3, c_4, c_5\}. \tag{A.13}$$

For the scenario with blockchain, the feasibility conditions are as follows:

$$\max\{0, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4\}. \tag{A.14}$$

Proof of Lemma A.3. For the scenario without blockchain, the conditions ensuring that demands are positive and the market is completely covered are as follows: $w_R^N > 0$, $p_o^N > 0$, $p_R^N > 0$, $p_T^N > 0$, $p_o^N > w_R^N$, $p_R^N > w_R^N$, $(1-\alpha)p_o^N - c - c_B > 0$, $\pi_M^N > 0$, $\pi_R^N > 0$, $\pi_T^N > 0$, $\pi_P^N > 0$, $U_R^N > 0$, $U_T^N > 0$. $\max\{c_1, c_2\} < c < \max\{c_3, c_4, c_5\}$ on c is derived by solving the set of inequalities presented above.

For the scenario with blockchain, the conditions ensuring that demands are positive and the market is completely covered are as follows: $w_R^B > 0$, $p_o^B > 0$, $p_R^B > 0$, $p_T^B > 0$, $p_o^B > w_R^B$, $p_R^B > w_R^B$, $(1-\alpha)p_o^B - c - c_B > 0$, $w_R^B - c_B > 0$, $\pi_M^B > 0$, $\pi_R^B > 0$, $\pi_T^B > 0$, $\pi_P^B > 0$, $U_R^B > 0$, $U_T^B > 0$. $\max\{0, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4\}$ on c_B is derived by solving the set of inequalities presented above. □

Proof of Lemma 4.1. **(a)** To compare w_R^{N*} with w_R^{B*}, we have

$$w_R^{B*} - w_R^{N*} = \frac{c_B(29\alpha - 50) - (\alpha - 1)(21\alpha(2\gamma - 1) - 50)\rho}{100\alpha - 100 + 21\alpha^2} > 0,$$

which means $w_R^{B*} > w_R^{N*}$. To compare p_o^{N*} with p_o^{B*}, we have $p_o^{B*} - p_o^{N*} =$

$$\frac{(51\alpha\gamma - 10 - 18\alpha - 30\gamma)\rho - 3c_B(20 + \alpha)}{100\alpha - 100 + 21\alpha^2} > 0,$$

which means $p_o^{B*} > p_o^{N*}$. To compare p_R^{N*} with p_R^{B*}, we have

$$p_R^{B*} - p_R^{N*} = \frac{15c_B(5\alpha - 26) + \big(\alpha(415 - 70\gamma) - 590 + 280\gamma - 21\alpha^2(10\gamma - 7)\big)\rho}{700\alpha - 700 + 147\alpha^2} > 0,$$

which means $p_R^{B*} > p_R^{N*}$.

(b) To compare p_T^{N*} with p_T^{B*}, we have

$$p_T^{B*} - p_T^{N*} = \frac{4\big(3c_B(20 + \alpha) + \big(10 - 70\gamma + 21\alpha^2\gamma + \alpha(18 + 49\gamma)\big)\rho\big)}{700 - 700\alpha - 147\alpha^2}.$$

We first examine its monotonicity with respect to the blockchain cost c_B. The first-order derivative is

$$\frac{\partial(p_T^{B*} - p_T^{N*})}{\partial c_B} = \frac{12(20 + \alpha)}{-700\alpha + 700 - 147\alpha^2} > 0.$$

Next, we determine the critical threshold of c_B, denoted c_B^5, where the price difference equals zero. Setting $p_T^{B*} - p_T^{N*} = 0$ and solving for $c_B^5 = \frac{(70\gamma - 10 - 21\alpha^2\gamma - \alpha(18+49\gamma))\rho}{3(20+\alpha)}$. When $0 < \gamma \le \frac{10+18\alpha}{70-49\alpha-21\alpha^2}$, $c_B^5 \le 0$. By analyzing prices, demands and the consumer utility, we get that γ can't meet $\gamma > \max\{\gamma_1, \gamma_2, \gamma_3, \gamma_5\}$ and $\gamma < \gamma_4$ at the same time, so we get that there is no feasible zone. When $\frac{10+18\alpha}{70-49\alpha-21\alpha^2} < \gamma \le 1$, $c_{BT} > 0$. If $0 < c_B \le c_B^5$, $p_T^{B*} \le p_T^{N*}$. If $c_B > c_B^5$, $p_T^{B*} > p_T^{N*}$.

(c) We have $\frac{\partial c_B^5}{\partial \alpha} = \frac{7\rho(50+3\gamma(50+40\alpha+\alpha^2))}{-(3(20+\alpha)^2)} < 0$. □

Proof of Lemma 4.2. **(a)** To compare d_o^{N*} with d_o^{B*}, we have

$$d_o^{B*} - d_o^{N*} = \frac{15(c_B(2 + \alpha) + (2 - 4\gamma + \alpha(4\gamma - 1))\rho)}{t(100\alpha - 100 + 21\alpha^2)}.$$

We first examine its monotonicity with respect to the blockchain cost c_B. The first-order derivative is

$$\frac{\partial(d_o^{B*} - d_o^{N*})}{\partial c_B} = \frac{15(2 + \alpha)}{t(\alpha(100 + 21\alpha) - 100)} < 0.$$

Next, we determine the critical threshold of c_B, denoted c_B^6. Setting $d_o^{B*} - d_o^{N*} = 0$ and solving for c_B^6. When $0 < \gamma \le \frac{\alpha-2}{4\alpha-4}$, $c_B^6 \le 0$. For any $c_B \ge 0$, we have $d_o^{B*} \le d_o^{N*}$. When $\frac{\alpha-2}{4\alpha-4} < \gamma \le 1$, $c_B^6 > 0$. If $0 < c_B \le c_B^6$, then $d_o^{B*} \ge d_o^{N*}$. If $c_B > c_B^6$, $d_o^{B*} < d_o^{N*}$.

(b) To compare d_R^{N*} with d_R^{B*}, we have

$$d_R^{B*} - d_R^{N*} = \frac{3\big(2c_B(5 + 16\alpha) + \big(60 - 70\gamma - 21\alpha^2\gamma + \alpha(91\gamma - 53)\big)\rho\big)}{7t(100 - 100\alpha - 21\alpha^2)}.$$

The first-order derivative is

$$\frac{\partial(d_R^{B*} - d_R^{N*})}{\partial c_B} = \frac{30 + 96\alpha}{700t - 700t\alpha - 147t\alpha^2}.$$

Similarly, it can be obtained $c_B^7 = \frac{(\alpha(53-91\gamma)-60+70\gamma+21\alpha^2\gamma)\rho}{10+32\alpha}$. When $0 < \alpha \le \frac{19-\sqrt{151}}{21}$ and $\frac{60-53\alpha}{70-91\alpha+21\alpha^2} < \gamma < 1$, $c_B^7 > 0$. If $0 < c_B \le c_B^7$, $d_R^{B*} \le d_R^{N*}$; If $c_B > c_B^7$, $d_R^{B*} > d_R^{N*}$. When $0 < \alpha \le \frac{19-\sqrt{151}}{21}$ and $0 < \gamma < \frac{60-53\alpha}{70-91\alpha+21\alpha^2}$, or $\frac{19-\sqrt{151}}{21} < \alpha \le \frac{1}{2}$, $c_B^7 < 0$. For any admissible $c_B > 0$, $d_R^{B*} > d_R^{N*}$.

(c) To compare d_T^{N*} with d_T^{B*}, we have

$$d_T^{B*} - d_T^{N*} = \frac{3\big(3c_B(20+\alpha) + \big(10 - 70\gamma + 21\alpha^2\gamma + \alpha(18+49\gamma)\big)\rho\big)}{7t(100 - 100\alpha - 21\alpha^2)}.$$

If $0 < c_B \le c_B^5$, then $d_T^{B*} \le d_T^{N*}$. If $c_B > c_B^5$, $d_T^{B*} > d_T^{N*}$. □

Proof of Proposition 4.1. **(a)** We look upon $\pi_M^{B*} - \pi_M^{N*}$ as a quadratic function opening upward of c_B, and get two roots of $\pi_M^{B*} - \pi_M^{N*} = 0$, c_B^8 and c_B^9. Combining Lemmas 4.1 and 4.2, the result follows. Therefore, $\pi_M^{B*} - \pi_M^{N*} > 0$ if $c_B < c_B^8$, and $\pi_M^{B*} - \pi_M^{N*} \le 0$ if $c_B > c_B^8$. When the demand and price are positive, we obtain $\max\{c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4\}$. Furthermore, $\max\{c_B^1, c_B^2\} \le 0$ if $c \ge \max\{c_6, c_7\}$, $\max\{c_B^1, c_B^2\} > 0$ and if $c < \max\{c_6, c_7\}$. Therefore, when $c \ge \max\{c_6, c_7\}$, we have $\pi_M^{B*} > \pi_M^{N*} \Leftrightarrow c_B < \min\{c_B^8, c_B^3, c_B^4\}$.

(b) When $c < \max\{c_6, c_7\}$, we have $\pi_M^{B*} > \pi_M^{N*} \Leftrightarrow \max\{c_B^1, c_B^2\} < c_B < \min\{c_B^8, c_B^3, c_B^4\}$. □

Proof of Proposition 4.2. **(a)** We look upon $\pi_R^{B*} - \pi_R^{N*}$ as a quadratic function opening upward of c_B, and get two roots of $\pi_R^{B*} - \pi_R^{N*} = 0$, c_B^7, and c_B^{10}. Combining with Lemma 4.2, we obtain that when $\gamma \le \frac{60-53\alpha}{70-91\alpha+21\alpha^2}$, we have $c_B^{10} < c_B^7 \le 0 \le c_B$, which means $\pi_R^{B*} \ge \pi_R^{N*}$.

(b) When $\gamma > \frac{60-53\alpha}{70-91\alpha+21\alpha^2}$, there are two possible solutions: $c_B \ge c_B^7$ or $0 < c_B \le c_B^{10}$. However, $c_B^{10} > 0$ contradicts the premise that demand and price are positive, and thus is discarded. By the same logic, by comparing c_B^7 with c_B^1, c_B^2, c_B^3, c_B^4, and c_B^8 respectively, when $\max\{c_B^7, c_B^1, c_B^2\} < c_B < \min\{c_B^3, c_B^4\}$, so we can get $\pi_R^{B*} > \pi_R^{N*}$. $\max\{c_B^7, c_B^1, c_B^2\} < c_B < \min\{c_B^8, c_B^3, c_B^4\}$ is achievable only under the premise of satisfying $c < \max\{c_6, c_7\}$. Here, the magnitude of c is determined by comparing c_B^7 with c_B^1, c_B^2, c_B^3, c_B^4, and c_B^8. □

Proof of Proposition 4.3. We look upon $\pi_T^{B*} - \pi_T^{N*}$ as a quadratic function opening upward of c_B, and get two roots of $\pi_T^{B*} - \pi_T^{N*} = 0$, c_B^{11} and c_B^5. Combining Lemmas 4.1 and 4.2, we obtain that when $0 < \gamma \le \frac{-10-18\alpha}{-70+49\alpha+21\alpha^2}$, the resulting conditions contradict the premises and are therefore discarded.

When $\gamma > \frac{-10-18\alpha}{-70+49\alpha+21\alpha^2}$, $c_B^5 > 0$. Furthermore, when $d_T^{B*} \ge 0$, we have

$$c_B > \frac{\begin{array}{c}7t(33\alpha-40) - 21c(10+3\alpha) - 3(21\alpha^2(\gamma - \delta + \gamma\rho) \\ +10(1+6\delta+\rho-7\gamma(1+\rho)) + \alpha(18 - 67\delta + 18 + 49\gamma(1+\rho)))\end{array}}{9(20+\alpha)}.$$

While $d_T^{N*} \ge 0$, if $c_B < c_B^{11}$ does not hold, $\pi_T^{B*} - \pi_T^{N*} > 0$. At this point, $\pi_T^{B*} - \pi_T^{N*} > 0$ holds if and only if $c_B > c_B^5$ is satisfied. Then, by comparing c_B^5 with c_B^1, c_B^2, c_B^3, c_B^4, and c_B^8 respectively, so we can get that $\pi_T^{B*} > \pi_T^{N*}$ when $\max\{c_B^1, c_B^2, c_B^5\} < c_B < \min\{c_B^3, c_B^4\}$. □

Proof of Proposition 4.4. **(a)** If the overseas manufacturer adopts blockchain, we have

$$\frac{\partial(\Delta\pi_M)}{\partial c_B} = \frac{\partial\big(\pi_M^{B*} - \pi_M^{N*}\big)}{\partial c_B} = \Delta_1 > 0.$$

(b) If the offline retailer benefits from blockchain, we have

$$\frac{\partial(\Delta\pi_R)}{\partial c_B} = \frac{\partial\big(\pi_R^{B*} - \pi_R^{N*}\big)}{\partial c_B} = \Delta_2 > 0.$$

(c) If the competitive manufacturer benefits from blockchain, we have

$$\frac{\partial(\Delta\pi_T)}{\partial c_B} = \frac{\partial\big(\pi_T^{B*} - \pi_T^{N*}\big)}{\partial c_B} = \Delta_3 > 0.$$

□

Proof of Proposition 4.5. **(a)** If the offline retailer benefits from blockchain, we have

$$\frac{\partial(\Delta\pi_R)}{\partial\delta} = \frac{\partial\left(\pi_R^{B*} - \pi_R^{N*}\right)}{\partial\delta} = \Delta_4 > 0 \Leftrightarrow \alpha > \alpha_1.$$

(b) If the competitive manufacturer benefits from blockchain, we have

$$\frac{\partial(\Delta\pi_T)}{\partial\delta} = \frac{\partial\left(\pi_T^{B*} - \pi_T^{N*}\right)}{\partial\delta} = \Delta_5 < 0.$$

□

Proof of Lemma 5.1. To compare w_R^{B*} with w_R^{HB}, we have $w_R^{HB} - w_R^{B*} = \frac{42h_o(\alpha-1)\alpha}{100\alpha-100+21\alpha^2} > 0$, which means $w_R^{HB} > w_R^{B*}$. To compare p_o^{B*} with p_o^{HB}, we have $p_o^{HB} - p_o^{B*} = \frac{h_o(30-51\alpha)}{100\alpha-100+21\alpha^2} < 0$, which means $p_o^{HB} < p_o^{B*}$. To compare p_R^{B*} with p_R^{HB}, we have $p_R^{HB} - p_R^{B*} = \frac{10h_o(\alpha-4+3\alpha^2)}{100\alpha-100+21\alpha^2} > 0$, which means $p_R^{HB} > p_R^{B*}$. To compare p_T^{B*} with p_T^{HB}, we have $p_T^{HB} - p_T^{B*} = \frac{4h_o(7\alpha-10+3\alpha^2)}{100\alpha-100+21\alpha^2} > 0$, which means $p_T^{HB} > p_T^{B*}$. To compare π_M^{B*} with π_M^{HB}, we have $\pi_M^{HB} - \pi_M^{B*} = \pi_1 < 0$, which means $\pi_M^{HB} < \pi_M^{B*}$. □

Proof of Proposition 5.1. **(a)** We look upon $\pi_M^{B*} - \pi_M^{HN*}$ as a quadratic function opening upward of c_B, and get two roots of $\pi_M^{HB*} - \pi_M^{HN*} = 0$, c_B^{H1} and c_B^{12}. From $c_B < c_B^{12}$, $c_B^{H1} < c_B^{12}$ and $\pi_M^{HB*} - \pi_M^{HN*} > 0$ with $c_B = 0$, we exclude root c_B^{12} and have $\pi_M^{B*} - \pi_M^{N*} > 0$ with $c_B < c_B^{H1}$ and $\pi_M^{HB*} - \pi_M^{HN*} \leq 0$ with $c_B > c_B^{H1}$. By analyzing prices, demands and the consumer utility with blockchain, we have feasible region with blockchain's cost: $\max\{c_B^{H4}, c_B^{H5}, 0\} < c_B < \min\{c_B^{H2}, c_B^{H3}\}$. When $c \geq \max\{c_1^H, c_2^H\}$, we have $\pi_M^{HB*} > \pi_M^{HN*} \Leftrightarrow c_B < \min\{c_B^{H1}, c_B^{H2}, c_B^{H3}\}$.

(b) When $c < \max\{c_1, c_2\}$, we have $\pi_M^{B*} > \pi_M^{N*} \Leftrightarrow \max\{c_B^{H4}, c_B^{H5}\} < c_B < \min\{c_B^{H1}, c_B^{H2}, c_B^{H3}\}$. □