



Research article

Should multinational firms participate in blockchain to provide quality verification under different market structures?

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Abstract: The e-tailers selling global brands' products on cross-border e-commerce platforms have been suffering from low-quality image. To solve this problem, some platforms (e.g., JD.com, eBay and Tmall Global) have utilized blockchain for quality verification. However, there is scant literature investigating the decision on blockchain adoption of the multinational firms on cross-border e-commerce platforms and its impact on the firms' production decisions. To address this gap, we developed a game-theoretic model to examine the supply chain parties' intention to participate in blockchain in a setting with one multinational firm (MNF) owning retail divisions, which competes with the e-tailers who sell the MNF's brand products in a low tax country. Considering the number of the e-tailers on the cross-border e-commerce platforms selling global brands' products is in a monopoly or in a duopoly, we investigated the blockchain adoption by multinational firms under different market structures. We found that, first, different blockchain adoption patterns will shape distinct channel competition structures, thereby directly affecting the MNF's pricing strategy and responsiveness to tax disparity by altering the degree of competitive equilibrium and channel symmetry. Second, blockchain is a double-edged sword for the MNF, which increases the MNF's wholesaling profit, but reduces the MNF's retailing and tax-planning profits. Consequently, when the e-tailer monopolizes the cross-border e-commerce market, the MNF tends to refuse to participate in blockchain. However, under a duopoly cross-border e-commerce market, the MNF prefers joint blockchain participation with both e-tailers when the stronger e-tailer has a high-quality image, particularly when the fixed cost of blockchain adoption and tax disparity are low. Third, the MNF's blockchain adoption incentive increases with e-tailers' quality image but decreases with cross-border tax disparity. In this study, we clarify that

the MNF and regulators should take downstream market structure and international tax disparity into consideration when promoting blockchain-enabled product quality-verification infrastructure.

Keywords: blockchain technology; market structure; cross-border e-commerce; quality image

Mathematics Subject Classification: 91B24, 91A80

1. Introduction

With the rapid development of economic globalization, cross-border e-commerce has become an important source of profits for a brand-owning multinational firm (MNF), which enables consumers to buy global-brand products online conveniently and further boosts market sales [1,2]. Many e-tailers are eager to purchase global-brand products and sell them on e-commerce platforms driven by growing market demand [3,4]. Moreover, in practice, an MNF's branded products may be sold simultaneously by different e-tailers across multiple cross-border e-commerce platforms. For example, goods from well-known global luxury brands, such as COACH, GUCCI, BVLGARI, and SWAROVSKI, are available on cross-border e-commerce platforms including JD.com, eBay, AliExpress, and Tmall Global.

However, products sold on e-commerce platforms suffer from inferior perceived quality image and customer suspicion [5–7], especially for global-brand products. There are two reasons for this: First, compared with offline offerings, goods sold via cross-border e-commerce platforms may harm firms' quality image and brand reputation due to inadequate market supervision [8,9]. Second, customers doubt product quality on e-commerce platforms because product information is incomplete and unreliable. Moreover, customers may remain suspicious of the authenticity of platform-sold goods even when e-tailers operating on these platforms hold official authorization to sell the MNF's products [10,11].

To resolve the above problems, blockchain technology has emerged. Supply-chain information (e.g., raw materials, production, logistics, inspection, inventory, and sales) can be integrated via blockchain [12,13]. Blockchain can guarantee information immutability, since supply-chain members cannot alter data once it has been written to the blockchain [14–16]. Blockchain consolidates multi-dimensional product information and enables customers to access verified on-chain records. Accordingly, when an MNF participates in blockchain together with its e-tailers, the perceived quality image of those e-tailers reselling the MNF's branded products is enhanced. Furthermore, blockchain mitigates consumer uncertainty regarding e-tailer credibility. In practice, platforms, including JD.com, eBay, AliExpress, and Tmall Global, have rolled out blockchain-enabled infrastructure that e-tailers can access free of charge. Even so, e-tailers still bear ancillary costs for on-chain operations such as data processing and business-process adaptation. These supporting costs, however, are relatively minor and can be reasonably neglected.

Although blockchain-enabled quality verification can improve e-tailers' perceived quality image [17], blockchain adoption across e-commerce platforms remains in its early stages [18,19]. An analysis of 7,598 Chinese A-share listed companies (2018–2021) shows that only 3.07% have adopted blockchain for product quality verification and supply-chain information sharing. For MNFs, one non-negligible barrier is the substantial setup and application costs associated with blockchain [16,20]. For example, in the diamond industry, firms must invest heavily in laser equipment to build authentication systems and generate digital fingerprints [21–23]. Additionally, global-brand MNFs often operate their own retail divisions within low-tax jurisdictions (such as Gucci, Rolex, Chanel, and Estée Lauder), and

e-tailers compete against these retail divisions. Therefore, when an MNF adopts blockchain together with its e-tailers, its retail division faces intensified competition stemming from the e-tailers' enhanced perceived quality image. For e-tailers, blockchain-driven higher wholesale prices and fiercer market competition raise their procurement costs and competitive pressure. Given the above considerations, blockchain participation constitutes a critical strategic choice for MNFs and e-tailers, which motivates two core research questions: Should an MNF adopt blockchain to enhance e-tailers' perceived quality image? Furthermore, will e-tailers be willing to join blockchain to strengthen consumer trust in the MNF's global brand?

In the international business area, blockchain-driven quality-image enhancement for MNFs is more consequential than for domestic-market counterparts [18]. For e-tailers, blockchain can elevate perceived product quality image and mitigate consumer belief uncertainty, thereby laying a solid foundation for long-term development. Although only a small number of firms have integrated blockchain into their operations, several cross-border e-commerce platforms hold positive outlooks for blockchain's application prospects. Accordingly, many cross-border e-commerce platforms have rolled out blockchain-related infrastructure and incentivized supply-chain members to take part. For instance, Tmall Global has launched a global traceability initiative: It leverages blockchain to trace the full supply-chain journey of imported goods and collect data, including production, transportation, customs clearance, inspection applications, and third-party inspection results. Furthermore, blockchain enables Tmall Global to assign a unique digital identifier to each cross-border imported product to boost consumer trust. This global traceability initiative covers 63 countries and regions, 3700 product categories, and 14500 overseas brands. Analogous cases of blockchain deployment within cross-border e-commerce are widely observed in the luxury industry.

The issue of whether to participate in blockchain among supply chain members has been studied in the literature [8,24]. These works assume that supply-chain members adopting blockchain operate within the same national jurisdiction. However, the utilization of blockchain in international business is different. On the one hand, from a competitive perspective, the utilization of blockchain is more likely to hurt the MNF's retail division, while the e-tailer can benefit more from blockchain due to the enhanced quality image. On the other hand, the differences in tax regimes between countries cannot be neglected, i.e., corporate income tax [18,25]. Many MNFs are headquartered in countries with high corporate income tax and tend to sell their products in countries with low corporate income tax. Without loss of generality, the MNFs are incentivized to increase pre-tax profit in countries with low corporate income tax to improve their after-tax profits. The aforementioned characteristics of MNFs can be summarized into two aspects. First, the utilization of blockchain intensifies market competition, which may hurt the MNFs' original profits. Second, different tax mechanisms (corporate income tax) might impact the behaviors and the profits of MNFs' and e-tailers. Nevertheless, this interactive relationship has largely been overlooked in the literature.

To bridge these research gaps, we integrate blockchain-adoption mechanisms and cross-border e-commerce characteristics within a unified model setting. An MNF headquartered in a high-tax jurisdiction sells its branded products via its internal retail division as well as third-party e-tailers operating on distinct e-commerce channels in a separate low-tax jurisdiction. The MNF and e-tailers must make blockchain-participation decisions. Distinguishing e-tailer monopoly and duopoly downstream market structures, we examine supply-chain agents' blockchain-participation incentives under alternative competitive environments. Two market configurations are analyzed: First, a single e-tailer monopolizes the cross-border e-commerce market and competes against the MNF's retail

division. Second, the downstream market operates as a duopoly, where two e-tailers resell the MNF's branded products and compete with the MNF's retail division. Furthermore, consumers exhibit heterogeneous channel preferences driven by divergent perceived quality images between e-tailers and the MNF's retail division. Adopting a game-theoretic approach [26–28], we pursue three research objectives: First, we derive the optimal decisions for the MNF, e-tailers, and the MNF's retail division under blockchain and non-blockchain scenarios across market structures. Second, we analyze how cross-border corporate-income-tax disparity and e-tailers' perceived quality images shape the optimal decisions and profits of the MNF, e-tailers, and retail division. Third, we explore whether the MNF and e-tailers should adopt blockchain to validate e-tailer product quality under different market-structure conditions.

Our main contributions can be summarized as follows: First, at the theoretical level, we identify a fundamental tension inherent in cross-border e-commerce: While blockchain technology enhances e-tailers' perceived quality image and expands market demand, it simultaneously intensifies channel competition and erodes the MNF's retail and tax-planning profits. Although researchers have examined blockchain adoption within domestic supply chains, the strategic interaction between blockchain participation decisions and downstream market structure (monopoly vs. duopoly) remains underexplored. We fill this gap by investigating how the MNF optimally balances the wholesale profit gains against the retail and tax-planning profit losses when deciding whether to participate in blockchain with e-tailers. Second, at the analytical level, we characterize the equilibrium conditions under which blockchain adoption becomes profitable for the MNF. We demonstrate that the MNF's blockchain incentive is critically shaped by three factors: e-tailers' existing quality image, cross-border tax disparity, and the fixed cost of blockchain adoption. In particular, we uncover a counterintuitive result: The MNF exhibits a stronger willingness to adopt blockchain under duopoly than under monopoly when the dominant e-tailer possesses a high quality image. This finding challenges the conventional wisdom that intensified downstream competition discourages upstream blockchain investment. Third, at the practical level, our results offer actionable guidelines for multinational brand owners and platform regulators. We show that e-tailers are always better off joining blockchain once the MNF participates, implying that blockchain adoption is driven by the MNF's incentives. We also demonstrate that policy interventions (such as subsidies or tax coordination) may be socially desirable, as blockchain enhances consumer surplus and potentially improves total welfare, even though it may reduce the MNF's private profits.

The remainder of this paper is organized as follows: In Section 2, we present the related-literature review. In Section 3, we describe the model setup. In Sections 4 and 5, we derive and characterize equilibrium outcomes for the e-tailer-monopoly and e-tailer-duopoly scenarios, respectively. Section 6 concludes this paper.

2. Literature review

Our research contributes to the literature on the cross-border e-commerce supply chain, especially on the main dimension related to the impact of corporate income tax when the cross-border e-commerce business occurs [2,25,29–32]. For example, Kim et al. [29] made the off-shoring and outsourcing decisions of the MNF by considering the supply chain cost and tax disparity between the countries. Niu et al. [30] investigated two competing MNFs' decisions, and they built a retail division to benefit from tax-planning. Next, Niu et al. [31] examined the MNF's order timing decisions which

considers the tax-planning benefit and a constraint related to the arm's length principle. Niu et al. [2] studied how the network effect and the corporate income tax affect the firms' decision to enter the global market. Liu et al. [32] studied the MNF's outsourcing strategies related to the MNF's retail division. They investigated the trade-off of wholesaling price between tax-planning and incentive role, and they found that the MNF should encourage its retail division to buy products from the off-shoring division. Niu et al. [25] employed a game-theoretic model to elucidate how tax disparities interact with factors such as market potential and channel competition to collectively shape MNFs strategic decisions. Distinct from the above stream of literature, we jointly evaluate blockchain adoption and cross-border tax disparity under alternative downstream market-structure scenarios (e-tailer monopoly versus duopoly). We further derive supply-chain members' optimal equilibrium decisions across these competitive contexts.

Our research also adds to the literature concerning blockchain adoption in supply chain, a research stream covering multiple research perspectives. On the one hand, several studies document the beneficial effects of blockchain for supply-chain firms. For example, Yoon et al. [33] showed that the utilization of blockchain could effectively reduce the transportation cost and lead time in the global logistics industry. Niu et al. [18] demonstrated that the adoption of blockchain traceability technology by e-commerce platforms not only safeguards brand owners but also enhances consumer trust, thereby attracting more high-end brands and customers to the platform. Moreover, Mishra et al. [34] highlighted smart contracts as the key enabler for blockchain to transform e-commerce supply chains. On the other hand, other researchers claim that the utilization of blockchain exerts negative impacts on firms. Babich and Hilary [35] summarized five weaknesses of the blockchain: For example, (i) the lack of privacy, (ii) the lack of standardization, (iii) the "garbage in, garbage out" problem, (iv) the black-box effect, and (v) inefficiency. Cao et al. [36] found that the energy consumption associated with blockchain operations poses a significant environmental and cost-related concern for firms considering its adoption. In addition, Kumar et al. [37] explored innovations and practical applications of blockchain in supply-chain management, pointing out that blockchain can improve supply-chain transparency, product traceability and multi-party trust while reducing fraud risks, yet it also faces prominent obstacles including high implementation costs, scalability limits, interoperability barriers, and regulatory uncertainties. Most of the above-cited works analyzed blockchain-related problems under deterministic-demand assumptions. In our paper, we examine the utilization of blockchain under a consumer heterogeneity model, which takes a very different viewpoint by investigating how the interplay between the cross-border e-commerce issues and the blockchain impacts the optimal decisions and the profits of the MNF and the e-tailers.

A closely related stream of research was represented by Niu et al. [2], who examined cross-border e-commerce and blockchain-adoption choices for an MNF and a single e-tailer. While their work and ours entail blockchain's role in cross-border settings, one key distinction is that they did not investigate the duopoly e-tailer market case. In practice, multiple e-tailers often sell the same branded product across distinct e-commerce platforms and compete against the MNF's internal retail division. Furthermore, e-tailers on different cross-border platforms and the MNF's retail division can exhibit divergent perceived quality images for the identical product. For instance, consumers tend to favor online purchases when e-tailers provide credible product quality verification. By contrast, when e-tailers cannot supply verified product information, consumers generally prefer offline purchases owing to the superior perceived quality image of offline retail channels. Accordingly, we address the research gaps left by Niu et al. [2]. We account not only for channel competition between e-tailers and

the MNF's retail division but also for heterogeneous perceived quality images across retail channels. Last, we compare blockchain-participation choices for both MNFs and e-tailers under alternative downstream-market-structure conditions.

3. Model description

Methodologically, we build upon the rigorous game-theoretic traditions in operations management. While our model adopts non-cooperative strategic interactions under Stackelberg leadership, we draw valuable methodological insights from the cooperative game theory framework proposed by [38] to refine our analysis of supply chain profit-allocation logic. Furthermore, we extend the analytical frameworks advanced by [28,39], who extensively apply game theory to supply chain optimization. Distinct from their focus on physical network structures, we integrate cross-border tax disparities and blockchain-enabled quality verification into the strategic interaction framework. This extension connects traditional supply chain optimization to the decision-making of multinational enterprises.

We consider a setting in which a multinational firm (MNF, denoted by F) operates a manufacturing division (denoted by M) in a high-tax country and a retail division (denoted by R) in a low-tax country. The MNF sells products in a low-tax country through its retail division and the third-party e-tailers (denoted by E) on one or more cross-border e-commerce platforms. There are two important types of tax in the MNF's global operations: corporate income tax and tariff. Regarding the corporate income tax, most MNFs are headquartered in the countries with high corporate income tax. We assume that the tax rate in the high/low tax country are r_H and r_L , respectively, where $r_H > r_L$. Normalizing the low tax rate, we get $r_L = 0$, and the tax disparity $\tau = r_H - r_L$. We normalize the low-tax country's corporate tax rate to zero to isolate the pure transfer-pricing incentive and to obtain tractable equilibrium solutions that reveal the MNF's strategic trade-off. Moreover, we assume that the tax disparity $\tau \leq \frac{1}{3}$ [40]. E-tailers purchase products from the MNF and then sell them on a cross-border e-commerce platform, where they compete against the MNF's retail division.

Consumers hold different valuations of the MNF's branded product purchased from the retail division and the e-tailers; that is, consumer willingness-to-pay varies across distinct distribution channels. We employ a discount factor α ($0 < \alpha < 1$) to capture consumer valuation for goods from the MNF's retail division. This accounts for the fact that online channels feature greater convenience and time-saving benefits compared with offline channels once blockchain confirms the authenticity of online product sources. We adopt discount factors ρ and φ ($0 < \varphi < \rho < \alpha < 1$) to denote consumer valuation discounts for respective e-tailers under the no-blockchain scenario. Without blockchain, online channels lack verified product authenticity, formal warranties and complete service packages, which leads to inferior perceived quality images. Heterogeneous online-channel preferences reflect divergent perceived quality images among cross-border-platform e-tailers. Without loss of generality, we assume e-tailers obtain identical perceived quality images once the MNF joins them on blockchain. Furthermore, consumers favor online channels over offline alternatives after e-tailers' product quality is verified via blockchain. Accordingly, we normalize consumer valuation for products sold by e-tailers to one ($\rho = \varphi = 1$) when the MNF and e-tailers participate in blockchain together. This modeling setup incorporates two real-world practical considerations: (1) blockchain ensures product authenticity; and (2) online channels intrinsically deliver shopping-convenience benefits. We use this normalization mainly to facilitate straightforward comparisons of consumer-valuation disparities across alternative sales channels.

3.1. Market structures

We examine two alternative downstream market structures for resale of the MNF's branded products. First, a single e-tailer sells the MNF's goods on a cross-border e-commerce platform, so this e-tailer monopolizes the e-commerce market and competes against the MNF's internal retail division in a low-tax country. Second, two or more e-tailers offer the MNF's products across separate cross-border e-commerce platforms and compete with one another as well as against the MNF's retail division. For the duopoly setting with exactly two e-tailers, we analyze four distinct blockchain-participation scenarios: The MNF adopts blockchain jointly with both e-tailers (Model PP); the MNF adopts blockchain with only one e-tailer (Model PN or Model NP); and the MNF does not adopt blockchain with any e-tailer (Model NN). Production and selling costs across all channels are normalized to zero for analytical simplicity (see a comparable assumption in [39]).

3.2. Consumer utility functions

In each market, consumers are heterogeneous with respect to their willingness-to-pay for the MNF's product under divergent perceived quality images, and each consumer buys at most one unit. Specifically, let θ represent consumers' base willingness-to-pay for the branded product, which follows a uniform distribution over $[0, a]$ with density $\frac{1}{a}$, where $a = \max\{a \mid q_i = 0\}$. This assumption implies that the total consumer population (i.e., potential market size) is normalized to one (see comparable assumptions in [41,42]).

We denote the retail price and consumer utility derived from purchasing the MNF's product as p_i and U_i , respectively. A consumer's utility from purchasing a product equals the difference between the consumer's willingness-to-pay and the corresponding retail price. Accordingly, we have $U_R^N = \alpha\theta - p_R$ in the retail division; and we have $U_{E1} = \rho\theta - p_{E1}$ and $U_{E2} = \varphi\theta - p_{E2}$ when consumers purchase products from e-tailer 1 and 2 under the no-blockchain scenario. We impose the condition $0 < \varphi < \rho < \alpha < 1$, capturing consumers' baseline preference (e.g., logistics capability, service quality, market reach) for offline over online channels in the absence of blockchain-enabled quality certification, as well as heterogeneous preferences across online channels. This preference pattern arises because cross-border online purchases suffer from unvalidated product provenance, incomplete warranty terms, and limited after-sales service. With blockchain deployment, we normalize consumers' base willingness-to-pay for products sold by e-tailers to one. Blockchain certification mitigates information asymmetry via immutable, traceable records; combining quality assurance with inherent online-shopping convenience shifts consumer preference toward online channels. Thus, we set $U_{Ei} = \theta - p_{Ei}$ ($i=1, 2$), which indicates that consumers favor online purchases over offline alternatives once blockchain traceability is implemented. For illustration, online sales of Dutch organic infant formula exceeded offline volumes after Tmall Global deployed blockchain traceability, enabling consumers to verify the full supply-chain history via QR-code scanning.

Similar to other studies [43,44], we apply the market-segmentation approach to derive demand functions from consumer utility functions.

3.3. Game sequence

The sequence of events for the MNF, the retail division, and the e-tailers is as follows: First, the MNF determines whether to adopt blockchain based on the market structure and the consumer preferences, and then sets the wholesale price [2]. Second, e-tailers decide whether to participate in blockchain. Third, the MNF's retail division and e-tailer i ($i \in E_1, E_2$) make the order quantities decisions in the monopoly or duopoly setting. Specifically, the MNF's retail division and each e-tailer compete against one another via Cournot competition across retail channels. We adopt Cournot competition, reflecting that order quantities are determined before retail prices are set, and consistent with the arm's-length principle, the MNF applies a uniform wholesale price to its retail division and e-tailers.

This timing sequence reflects real-world multi-level firm decision-making. Blockchain-participation choices are made upfront, as this represents a long-run strategic decision that shapes subsequent market-related choices for all supply-chain participants. All notations are summarized in Table 1.

Table 1. Notations.

Sales market

θ : consumer's willingness to pay for the MNF's product

τ : the tax disparity of the corporate income in different countries

p_i : sales price of the retail division, the e-tailer 1 and the e-tailer 2, $i \in \{R, E1, E2\}$

w : the wholesale price of the MNF to the retail division and the e-tailers

q_i : sales quantities of the retail division, the e-tailer 1 and the e-tailer 2, $i \in \{R, E1, E2\}$

π_i : profits of the MNF, the retail division, the e-tailer 1 and the e-tailer 2, $i \in \{F, R, E1, E2\}$

The parameters of the consumer preference

α : fraction of the consumer preference related to the retail division

φ : fraction of the consumer preference related to the e-tailer 2 when there is no blockchain

ρ : fraction of the consumer preference related to the e-tailer 1 when there is no blockchain

Nomenclature

N : Model N (no blockchain)

P : Model P (with blockchain)

NN : Model NN (the MNF does not participate in blockchain with any e-tailer)

NP : Model NP (the MNF participates in blockchain with the e-tailer 2 but not with the e-tailer 1)

PN : Model PN (the MNF participates in blockchain with the e-tailer 1 but not with the e-tailer 2)

PP : Model PP (the MNF participates in blockchain with the two e-tailers)

subscripts i : $i \in \{F, R, E1, E2\}$ refers to the MNF, the retail division, the e-tailer 1 and the e-tailer 2

superscripts j : $j \in \{N, P, NN, NP, PN, PP\}$

4. A monopoly e-tailer

In this section, we analyze the scenario where a single e-tailer monopolizes the e-commerce market. This setup reflects practical business contexts in which a dominant or emerging e-tailer exclusively sells the MNF's branded products on an e-commerce platform from a low-tax country (see Figure 1). We investigate two subcases: In the first subcase, neither the MNF nor the e-tailer adopts blockchain; and in the second subcase, the MNF and the e-tailer jointly adopt blockchain.

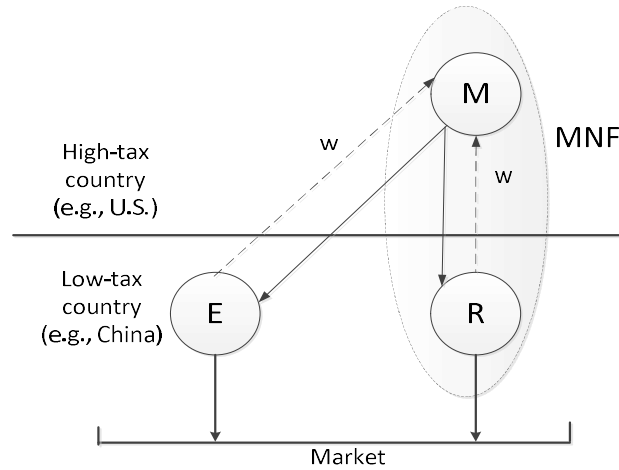


Figure 1. Market structure with one e-tailer.

4.1. No participation in blockchain - Model N

In Model N, neither the MNF nor the e-tailer adopts blockchain. According to the consumer utility functions in Section 3 and setting $U_R^N = U_E^N$, the consumer willingness-to-pay indifference point between buying from the e-tailer and the internal retail division (see Figure 2), denoted by θ_1^N , satisfies $\theta_1^N = \frac{p_R^N - p_E^N}{\alpha - \rho}$. Intuitively, θ_1^N represents a threshold: Consumers select either the MNF's retail division or the e-tailer. Consumers purchase from the MNF's retail division when $\theta \in (\theta_1^N, a]$. Setting $U_E^N = 0$, we obtain another indifference point denoted by θ_2^N , where $\theta_2^N = \frac{p_E^N}{\rho}$. Accordingly, consumers buy from the e-tailer when $\theta \in [\theta_1^N, \theta_2^N]$ and make no purchase when $\theta \in [0, \theta_2^N]$. Given the market density for consumer willingness-to-pay ($\frac{1}{a}$), we obtain $q_R^N = \frac{1}{a}(a - \frac{p_R^N - p_E^N}{\alpha - \rho})$, $q_{E1}^N = \frac{1}{a}(\frac{p_R^N - p_E^N}{\alpha - \rho} - \frac{p_E^N}{\rho})$. The corresponding inverse demand functions are therefore $p_R^N = a(\alpha - \alpha q_R^N - \rho q_E^N)$, $p_E^N = a\rho(1 - q_E^N - q_R^N)$. Under Scenario N, the e-tailer cannot offer product-quality verification, and Cournot competition takes place between the e-tailer and the MNF's retail division within the same market. Each supply-chain member maximizes its respective profit: $\max_{w^N} \pi_F^N = w^N(q_E^N + q_R^N)(1 - \tau) + (p_R^N - w^N)q_R^N$, $\max_{q_R^N} \pi_R^N = (p_R^N - w^N)q_R^N$, $\max_{q_E^N} \pi_E^N = (p_E^N - w^N)q_E^N$. The MNF's profit consists of two parts: wholesaling profit $w^N(q_E^N + q_R^N)(1 - \tau)$, retailing profit $(p_R^N - w^N)q_R^N$.

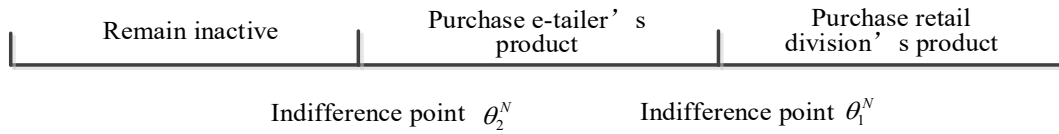


Figure 2. Consumer's behavior under differentiated willingness-to-pay in Model N.

According to backward induction, we first solve the equations $\frac{\partial \pi_R^N}{\partial q_R^N} = 0$, $\frac{\partial \pi_E^N}{\partial q_E^N} = 0$, and it follows

that the sales quantities of the MNF's retail division and the e-tailer are $q_R^N = \frac{2a\alpha - w^N - a\rho}{4a\alpha - a\rho}$,

$q_E^N = \frac{a\alpha\rho - w^N(2\alpha - \rho)}{a(4\alpha - \rho)\rho}$. Subsequently, solving equation $\frac{\partial \pi_F^N}{\partial w^N} = 0$, then, we can get the equilibrium results without blockchain in Proposition 1.

Proposition 1. When the e-tailer monopolizes the cross-border ecommerce market and the MNF does not adopt blockchain, the optimal strategies are given sequentially by the backward induction:

$$w^N = \frac{a\rho(\alpha\rho(5-7\tau) - \rho^2(1-\tau) - 4\alpha^2(2-3\tau))}{2\alpha(\rho(3-2\tau) - 8\alpha(1-\tau))}, \quad q_R^N = \frac{(8\alpha^2 - 7\alpha\rho + \rho^2)(1-\tau)}{2\alpha(8\alpha(1-\tau) - \rho(3-2\tau))},$$

$$q_{E1}^N = \frac{\rho^2(1-\tau) - 2\alpha^2\tau - \alpha\rho(3-5\tau)}{2\alpha(\rho(3-2\tau) - 8\alpha(1-\tau))}.$$

According to the optimal strategies in Proposition 1, the corresponding sales prices and profits of each member in the supply chain are:

$$p_R^N = \frac{a(2\alpha\rho^2(2-3\tau) - 8\alpha^3(1-\tau) - \rho^3(1-\tau) - \alpha^2\rho(1-5\tau))}{2\alpha(\rho(3-2\tau) - 8\alpha(1-\tau))}, \quad p_{E1}^N = \frac{a\rho(\alpha(4-5\tau) - \rho(1-\tau))}{8\alpha(1-\tau) - \rho(3-2\tau)},$$

$$\pi_R^N = \frac{a(8\alpha^2 - 7\alpha\rho + \rho^2)^2(1-\tau)^2}{4\alpha(\rho(3-2\tau) - 8\alpha(1-\tau))^2}, \quad \pi_{E1}^N = \frac{a\rho(\alpha\rho(3-5\tau) - \rho^2(1-\tau) + 2\alpha^2\tau)^2}{4\alpha^2(\rho(3-2\tau) - 8\alpha(1-\tau))^2},$$

$$\pi_F^N = \frac{a(2\alpha\rho^2(1-4\tau+3\tau^2) - 8\alpha^3(1-\tau) - \rho^3(1-\tau)^2 + 3\alpha^2\rho(1+2\tau-3\tau^2))}{4\alpha(\rho(3-2\tau) - 8\alpha(1-\tau))}.$$

4.2. Participation in blockchain - Model P

In Model P, where the MNF and the e-tailer jointly adopt blockchain, consumers' belief of the e-tailer's products will be significantly improved. Accordingly, we have $\rho = 1$, which indicates that if the products from the online platform provide the quality verification, the consumer will prefer to purchase the same product from the e-tailer to the MNF's retail division.

When the MNF and the e-tailer jointly adopt blockchain, the consumer utilities for purchasing the product from the retail division and the e-tailer are $U_R^P = \alpha\theta - p_R^P$, $U_E^P = \theta - p_E^P$, respectively. The calculation method of the demand functions of the two channels are similar to that of the case in Model N, and we omit the specific progress.

When the MNF participates in blockchain, we derive that $q_E^P = \frac{1}{a}(a - \frac{p_R^P - p_E^P}{\alpha - 1})$, $q_R^P = \frac{1}{a}(\frac{p_R^P - p_E^P}{\alpha - 1} - \frac{p_R^P}{\alpha})$. Accordingly, we infer that the corresponding reverse demand functions are

$p_R^P = a\alpha(1 - q_E^P - q_R^P)$, $p_E^P = a(1 - q_E^P - \alpha q_R^P)$. Each member in the supply chain will maximize their profits $\max_{w^P} \pi_F^P = w^P(q_{E1}^P + q_R^P)(1 - \tau) + \pi_R^P - F$, $\max_{q_R^P} \pi_R^P = (p_R^P - w^P)q_R^P$, $\max_{q_{E1}^P} \pi_{E1}^P = (p_{E1}^P - w^P)q_{E1}^P$. According to backward induction, we derive the sales quantities of the MNF's retail division and the e-tailer are $q_R^P = \frac{a\alpha - w^P(2 - \alpha)}{a(4 - \alpha)\alpha}$, $q_E^P = \frac{a - w^P}{a + 2a\alpha}$. Subsequently, solving the equation $\frac{\partial \pi_F^P}{\partial w^P} = 0$, and we can get the equilibrium results when the MNF participates in blockchain with the e-tailer in Proposition 2.

Proposition 2. When the e-tailer monopolizes the cross-border ecommerce market and the MNF participates in blockchain, the optimal strategies are given sequentially by backward induction:

$$w^P = \frac{a\alpha(8 - \alpha(5 - 7\tau) + \alpha^2(1 - \tau) - 12\tau)}{2(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))}, q_R^P = \frac{(5\alpha - 2 - \alpha^2)(1 - \tau)}{2(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))}, q_{E1}^P = \frac{4 - \alpha - 8\tau + 7\alpha\tau - \alpha^2(1 + \tau)}{2(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))}.$$

The corresponding sales prices and the payoffs of each member in the supply chain are:

$$p_R^P = \frac{a\alpha(3 - (5 - \alpha)\tau)}{4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau)}, p_{E1}^P = \frac{a(4 - 6\alpha^2(1 - \tau) + \alpha^3(1 - \tau) - 8\tau + \alpha(7 - 5\tau))}{2(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))},$$

$$\pi_R^P = \frac{a\alpha(2 - 5\alpha + \alpha^2)^2(1 - \tau)^2}{4(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))^2}, \pi_{E1}^P = \frac{a(4 - \alpha - 8\tau + 7\alpha\tau - \alpha^2(1 + \tau))^2}{4(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))^2},$$

$$\pi_F^P = \frac{a\alpha(1 - \tau)(5 - 2\alpha(1 - 3\tau) + \alpha^2(1 - \tau) - 9\tau)}{4(4 - \alpha^2 - 8\tau + 2\alpha(1 + \tau))} - F.$$

4.3. Comparative analysis in Models N and P

4.3.1. Comparative analysis of equilibrium results

In Corollary 1, we analyze the effects of the parameter related to the consumers' maximum willingness-to-pay a on the firms' decisions and profits in Model N and P when the e-tailer monopolizes the cross-border ecommerce market. The proofs throughout the paper are shown in the Appendix.

Corollary 1. The supply chain members' equilibrium pricing strategies and profits are affected by the consumers' maximum willingness-to-pay a , and it is analyzed as follows:

- (i) w, p_R, p_{E1} and π_R, π_E, π_F are increased in a in Model N and P.
- (ii) a has a more significant impact on the retail division's profit than the e-tailer in Model N (i.e., $\frac{\partial \pi_R^N}{\partial a} > \frac{\partial \pi_E^N}{\partial a} > 0$); however, a has a more significant impact on the e-tailer's profit than the retail division in Model P (i.e., $\frac{\partial \pi_E^P}{\partial a} > \frac{\partial \pi_R^P}{\partial a} > 0$).

Without loss of generality, an increase in the maximum willingness-to-pay of consumers implies an increase in the consumers' mean willingness-to-pay for the MNF's product. Corollary 1 characterizes equilibrium outcomes for the MNF, the e-tailer, and the internal retail division under Scenario N and Scenario P for the e-tailer-monopolized cross-border e-commerce market: (i) When the consumers' maximum willingness-to-pay (a) for the MNF's product increases, we find that the MNF will set a higher wholesale price for its brand product in Model N and Model P. Consequently, the MNF's retail division and the e-tailer will increase their sales prices due to the higher wholesale

price and the rise in consumers' willingness-to-pay. Based on these analyses, we conclude that the profits of the MNF, the e-tailer, and the retail division increase with consumers' maximum willingness-to-pay in both Model N and Model P. This result indicates that higher consumer willingness-to-pay for the brand product enables all supply chain members to set higher prices, benefiting the MNF, the e-tailer, and the retail division simultaneously.

Corollary 1 (ii) shows that consumers' maximum willingness-to-pay for the MNF's product has different impacts on the MNF's retail division and the e-tailer in Models N and P. In Model N, growth in consumer willingness-to-pay generates a larger profit increment for the MNF's retail division relative to the e-tailer. By contrast, in Model P, the e-tailer captures greater marginal profit improvement from rising a compared with the MNF's retail division. This conclusion provides a management insight: Increased consumers' willingness-to-pay for the MNF's product is more conducive to improving the profit of the channel with a high-quality image. Moreover, the higher the consumers' willingness-to-pay is, the more favorable it is for the channel with a high-quality image.

Corollary 2 indicates that, in equilibrium, we have (i) $p_R^N > p_E^N$, $q_R^N > q_E^N$; (ii) $p_R^P < p_E^P$, $q_R^P < q_E^P$.

In Model N, neither the MNF nor the e-tailer participates in blockchain, which gives the MNF's retail division a market advantage over the e-tailer due to its high-quality image. This is because the MNF's retail division can ensure the authentic source of the MNF's products, and consumers can enjoy more convenient offline experiences and better after-sales service in physical stores. This leads to the retail division's higher sales price and greater sales quantities. These findings are confirmed by practical cases. In a recent report, 82% of customers preferred to buy luxuries from offline channels such as the MNF's retail division rather than from e-tailers on e-commerce platforms regardless of price, when there is no blockchain. The main reason is the MNF's offline channel advantages, including sensory experiences, tactile interactions, and other shopping experiences that reduce customers' price sensitivity. Therefore, the MNF's retail division can sell more products at a higher retail price.

Corollary 2 (ii) shows that the MNF's participation in blockchain removes the market advantage of the MNF's retail division. The e-tailer will sell more quantities with a higher sales price than the MNF's retail division when the MNF participates in blockchain. The underlying reasons are as follows: On the one hand, the utilization of blockchain permits the e-tailer to provide the true source of the MNF's products online. On the other hand, an increasing number of consumers are accustomed to buying products online, especially when an online e-tailer can provide the authentic items, because the online shopping is more time-saving and convenient. By comparing Corollary 2 (i) and (ii), we find that: Without blockchain, consumers prefer purchasing the MNF's products through offline channels that ensure quality; with blockchain, consumers shift to online channels that not only guarantee quality but also offer convenience.

Corollary 3. (i) the equilibrium wholesale price $w^{N/P}$ will decrease in tax disparity (τ) in Model N and P (i.e., $\frac{\partial w^P}{\partial \tau} < \frac{\partial w^N}{\partial \tau} < 0$; and (ii) the equilibrium sales prices $p_R^{N/P}$ and $p_E^{N/P}$ will decrease in τ in Scenarios N and P (i.e., $\frac{\partial p_E^N}{\partial \tau} < \frac{\partial p_R^N}{\partial \tau} < 0$, $\frac{\partial p_R^P}{\partial \tau} < \frac{\partial p_E^P}{\partial \tau} < 0$); accordingly, the equilibrium sales quantities $q_R^{N/P}$ and $q_E^{N/P}$ will increase in τ (i.e., $0 < \frac{\partial q_E^N}{\partial \tau} < \frac{\partial q_R^N}{\partial \tau}$, $0 < \frac{\partial q_R^P}{\partial \tau} < \frac{\partial q_E^P}{\partial \tau}$).

A large τ implies a large tax disparity between the high-tax and the low-tax countries, which offers the MNF opportunities to benefit from tax planning. According to the assumption, the tax rate in the low-tax country is zero, so τ not only represent the tax disparity but also represent tax rate in the high-tax country. Corollary 3(i) shows that the MNF will reduce its wholesale price to its retail division in the low-tax country as the tax disparity increases, to fully leverage this advantage in Scenarios N and P. This enables the MNF to gain more tax-planning profit. Moreover, this wholesale price reduction also benefits the e-tailer in the low-tax country, because the ALP rule requires the MNF to set an equal wholesale price for the retail division and the e-tailer. Thus, the e-tailer in the low-tax country also benefits from a lower wholesale price due to the tax disparity (τ). Additionally, we find that the equilibrium wholesale price in Model N decreases more significantly with the tax disparity than in Model P (i.e., $\frac{\partial w^P}{\partial \tau} < \frac{\partial w^N}{\partial \tau} < 0$). This is because in Model N, the increased tax disparity and reduced wholesale price provide greater benefits to the MNF, enabling its retail division to gain more market advantage than in Model P.

With the increase in the tax disparity (i.e., large τ), the market demand is significantly stimulated by the low wholesale price. Therefore, the e-tailer and the retail division will sell more quantities related to the MNF's products, as derived in Corollary 3 (ii). Correspondingly, the sales prices of the e-tailer and the retail division decrease due to the low wholesale price and the MNF's goal to appeal to more consumers. Moreover, Corollary 3 (ii) also shows that the MNF's retail division can sell more quantities with a higher sales price in Model N (i.e., $\frac{\partial p_E^N}{\partial \tau} < \frac{\partial p_R^N}{\partial \tau} < 0$, $0 < \frac{\partial q_E^N}{\partial \tau} < \frac{\partial q_R^N}{\partial \tau}$), while the e-tailer on the e-commerce platform will sell more quantities with a higher sales price in Model P (i.e., $\frac{\partial p_R^P}{\partial \tau} < \frac{\partial p_E^P}{\partial \tau} < 0$, $0 < \frac{\partial q_R^P}{\partial \tau} < \frac{\partial q_E^P}{\partial \tau}$). The main reason for this difference lies in consumers' trust and preferences toward online and offline channels. For example, when there is no blockchain, the MNF's retail division has more market advantage because consumers will doubt the source and authenticity of online products. When the MNF and the e-tailer participate in blockchain, consumers will prefer the online channel to the MNF's retail division due to the time-saving benefits and convenience of online shopping, enabled by the development of network technologies.

4.3.2. Numerical analysis

In this section, we compare the equilibrium results and profits of the e-tailer and the MNF using a numerical example. We discuss the characteristics of equilibrium decisions and profits to illustrate the firms' behaviors with respect to changes in consumer attributes, the tax rate, and the fixed cost of utilizing blockchain. We perform numerical experiments by assigning different values to each parameter and consider a base parametric setting as the example.

Based on other studies [41], the base parametric settings are as follows: $\alpha=0.8$ and $a=4$. The product quality can be guaranteed when the MNF participates in blockchain with the e-tailer, which increases the e-tailer's quality image; thus, we suppose $\rho=1$ in case that the MNF participates in blockchain. Figure 3(a) plots the MNF's equilibrium wholesale price with the e-tailer's quality image and the tax disparity in Model N and P, which indicates that, the equilibrium wholesale price in Model P is higher than that in Model N (i.e., $w^P - w^N > 0$). This is because the verified quality in Model P can appeal to more consumers, thereby enlarging the market potential, which incentivizes the MNF to set a higher wholesale price. Moreover, Figure 3(a) also shows that the wholesale price will increase

with the e-tailer's quality image in Model N, because the market potential related to the sales quantities will be higher when consumers perceive a higher quality image of the e-tailer.

Figure 3(b) and (c) show that the equilibrium sales prices of the e-tailer and the retail division in Model P will be higher than that in Model N (i.e., $p_E^N < p_E^P$ and $p_R^N < p_R^P$) because of the higher wholesale price in Model P. Figure 3(c) shows that the MNF's equilibrium sales price will increase first and then decrease with ρ when there is no blockchain. Two reasons account for this result. On the one hand, the MNF's equilibrium wholesale price will increase in ρ in Model N according to Figure 3(a), which incentivizes the MNF to increase its sales price in the offline market. On the other hand, the increased ρ enhances the competitiveness of e-tailer, which intensifies the market competition and leads to a lower sales price for the MNF's retail division. Additionally, Figure 3(b) presents that the e-tailer's sales price will increase with ρ , because on the one hand, a large ρ narrows down the retail division's market advantage, which enables the e-tailer to sell more products with a higher sales price; on the other hand, an increasing ρ results in a higher wholesale price for the e-tailer. These results imply that, despite the MNF raising the wholesale price, the e-tailer's market potential increases. Thus, the e-tailer can manage to compensate such a wholesale price disadvantage by increasing the sell price, moreover, the e-tailer also can benefit itself by increasing its sales quantities. Figure 3(d) presents that, the e-tailer's sales quantities in Model P are higher than those in Model N (i.e., $q_E^N < q_E^P$), because the market potential advantage of the retail division will be removed when the MNF participates in the blockchain with the e-tailer. Figure 3(e) shows that the sales quantities of the retail division are higher in Model N compared to Model P (i.e., $q_R^N > q_R^P$), since it must compete with the e-tailer's increased market potential, reducing its order quantities in Model P.

When the downstream firms in a supply chain make a large quantity order, the seller's power of the supplier might be accordingly increased, especially when the supplier is a monopoly firm in the upstream market [1]. From Figure 3, we observe that the e-tailer's sales quantities increase when the MNF participates in blockchain, which incentivizes the MNF to set a higher wholesale price. This conclusion is consistent with [1], who indicated that market competition among downstream firms can enable upstream firms to increase the wholesale price. In Model P, the e-tailer's improved quality image (i.e., $\rho = 1$) narrows the market potential difference between the e-tailer and the MNF's retail division, which intensifies the market competition among downstream firms. Therefore, the MNF increases its wholesale price in Model P, and the e-tailer and the MNF's retail division face the impact of the higher wholesale price. According to the above findings, we obtain some management insights for the MNF and the e-tailer. For the MNF, participating in blockchain may still be beneficial even if it increases its competitor's market competitiveness, as the higher wholesale price boosts wholesale profit. For the e-tailer on the cross-border e-commerce platform, its improved quality image in Model P may offset the disadvantage of a higher wholesale price when the MNF adopts blockchain.

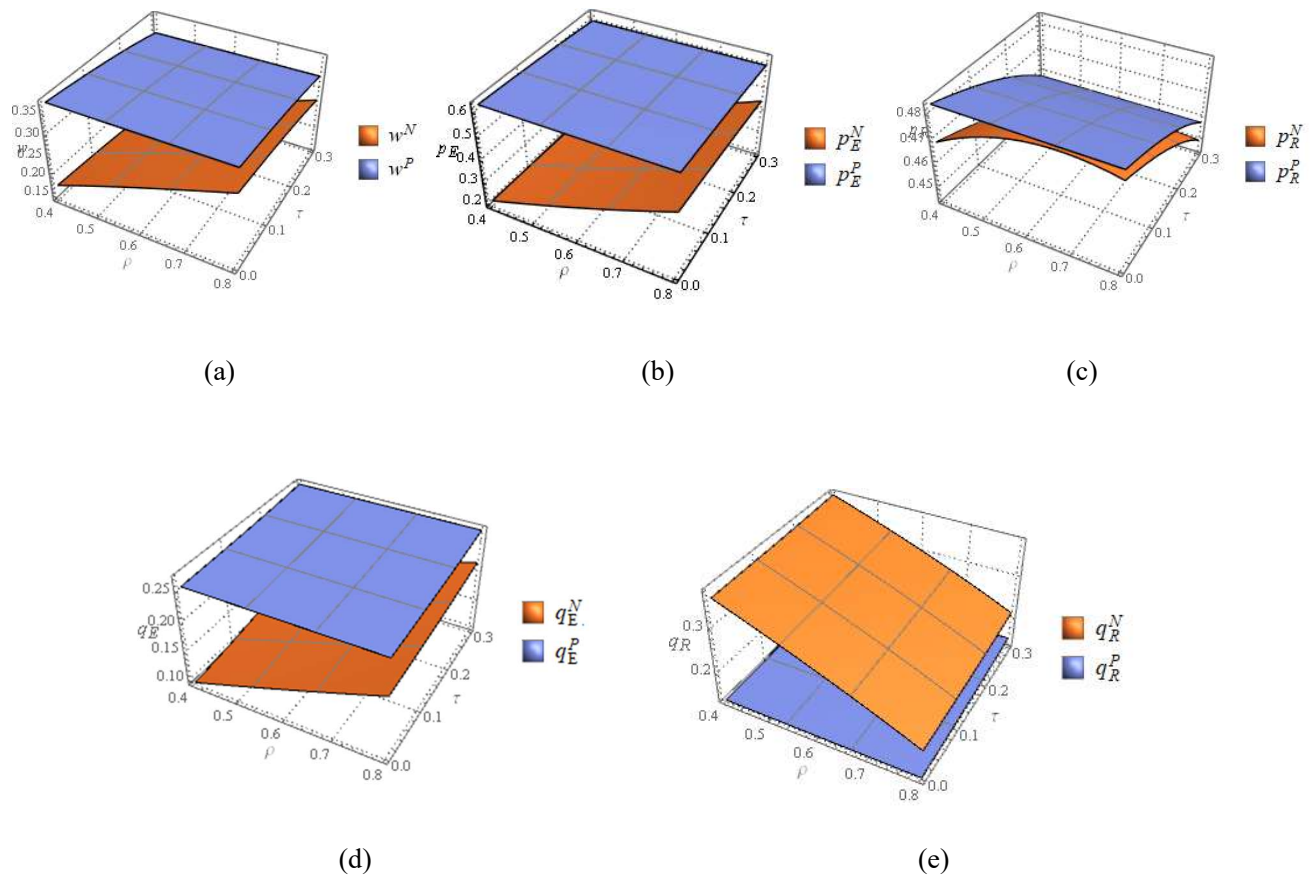


Figure 3. Equilibrium results of the MNF and the e-tailer with ρ and τ .

Figure 4(a) and (b) reveal that the MNF tends to reject blockchain adoption under most parameter combinations. Only when the fixed cost of blockchain and tax disparity are sufficiently low, and the e-tailer's quality image is close to that of the MNF's retail division, will the MNF be willing to adopt blockchain. By contrast, Figure 4(c) illustrates that the e-tailer always prefers blockchain participation.

For the MNF, although blockchain participation raises its wholesale price, it erodes the market competitive advantage of the MNF's internal retail division. Under the no-blockchain scenario, the MNF's retail division can achieve larger sales volume and capture higher retail-side profit, which constitutes a major disincentive for the MNF to deploy blockchain. Even under the e-tailer monopolized e-commerce setting, the MNF still hesitates to adopt blockchain except for the above-mentioned narrow parameter region.

For the e-tailer, blockchain adoption expands its market demand, enabling it to sell more products at a higher retail price. Despite the higher wholesale price charged by the MNF, the e-tailer can still benefit substantially. Under the ALP rule, the MNF must impose the same elevated wholesale price on its own internal retail division. Consequently, the demand-expansion benefit outweighs the adverse effect of higher wholesale cost for the e-tailer. Therefore, even though the e-tailer faces an increased wholesale price in the blockchain-enabled scenario, the market expansion gain offsets this disadvantage.

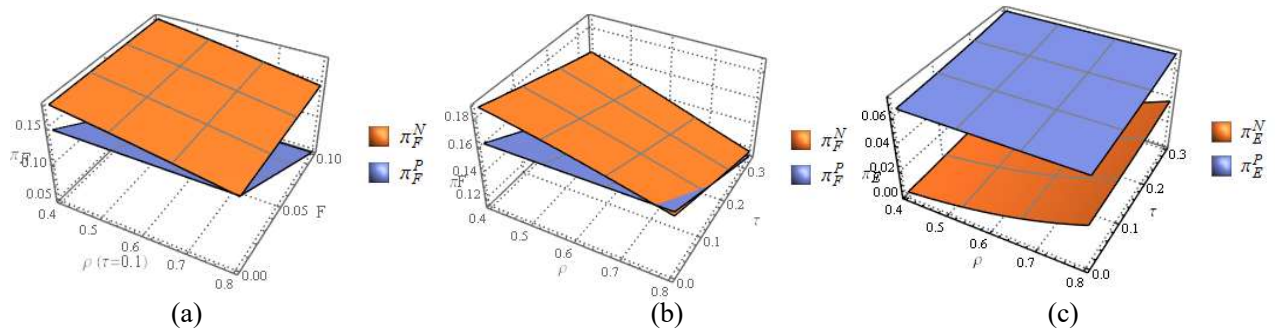


Figure 4. Profits of the MNF and the e-tailer with ρ , F , and τ .

5. Duopoly e-tailers

In this section, we examine a setting where two online e-tailers compete with the MNF's retail division. This setting reflects the real practice that two or more e-tailers sell a MNF's brand product on different cross-border e-commerce platforms. Figure 5 illustrates this case.

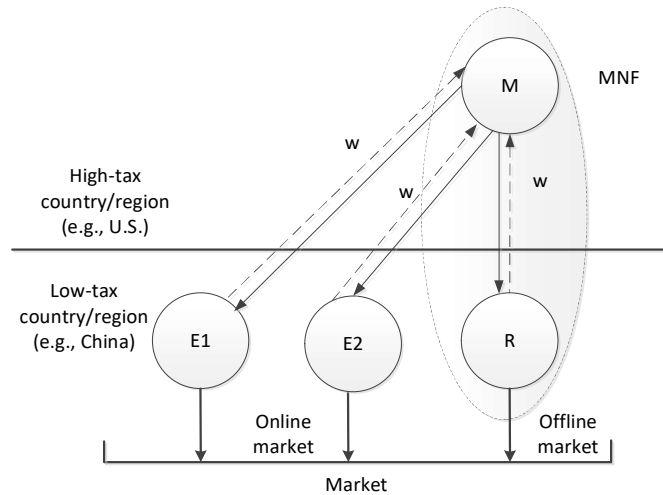


Figure 5. Market structure with two e-tailers.

5.1. No participation in blockchain - Model NN

In Model NN, the MNF will not participate in blockchain with any e-tailer. We assume that consumers will have different valuations of products from the e-tailers 1 and 2. Moreover, we suppose that consumers prefer to purchase the product of the e-tailer 1 than e-tailer 2 if the two e-tailers do not provide the quality verification of the products. We use a discount factor φ ($0 < \varphi < \rho < 1$) to present the discount value of the e-tailer 2's product that reflects its lower quality reputation compared to e-tailer 1 if there is no blockchain. By letting $U_R^{NN} = U_{E1}^{NN}$, it follows that the indifference point of consumers' willingness-to-pay for the MNF's retail division and e-tailer 1 when there is no blockchain for the two e-tailers (see Figure 6), denoted as θ_1^{NN} , is $\theta_1^{NN} = \frac{p_R^{NN} - p_{E1}^{NN}}{\alpha - \rho}$. Consumers will purchase the product from the MNF's retail division if $\theta \in (\theta_1^{NN}, a]$. When $U_{E1}^{NN} = U_{E2}^{NN}$, it follows that the indifference point of consumers' willingness-to-pay for the e-tailers 1 and 2, denoted as θ_2^N , is

$\theta_2^{NN} = \frac{p_{E1}^{NN} - p_{E2}^{NN}}{\rho - \varphi}$. Consumers will purchase the product from the e-tailer 1 if $\theta \in (\theta_2^{NN}, \theta_1^{NN}]$. By letting $U_{E2}^{NN} = 0$, it follows that the indifference point of consumers to purchase the e-tailer 2's product or buy nothing, denoted as θ_3^{NN} , is $\theta_3^{NN} = \frac{p_{E2}^{NN}}{\rho}$, which implies that consumers will purchase the e-tailer 2's product if $\theta \in [\theta_2^{NN}, \theta_3^{NN}]$ and remain inactive if $\theta \in [0, \theta_3^{NN})$. Then we derive that $q_R^{NN} = \frac{1}{a}(a - \frac{p_R^{NN} - p_{E1}^{NN}}{\alpha - \rho})$, $q_{E1}^{NN} = \frac{1}{a}(\frac{p_R^{NN} - p_{E1}^{NN}}{\alpha - \rho} - \frac{p_{E1}^{NN} - p_{E2}^{NN}}{\rho - \varphi})$, $q_{E2}^{NN} = \frac{1}{a}(\frac{p_{E1}^{NN} - p_{E2}^{NN}}{\rho - \varphi} - \frac{p_{E2}^{NN}}{\varphi})$. We infer that the corresponding reverse demand functions are $p_R^{NN} = a(\alpha(1 - q_R^{NN}) - \varphi q_{E2}^{NN} - \rho q_{E1}^{NN})$, $p_{E1}^{NN} = a(\rho(1 - q_{E1}^{NN} - q_R^{NN}) - \varphi q_{E2}^{NN})$, $p_{E2}^{NN} = \varphi a(1 - q_{E1}^{NN} - q_{E2}^{NN} - q_R^{NN})$. Each member in the supply chain will maximize its profit $\max_{q_R^{NN}} \pi_R^{NN} = (p_R^{NN} - w^{NN})q_R^{NN}$, $\max_{q_{E1}^{NN}} \pi_{E1}^{NN} = (p_{E1}^{NN} - w^{NN})q_{E1}^{NN}$, $\max_{q_{E2}^{NN}} \pi_{E2}^{NN} = (p_{E2}^{NN} - w^{NN})q_{E2}^{NN}$, $\max_{w^{NN}} \pi_F^{NN} = w^{NN}(q_{E1}^{NN} + q_{E2}^{NN} + q_R^{NN})(1 - \tau) + \pi_R^{NN}$. According to backward induction, we can get the sales quantities of the MNF's retail division and the e-tailers are $q_R^{NN} = \frac{a\alpha\varphi + \rho w^{NN} - 4a\alpha\rho + 2a\rho^2}{2a\alpha\varphi - 8a\alpha\rho + 2a\rho^2}$, $q_{E1}^{NN} = \frac{2a\alpha w^{NN} + a\alpha\varphi - \rho w^{NN} - 2a\alpha\rho}{2a\alpha\varphi - 8a\alpha\rho + 2a\rho^2}$, $q_{E2}^{NN} = \frac{a\alpha\varphi\rho + w^{NN}(2\alpha(\varphi - 2\rho) + \rho^2)}{2a\varphi(\alpha(4\rho - \varphi) - \rho^2)}$. Subsequently, solving the equation $\frac{\partial \pi_F^{NN}}{\partial w^{NN}} = 0$, we can get the equilibrium results in Proposition 3 when the MNF does not participate in blockchain.

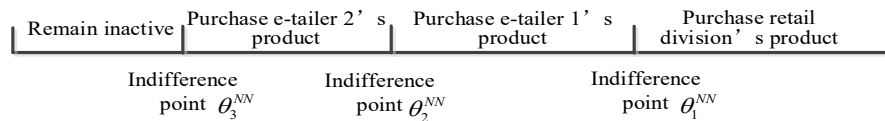


Figure 6. Consumer's behavior under differentiated willingness-to-pay in Model NN.

Proposition 3. When there are two e-tailers and the MNF doesn't participate in blockchain with any e-tailer, the optimal strategies are derived sequentially by backward induction:

$$w^{NN} = \frac{a\varphi(\alpha^2(\varphi - 4\rho)(\rho(6 - 7\tau) + 2\varphi\Omega) + \alpha\rho^2(\rho(13 - 15\tau) - 4\varphi\Omega) - 2\rho^4\Omega)}{\rho(8\alpha^2(\varphi - 4\rho)\Omega - 2\rho^3\Omega - \alpha\rho(\varphi - 16\rho\Omega - 2\varphi\tau))},$$

$$q_R^{NN} = \frac{(8\alpha^2(\varphi - 4\rho) - 2\rho^2(\varphi + 2\rho) - \alpha(2\varphi^2 - 5\theta\rho - 24\rho^2))\Omega}{2(8\alpha^2(\varphi - 4\rho)\Omega - 2\rho^3\Omega - \alpha\rho(\varphi - 16\rho\Omega - 2\varphi\tau))},$$

$$q_{E1}^{NN} = \frac{2\alpha^2(\varphi\rho(10 - 11\tau) - 2\varphi^2\Omega - 8\rho^2\Omega) + 2\varphi\rho^3\Omega + \alpha\rho(2\varphi^2\Omega + 4\rho^2\Omega - \varphi\rho(11 - 13\tau))}{2\rho(8\alpha^2(\varphi - 4\rho)\Omega - 2\rho^3\Omega - \alpha\rho(\varphi - 16\rho\Omega - 2\varphi\tau))},$$

$$q_{E2}^{NN} = \frac{2\rho^4\Omega + \alpha^2(4\rho^2(4 - 5\tau) + 4\varphi^2\Omega - 2\varphi\rho(10 - 11\tau)) + \alpha\rho^2(6\varphi\Omega - \rho(11 - 13\tau))}{2\rho(8\alpha^2(\varphi - 4\rho)\Omega - 2\rho^3(1 - \tau) - \alpha\rho(\varphi - 16\rho\Omega - 2\varphi\tau))}, \text{ where } \Omega = (1 - \tau).$$

The corresponding sales prices of each member are:

$$p_R^{NN} = \frac{a(4\alpha\rho^2(\varphi\rho\Omega - \Omega(2\varphi^2 + \rho^2)) + 4\Omega(2\alpha^3\rho\Omega - \varphi\rho^4) + \alpha^2(\varphi^2\rho(26 - 28\tau) - \varphi\rho^2(43 - 51\tau) - \Omega(4\varphi^3 - 6\rho^3)))}{2\rho(8\alpha^2\Omega\Omega - 2\rho^3\Omega - \alpha\rho(\varphi - 16\rho\Omega - 2\varphi\tau))},$$

$$p_{E1}^{NN} = \frac{a(\alpha\rho^2(\varphi\rho(15 - 17\tau) - (6\varphi^2 - 4\rho^2)\Omega) - 2\varphi\rho^4\Omega + 2\alpha^2(\varphi^2\rho(12 - 13\tau) - (2\varphi^3 + 8\rho^3)\Omega - \varphi\rho^2(14 - 17\tau)))}{2\rho(8\alpha^2(\varphi - 4\rho)\Omega - 2\rho^3\Omega - \alpha\rho(\varphi - 16\rho\Omega - 2\varphi\tau))},$$

$$p_{E2}^{NN} = \frac{a\varphi(4\alpha^2(\rho(8-9\tau)-2\varphi\Omega)+2\rho^3\Omega+\alpha\rho(2\varphi\Omega-\rho(15-17\tau)))}{2(2\rho^3\Omega-8\alpha^2(\varphi-4\rho)\Omega+\alpha\rho(\varphi-16\rho\Omega-2\varphi\tau))}$$

where $\mathbb{R}=6-7\tau$, $\mathbb{Z}=\theta-4\rho$.

5.2. Participation in block chain with e-tailer 1 - Model PN

In Model PN, we assume that the MNF participates in blockchain with part of the e-tailers; for example, the MNF participates in blockchain with e-tailer 1 but not with e-tailer 2. The calculation method of the demand functions is similar to that of the case where the MNF does not participate in blockchain with any e-tailer, and we omit the specific process. Then, we derive that

$$q_R^{PN} = \frac{1}{a} \left(\frac{p_R^{PN} - p_{E1}^{PN}}{\alpha - 1} - \frac{p_R^{PN} - p_{E2}^{PN}}{\alpha - \varphi} \right), \quad q_{E1}^{PN} = \frac{1}{a} \left(a - \frac{p_R^{PN} - p_{E1}^{PN}}{\alpha - 1} \right), \quad q_{E2}^{PN} = \frac{1}{a} \left(\frac{p_R^{PN} - p_{E2}^{PN}}{\alpha - \varphi} - \frac{p_{E2}^{PN}}{\varphi} \right).$$

Additionally, we infer that the corresponding reverse demand functions are $p_R^{PN} = a((1 - q_{E1}^{PN} - q_R^{PN})\alpha - \varphi q_{E2}^{PN})$, $p_{E1}^{PN} = a(1 - q_{E1}^{PN} - \alpha q_R^{PN} - \varphi q_{E2}^{PN})$, $p_{E2}^{PN} = \varphi a(1 - q_{E1}^{PN} - q_{E2}^{PN} - q_R^{PN})$. Then the supply chain members will maximize their profits

$$\max_{q_R^{PN}} \pi_R^{PN} = (p_R^{PN} - w^{PN})q_R^{PN}, \quad \max_{q_{E1}^{PN}} \pi_{E1}^{PN} = (p_{E1}^{PN} - w^{PN})q_{E1}^{PN}, \quad \max_{q_{E2}^{PN}} \pi_{E2}^{PN} = (p_{E2}^{PN} - w^{PN})q_{E2}^{PN},$$

$\max_{w^{PN}} \pi_F^{PN} = w^{PN}(q_{E1}^{PN} + q_{E2}^{PN} + q_R^{PN})(1 - \tau) + \pi_R^{PN} - F$. According to backward induction, we obtain the sales quantities of the MNF's retail division and e-tailers as $q_R^{PN} = \frac{a(2\alpha - \varphi) - w^{PN}(2 - \alpha)}{2a(4\alpha - \alpha^2 - \varphi)}$,

$$q_{E1}^{PN} = \frac{a(4\alpha - 2\alpha^2 - \varphi) - w^{PN}\alpha}{2a(4\alpha - \alpha^2 - \varphi)}, \quad q_{E2}^{PN} = \frac{a\alpha\varphi - w^{PN}(4\alpha - \alpha^2 - 2\varphi)}{2a\varphi(4\alpha - \alpha^2 - \varphi)}.$$

Subsequently, solving the equation $\frac{\partial \pi_F^{PN}}{\partial w^{PN}} = 0$, we can get the equilibrium results in Proposition 4 when the MNF participates only in blockchain with e-tailer 1.

Proposition 4. When there are two e-tailers and the MNF participates in blockchain only with e-tailer 1 but not with e-tailer 2, the optimal strategies are derived sequentially by backward induction:

$$w^{PN} = \frac{a\varphi(\alpha^3(13-15\tau) + \alpha\varphi(13-15\tau) - 2(1-\tau)(\alpha^4 + \varphi^2) - \alpha^2(24+3\varphi-28\tau-4\varphi\tau))}{\alpha(2\alpha(\varphi(-3+\tau)-16(1-\tau)) + \alpha^2(16+\varphi-16\tau)+4\varphi(3-2\tau)-2\alpha^3(1-\tau))},$$

$$q_R^{PN} = \frac{(\alpha(22-\alpha(13-2\alpha))\varphi - 4(4-\alpha)\alpha^2 - 2(2-\alpha)\varphi^2)(1-\tau)}{2\alpha(-2(4-\alpha)^2\alpha + 12\varphi - (6-\alpha)\alpha\varphi - 2(4-\alpha)(\varphi - (4-\alpha)\alpha)\tau)},$$

$$q_{E1}^{PN} = \frac{2\varphi(6-\varphi(1-\tau)-4\tau) - 4\alpha^3(1-\tau) + 2\alpha^2(12-(12-\varphi)\tau) - \alpha(32+\varphi-32\tau+5\varphi\tau)}{2(12\varphi - (6-\alpha)\alpha\varphi - 2(4-\alpha)^2\alpha - 2(4-\alpha)(-\varphi + (4-\alpha)\alpha)\tau)},$$

$$q_{E2}^{PN} = \frac{\alpha^2(16+\varphi(4-6\tau)-20\tau) + 2\alpha^4(1-\tau) + 4\varphi^2(1-\tau) - 2\alpha\varphi(9-11\tau) - \alpha^3(11-13\tau)}{2\alpha(12\varphi - 2(4-\alpha)^2\alpha - (6-\alpha)\alpha\varphi - 2(4-\alpha)(\varphi - (4-\alpha)\alpha)\tau)}.$$

The corresponding sales prices of each member are:

$$p_R^{PN} = \frac{a(\alpha^3(\varphi(13-17\tau)-16\Omega) + 2\alpha\varphi^2(11-13\tau) + 2\alpha^4(2-\varphi)\Omega - 4\varphi^3\Omega - 2\alpha^2\varphi(13-17\tau+\varphi(2-3\tau)))}{2\alpha(12\varphi - 2\Delta^2\alpha - (6-\alpha)\alpha\varphi - 2\Delta(\varphi - (4-\alpha)\alpha)\tau)},$$

$$p_{E1}^{PN} = \frac{4a\alpha\varphi(3+\varphi\mathbb{R}-2\tau) - 4\varphi^3\Omega - 4\alpha^4(1+\varphi)\Omega + \alpha^3(24\Omega + 26\varphi - 28\varphi\tau) - \alpha^2(32\Omega - \varphi(49-51\tau+\varphi(6-8\tau)))}{2\alpha(12\varphi - 2\Delta^2\alpha - (6-\alpha)\alpha\varphi - 2\Delta(\varphi - \Delta\alpha)\tau)},$$

$$p_{E2}^{PN} = \frac{a\varphi(8\varphi - \alpha(32 - 15\alpha + 2(\alpha^2 + \varphi)) - \Delta(2\varphi - \alpha(9 - 2\alpha))\tau)}{2(12\varphi - 2\Delta)^2\alpha - (6 - \alpha)\alpha\varphi - 2\Delta((\varphi - \Delta\alpha)\tau)}, \text{ where } \Delta = 4 - \alpha, \mathbb{R} = 6 - 7\tau, \Omega = (1 - \tau).$$

5.3. Participation in block chain with e-tailer 2 - Model NP

In Model NP, we assume that the MNF participates only in blockchain with e-tailer 2 but not with e-tailer 1. Then we derive that $q_R^{NP} = \frac{1}{a}(\frac{p_R^{NP} - p_{E2}^{NP}}{\alpha - 1} - \frac{p_R^{NP} - p_{E1}^{NP}}{\alpha - \rho})$, $q_{E1}^{NP} = \frac{1}{a}(\frac{p_R^{NP} - p_{E1}^{NP}}{\alpha - \rho} - \frac{p_{E1}^{NP}}{\rho})$, $q_{E2}^{NP} = \frac{1}{a}(a - \frac{p_R^{NP} - p_{E2}^{NP}}{\alpha - 1})$. We infer that the corresponding reverse demand functions are $p_R^{NP} = a((1 - q_{E2}^{NP} - q_R^{NP})\alpha - \rho q_{E1}^{NP})$, $p_{E1}^{NP} = a(1 - q_{E1}^{NP} - q_{E2}^{NP} - q_R^{NP})\rho$, $p_{E2}^{NP} = a(1 - q_{E2}^{NP} - \rho q_{E1}^{NP} - \alpha q_R^{NP})$. Each member in the supply chain will maximize their profits $\max_{q_R^{NP}} \pi_R^{NP} = (p_R^{NP} - w^{NP})q_R^{NP}$, $\max_{q_{E1}^{NP}} \pi_{E1}^{NP} = (p_{E1}^{NP} - w^{NP})q_{E1}^{NP}$, $\max_{q_{E2}^{NP}} \pi_{E2}^{NP} = (p_{E2}^{NP} - w^{NP})q_{E2}^{NP}$, $\max_{w^{NP}} \pi_F^{NP} = w^{NP}(q_{E1}^{NP} + q_{E2}^{NP} + q_R^{NP})(1 - \tau) + \pi_R^{NP} - F$. According to backward induction, we can get the sales quantities of the MNF's retail division, and the e-tailers are $q_R^{NP} = \frac{a(2\alpha - \rho) - w^{NP}(2 - \alpha)}{2a(4\alpha - \alpha^2 - \rho)}$, $q_{E1}^{NP} = \frac{a\alpha\rho - w^{NP}(4\alpha - \alpha^2 - 2\rho)}{2a\rho(4\alpha - \alpha^2 - \rho)}$, $q_{E2}^{NP} = \frac{a(4\alpha - 2\alpha^2 - \rho) - w^{NP}\alpha}{2a(4\alpha - \alpha^2 - \rho)}$. Subsequently, solving the equation $\frac{\partial \pi_F^{NP}}{\partial w^{NP}} = 0$, we can get the equilibrium results in Proposition 5 when the MNF participates only in blockchain with e-tailer 2.

Proposition 5. When there are two e-tailers on different cross-border e-commerce platforms, and the MNF participates in blockchain with e-tailer 2 but not with e-tailer 1, the optimal strategies are derived sequentially by backward induction:

$$w^{NP} = \frac{a\rho(\alpha^3(13 - 15\tau) + \alpha\rho(13 - 15\tau) - 2\alpha^4(1 - \tau) - 2\rho^2(1 - \tau) - \alpha^2(24 + 3\rho - 28\tau - 4\rho\tau))}{\alpha(16(1 - \tau) - 2\alpha(\rho(3 - \tau)) + \alpha^2(16 + \rho - 16\tau) + 4\rho(3 - 2\tau) - 2\alpha^3(1 - \tau))},$$

$$q_R^{NP} = \frac{(\alpha(22 - \alpha(13 - 2\alpha))\rho - 4(4 - \alpha)\alpha^2 - 2(2 - \alpha)\rho^2)(1 - \tau)}{2\alpha(12\rho - 2(4 - \alpha)^2\alpha - (6 - \alpha)\alpha\rho - 2(4 - \alpha)(\rho - (4 - \alpha)\alpha)\tau)},$$

$$q_{E1}^{NP} = \frac{\alpha^2(16 + \rho(4 - 6\tau) - 20\tau) + (2\alpha^4 + 4\rho^2)(1 - \tau) - 2\alpha\rho(9 - 11\tau) - \alpha^3(11 - 13\tau)}{2\alpha(12\rho - 2(4 - \alpha)^2\alpha - (6 - \alpha)\alpha\rho - 2(4 - \alpha)(\rho - (4 - \alpha)\alpha)\tau)},$$

$$q_{E2}^{NP} = \frac{2\rho(6 - \rho(1 - \tau) - 4\tau) - 4\alpha^3(1 - \tau) + 2\alpha^2(12 - (12 - \rho)\tau) - \alpha(32 + \rho - 32\tau + 5\rho\tau)}{2(12\rho - 2(4 - \alpha)^2\alpha - (6 - \alpha)\alpha\rho - 2(4 - \alpha)(\rho - (4 - \alpha)\alpha)\tau)}.$$

The corresponding sales prices of each member are:

$$p_R^{NP} = \frac{a(\alpha^3(\rho(13 - 17\tau) - 16(1 - \tau)) + 2\alpha\rho^2(11 - 13\tau) + 2\alpha^4(2 - \rho)(1 - \tau) - 4\rho^3(1 - \tau) + 2\alpha^2\rho(13 - 17\tau + \rho(2 - 3\tau)))}{2\alpha(12\rho - 2(4 - \alpha)^2\alpha - (6 - \alpha)\alpha\rho - 2(4 - \alpha)(\rho - (4 - \alpha)\alpha)\tau)},$$

$$p_{E1}^{NP} = \frac{a\rho(8\rho - \alpha(32 - 15\alpha + 2\alpha^2 + 2\rho) - (4 - \alpha)(2\rho - \alpha(9 - 2\alpha))\tau)}{2(12\rho - 2(4 - \alpha)^2\alpha - (6 - \alpha)\alpha\rho - 2(4 - \alpha)(\rho - (4 - \alpha)\alpha)\tau)},$$

$$p_{E2}^{NP} = \frac{a(4\alpha\rho(3 + \rho(6 - 7\tau) - 2\tau) - 4(\rho^3 + \alpha^4(1 + \rho))(1 - \tau) + \alpha^3(24 + 26\rho - 24\tau - 28\rho\tau) + \alpha^2(\rho(49 - 51\tau + \rho(6 - 8\tau)) - 32(1 - \tau)))}{2\alpha(12\rho - 2\alpha(4 - \alpha)^2 - (6 - \alpha)\alpha\rho - 2(4 - \alpha)(\rho - (4 - \alpha)\alpha)\tau)}.$$

5.4. Participation in block chain with the two e-tailers - Model PP

When the MNF participates in blockchain with the two e-tailers, consumers will perceive a same valuation for the product provided by e-tailer 1 and e-tailer 2. Therefore, we have $\rho = \varphi = 1$. Then we derive that $q_R^{PP} = \frac{1}{a}(\frac{p_R^{PP} - p_{E1/E2}^{PP}}{\alpha - 1} - \frac{p_R^{PP}}{\alpha})$, $q_{E1}^{PP} + q_{E2}^{PP} = \frac{1}{a}(a - \frac{p_R^{PP} - p_{E1/E2}^{PP}}{\alpha - 1})$. We infer that the corresponding reverse demand functions are $p_R^{PP} = -a\alpha(-1 + q_{E1}^{PP} + q_{E2}^{PP} + q_R^{PP})$, $p_{E1}^{PP} = p_{E2}^{PP} = -a(-1 + q_{E1}^{PP} + \alpha q_R^{PP})$. Each member in the supply chain will maximize their profits $\max_{q_R^{PP}} \pi_R^{PP} = (p_R^{PP} - w^{PP})q_R^{PP}$, $\max_{q_{E1}^{PP}} \pi_{E1}^{PP} = (p_{E1}^{PP} - w^{PP})q_{E1}^{PP}$, $\max_{q_{E2}^{PP}} \pi_{E2}^{PP} = (p_{E2}^{PP} - w^{PP})q_{E2}^{PP}$, $\max_{w^{PP}} \pi_F^{PP} = w^{PP}(q_{E1}^{PP} + q_{E2}^{PP} + q_R^{PP})(1 - \tau) + \pi_R^{PP} - F$. The other calculation method of the decision variables is similar to the other models (NN, NP, PP). We can get the equilibrium results in Proposition 6 when the MNF participates in blockchain with the two e-tailers.

Proposition 6. When there are two e-tailers on different cross-border e-commerce platforms and the MNF participates in blockchain with the two e-tailers, the optimal strategies are derived sequentially by backward induction:

$$w^{PP} = \frac{a\alpha(\alpha(9 - 11\tau) + 2\alpha^2(-1 + \tau) + 3(-4 + 5\tau))}{-9 + 4\alpha^2 + 18\tau - 6\alpha(1 + \tau)}, \quad q_R^{PP} = -\frac{(9 + 4(-4 + \alpha)\alpha)(-1 + \tau)}{2(-9 + 4\alpha^2 + 18\tau - 6\alpha(1 + \tau))},$$

$$q_{E1}^{PP} = q_{E2}^{PP} = \frac{(-3 + 2\alpha)(2 + \alpha + (-4 + \alpha)\tau)}{2(-9 + 4\alpha^2 + 18\tau - 6\alpha(1 + \tau))}.$$

The corresponding sales prices of each member are:

$$p_R^{PP} = \frac{a\alpha(-15 + 2\alpha + 21\tau - 6\alpha\tau)}{2(-9 + 4\alpha^2 + 18\tau - 6\alpha(1 + \tau))}, \quad p_{E1}^{PP} = p_{E2}^{PP} = \frac{a(-6 + 12\tau + \alpha(-23 + 4(-5 + \alpha)\alpha(-1 + \tau) + 19\tau))}{2(-9 + 4\alpha^2 + 18\tau - 6\alpha(1 + \tau))}.$$

5.5. Comparative analysis in Model NN, PN, NP and PP

5.5.1. Comparative analysis of equilibrium results

We next characterize equilibrium decisions to show how the firms behave with respect to changes in the e-tailers' quality image and tax disparity. First, according to the above assumption, we assume that $0 < \tau < \frac{1}{3}$. Second, for analytical convenience and the robustness of our conclusions, we assume

that $\rho = \theta$, $\alpha \rightarrow 1$. These assumptions imply that consumers have identical preferences across online platforms and that their preference for the offline channel tends toward 1. We adopt the aforementioned assumptions primarily for the following reasons. On the one hand, identical consumer preferences across online platforms can simplify model solving and analysis, thereby enabling a more targeted and specialized examination of key variables. On the other hand, the assumption that consumers' offline purchase preference tends toward 1 implies that consumers' preference for the offline channel is close to that for the blockchain-endorsed online channel. This assumption maximizes the baseline preference for the offline channel, making consumer shifts to online channels more difficult for the MNF. Its core purpose is to construct a most adverse test [45,46] to verify the robustness of our conclusions: If the

model still demonstrates the MNF's willingness to pay for blockchain under this unfavorable setting, it suggests that the efficiency gains brought by blockchain can offset the costs arising from customer diversion away from offline channels.

Using the above assumption, we analyze the effect of the parameter ρ and τ on the decisions of the MNF and the e-tailers in the NN, NP, PN, and PP models, and comparing them in the four models, we have the following Corollaries 4, 5, and 6.

Corollary 4. The equilibrium wholesale price of the MNF in the four models satisfy:

$$(i) \quad \frac{\partial w^{PN/PP}}{\partial \rho} > 0; \quad \frac{\partial w^{NN}}{\partial \rho} > 0; \quad \text{when } 0 < \rho < A, \quad \frac{\partial w^{PN/PP}}{\partial \rho} > \frac{\partial w^{NN}}{\partial \rho}; \quad \text{when } A < \rho < \alpha, \quad \frac{\partial w^{PN/PP}}{\partial \rho} < \frac{\partial w^{NN}}{\partial \rho}.$$

$$(ii) \quad \frac{\partial w^{PP}}{\partial \tau} < \frac{\partial w^{NN}}{\partial \tau} < \frac{\partial w^{NP/PN}}{\partial \tau} < 0.$$

$$(iii) \quad w^{NN} < w^{PN/PP} < w^{PP}.$$

Proof. See Appendix.

Corollary 4 characterizes the equilibrium wholesale price across the four blockchain adoption models. Three findings emerge.

Corollary 4(i) shows that the wholesale price always increases with e-tailers' quality image (ρ). This is because, on the one hand, the adoption of blockchain technology by e-commerce firms enhances online platform trustworthiness, which directly expands their market share in the online market; as the supply chain leader, the MNF can raise wholesale prices to directly capture profits from the online market. On the other hand, an increase in online platform trustworthiness intensifies competition between online and offline channels; the MNF can curb their excessive expansion by raising the wholesale price for online platforms, thereby protecting its high-margin offline direct-sales channels.

Notably, the sensitivity of the wholesale price to ρ differs across models. In the "single-chain" mode, the wholesale price increases rapidly with the growth of online platform trust when the trust level is relatively low, because an increase in trust in the "single-chain" platform can significantly change the channel structure; thus, the MNF can swiftly raise its wholesale price to capture the technological dividend. In the "no-chain" mode, by contrast, the wholesale price increases rapidly only when the trust level is already relatively high, because when the trust level of the e-tailer is high without blockchain, the competitive landscape of the market tends to stabilize; for the e-tailer with blockchain, the technological dividend gradually diminishes, whereas the e-tailer without blockchain has already built a solid market foundation despite lacking technological advantages.

Corollary 4(ii) shows that, as the tax disparity widens, the wholesale price declines at the fastest rate under the "dual-chain" mode, at a moderate rate under the "no-chain" mode, and at the slowest rate under the "single-chain" mode. This phenomenon primarily stems from the differences in competitive structures shaped by different blockchain models. Specifically, the widening tax disparity significantly enhances the price advantage and profit margin for sales in low-tax regions, while the competitive dynamics across channels under different models directly influence the speed and extent to which the MNF adjusts wholesale prices to leverage this advantage.

Under the “dual-chain” mode, both online platforms are on-chain and engage in equitable and transparent competition with offline channels. When the tax disparity expands, the MNF can discern the competitive dynamics across channels and swiftly incentivize the shift of online demand to low-tax regions by lowering wholesale prices, thereby maximizing profits across the entire channel network. Consequently, the wholesale price declines most rapidly. Under the “single-chain” mode, the asymmetric competitive channel structure creates significant competitive disparities and conflicting interests between the on-chain and off-chain channels. When adjusting wholesale prices, the MNF must simultaneously consider the transparent advantages of the on-chain channel and the pricing stability of the off-chain channel. The mutual constraints between channels complicate decision-making, so the MNF adopts a more cautious and slower price adjustment approach, leading to the slowest decline rate. Under the “no-chain” mode, the competitive structure is dominated by offline channels. Although blockchain technology is absent and information transparency is lower, the MNF relies more on the market performance and competitive dynamics of offline channels in pricing, given the relative weakness of online channels. While the widening tax disparity can create price advantages in low-tax online regions, the MNF’s grasp of online opportunities is relatively delayed, and pricing adjustments tend to be tentative. Therefore, the decline rate falls between that of the dual-chain and single-chain modes. In summary, different blockchain models shape distinct channel competition structures, which directly influence the MNF’s pricing strategy and response speed when the tax disparity widens. The degree of competitive equilibrium, channel symmetry, and the distribution of dominant forces are key mechanisms driving this phenomenon.

Corollary 4(iii) shows that the wholesale price satisfies $w^{NN} < w^{PN/NP} < w^{PP}$. In the absence of blockchain-based trust endorsement under the no-chain (NN) setting, online e-tailers suffer from low consumer trust and limited willingness-to-pay. To guarantee downstream e-tailers’ profit margins and participation incentives, the MNF has to set the lowest wholesale price. Under the single-chain (PN/NP) mode, only one e-tailer obtains blockchain trust authentication. Blockchain improves consumer valuation for the certified e-tailer, which creates room for the MNF to raise wholesale price relative to the no-chain case. Nevertheless, the other e-tailer remains without blockchain endorsement and faces weaker consumer acceptance. Constrained by the arm’s-length principle, the MNF must charge a uniform wholesale price for both e-tailers. The uncertified e-tailer imposes downward pressure on the wholesale price, so the equilibrium wholesale price cannot reach the level under dual-chain mode. Under the dual-chain (PP) mode, both e-tailers are equipped with blockchain trust endorsement. Blockchain simultaneously lifts consumers’ willingness-to-pay for both online channels. Since both downstream e-tailers enjoy enhanced consumer trust, there is no low-trust e-tailer to suppress the wholesale price. Accordingly, the MNF can set the highest wholesale price to capture the trust-driven value increment from the two online channels.

Corollary 5. The equilibrium sales prices of the MNF’s retail division and the e-tailer in the four models satisfy:

$$(i) \quad \frac{\partial p_R^{PN/NP}}{\partial \rho} > 0; \quad \frac{\partial p_R^{NN}}{\partial \rho} > 0; \quad \frac{\partial p_{E1}^{NP}}{\partial \rho} > 0; \quad \frac{\partial p_{E1}^{NN}}{\partial \rho} > 0.$$

$$(ii) \quad \frac{\partial p_R^{PP}}{\partial \tau} < \frac{\partial p_R^{NN}}{\partial \tau} < \frac{\partial p_R^{NP/PN}}{\partial \tau} < 0; \quad \frac{\partial p_{E1}^{PP}}{\partial \tau} < \frac{\partial p_{E1}^{NN}}{\partial \tau} < \frac{\partial p_{E1}^{PN/NP}}{\partial \tau} < 0.$$

(iii) $p_R^{NN}, p_R^{PP} > p_R^{PN/NP}$; when ρ and τ are larger, there exists $p_R^{NN} > p_R^{PP}$; when ρ and τ are smaller, there exists $p_R^{NN} < p_R^{PP}$.

Proof. See Appendix.

Corollary 5 characterizes the equilibrium sales prices across the four models.

Corollary 5(i) shows that a higher quality image of the e-tailer increases consumers' willingness to pay for online products, thereby enabling the e-tailer to set a higher sales price. Moreover, the sales price of the MNF's retail division also increases with the rise in the e-tailer's quality image. This is because the improved quality image of the e-tailer strengthens the overall brand image; to maintain a premium brand positioning across all channels and avoid diluting brand value with lower offline prices, the MNF must align pricing. In addition, the quality image established in the online channel alters consumers' perceived value of the product in all contexts, making consumers more willing to accept correspondingly higher prices in offline settings. By coordinating price increases across channels, the MNF shifts the competitive focus from inter-channel price wars to value-based competition, thereby maximizing total profits from omnichannel loyal customers.

Corollary 5(ii) shows that a greater tax disparity drives price reductions in the online and offline channels and increases the sales quantities in the low-tax region, which enables the MNF to achieve higher profits and lower its total tax payment. Moreover, the rate at which the sales prices in the online and offline channels change with respect to τ is analogous to that of the wholesale price under the different blockchain models, and the underlying rationale for this pattern aligns with the analysis provided in Corollary 4(ii).

Corollary 5(iii) shows that the sales price of the MNF's retail division in the "no-chain" model and the "dual-chain" model are always higher than that in the "single-chain" model. This is because the symmetric scenario (NN or PP) establishes a stable competitive landscape, enabling the MNF's retail division channel to focus on serving premium segments, while the "single-chain" model disrupts this competitive balance. The e-tailer without blockchain is compelled to compete on price, dragging the MNF's retail division into a price war and consequently compressing the overall profit margin.

However, the relative ranking between the "no-chain" and "dual-chain" models depends on the levels of quality image and tax disparity. When the e-tailer's quality image is high and the tax disparity is large, the sales price of MNF's retail division is higher under the "no-chain" model. This is because, under the "no-chain" model, the e-tailer inherently possesses certain competitive advantages, enabling it to set a relatively higher sales price; the price effect permits the MNF's retail division to also set a relatively higher retail price. Moreover, to maximize after-tax profits, the MNF has an incentive to coordinately set higher online and offline retail prices to create greater profits, and a higher offline price helps solidify the brand's premium positioning, preventing consumers from questioning the rationality of higher online prices due to lower offline prices. By contrast, when the e-tailer's quality image is low and the tax disparity is small, the sales price of MNF's retail division is higher under the "dual-chain" model. This is because, under the "dual-chain" model, information transparency imposes strict constraints on the e-tailers' sales price, causing competition to directly revert to price wars based on actual costs and efficiency, resulting in lower equilibrium prices; however, when quality image and tax disparity are sufficiently high, the branding and tax-planning effects under the "no-chain" model dominate, yielding higher retail prices.

Corollary 6. The equilibrium sales quantities of the MNF's retail division and the e-tailer in the four models satisfy:

$$(i) \quad \frac{\partial q_R^{PN}}{\partial \rho} < 0; \quad \frac{\partial q_R^{NN}}{\partial \rho} < 0; \quad \frac{\partial q_{EI}^{NP}}{\partial \rho} > 0; \quad \frac{\partial q_{EI}^{NN}}{\partial \rho} > 0.$$

$$(ii) \quad \frac{\partial q_R^{PP}}{\partial \tau} > \frac{\partial q_R^{NN}}{\partial \tau} > \frac{\partial q_R^{NP}}{\partial \tau} = \frac{\partial q_R^{PN}}{\partial \tau} > 0; \quad \frac{\partial q_{EI}^{PP}}{\partial \tau} > 0; \quad \frac{\partial q_{EI}^{NN}}{\partial \tau} > 0; \quad \frac{\partial q_{EI}^{PN}}{\partial \tau} > \frac{\partial q_{EI}^{NP}}{\partial \tau} > 0.$$

$$(iii) \quad q_R^{NN} > q_R^{PN/NP} > q_R^{PP}.$$

Proof. See Appendix.

Corollary 6 characterizes the equilibrium sales quantities across the four models.

Corollary 6(i) shows that the higher the quality image of the e-tailers, the greater their sales quantities. Correspondingly, this results in a shift in sales distribution: As the e-tailers' quality image improves, the sales quantities of the MNF's retail division decrease.

Corollary 6(ii) shows that, first, the greater the tax disparity, the more the MNF increases its sales in low-tax regions, regardless of whether e-tailer is participated in blockchain and regardless of sales channel (online or offline), to boost profits in low-tax region and mitigate tax liability. Second, the ranking of sensitivity to tax differentials, in terms of growth rate across sales channels, is as follows: "dual-chain" > "no-chain" > "single-chain". This can be attributed to the following reasons: In the "dual-chain" model, information transparency across both e-tailers creates a symmetrical and frictionless decision-making environment. This allows the MNF to synchronously raise its wholesale price to shift profits to low-tax regions, thereby "crowding out" price-sensitive consumers from online channels and redirecting them to offline channels. As a result, the sales quantities of MNF's retail division exhibit the highest sensitivity to tax disparity. In the "no-chain" model, information asymmetry between the two e-tailers introduces decision-making friction and uncertainty. Unable to accurately monitor real-time market competition across online channels, the MNF's pricing adjustments become tentative and incomplete. Consequently, online price adjustments are more conservative in magnitude and speed, leading to a correspondingly moderate effect on consumer channel shifting and offline sales growth. In the "single-chain" model, the mixed blockchain structure creates a fundamental strategic conflict. This structural conflict severely constrains the MNF's feasible strategy set, endogenously limiting pricing adjustments to a minimal range. Thus, the stimulus effect of online price changes on offline demand is weakest, resulting in the lowest sensitivity.

Corollary 6(ii) shows that the greater the tax disparity, the more the MNF increases its sales in low-tax regions, regardless of whether e-tailers participate in blockchain and regardless of sales channel (online or offline), to boost profits in the low-tax region and mitigate tax liability. Moreover, the ranking of sensitivity to tax differentials, in terms of growth rate across different sales channels, is as follows: "dual-chain" > "no-chain" > "single-chain". This ranking can be attributed to the differences in competitive structures shaped by different blockchain models.

Specifically, in the "dual-chain" model, information transparency across both e-tailers creates a symmetrical and frictionless decision-making environment. This allows the MNF to synchronously raise its wholesale price to shift profits to low-tax regions, thereby "crowding out" price-sensitive consumers from online channels and redirecting them to offline channels. As a result, the sales quantities of the MNF's retail division exhibit the highest sensitivity to tax disparity. In the "no-chain" model, information asymmetry between the two e-tailers introduces decision-making friction and uncertainty. Unable to accurately monitor real-time market competition across online channels, the

MNF's pricing adjustments become tentative and incomplete, leading to a moderate effect on consumer channel shifting and offline sales growth. In the "single-chain" model, the mixed blockchain structure creates a fundamental strategic conflict that severely constrains the MNF's feasible strategy set, endogenously limiting pricing adjustments to a minimal range, resulting in the lowest sensitivity.

Corollary 6(iii) shows that the sales quantities of the MNF's retail division satisfy $q_R^{NN} > q_R^{PN/PP} > q_R^{PP}$. In the "no-chain" model, both e-tailers lack blockchain-enabled trust endorsement and are at a competitive disadvantage. Consumers hold low willingness-to-pay for online channels, and a large share of consumers turn to the MNF's retail division, generating the highest offline retail sales quantity. In the "single-chain" model, only one e-tailer obtains blockchain trust authentication. The certified e-tailer gains enhanced consumer trust and diverts some consumers away from the MNF's retail division. Moreover, the other uncertified e-tailer still suffers trust deficiency and cannot compete fiercely against offline retail. As a result, the sales quantity of the MNF's retail division falls between the no-chain and dual-chain scenarios. In the "dual-chain" model, both e-tailers are equipped with blockchain trust endorsement. The trust deficit of both online channels is fully eliminated. Two competitive online e-tailers jointly siphon consumer demand from the MNF's retail division, which leads to the lowest sales quantity for the offline retail division.

5.5.2. Numerical analysis

In this section, considering the analytical solutions are very complex, we use the numerical example to illustrate the impacts of the e-tailers' quality image and tax disparity on the equilibrium results and profits of the two e-tailers and the MNF [47,48]. Moreover, we compare the optimal results in Models NN, PN, NP, and PP, respectively. To ensure that all the assumptions hold and the results are representative, we consider the following base settings for the equilibrium analyses [2]: $\alpha=0.8$, $a=4$, $0 < \tau < \frac{1}{3}$. Additionally, for convenience, we assume that $\varphi = 0.4$ when the MNF does not participate in blockchain with the e-tailer 2.

According to the model hypothesis in model description (in section 3), first, when the MNF does not participate in blockchain, on the one hand, consumers prefer to purchase the products of the MNF's retail division than the e-tailers, because consumers are skeptical about the products' authenticity source in the online market; on the other hand, consumers prefer to purchase the e-tailer 1's products than e-tailer 2's because of the e-tailer 1's higher quality image. Therefore, we set the parameter values of the quality image to satisfy $0 < \varphi < \rho \in (0.4, 0.8) < \alpha < 1$ when there is no blockchain. Second, when the MNF participates in blockchain, consumers will prefer to purchase products from the e-tailers than the MNF's retail division because of the time saving and convenience of the online shopping. Therefore, we assume $\rho = \varphi = 1$ when the MNF's participation in blockchain with the e-tailers.

Figure 7 illustrates the MNF's equilibrium wholesale price decision with respect to the quality image of the e-tailer 1 (ρ) and the tax disparity (τ).

First, regarding the effect of e-tailer 1's quality image, Figure 7 indicates that the wholesale price increases with ρ in Model NP, PN, and PP, but decreases in Model NN. In Model NP, the MNF joins blockchain with e-tailer 2, which enables e-tailer 2 to set a higher sales price; moreover, an improved quality image enables e-tailer 1 to also set a higher price. Both effects drive the MNF to set a higher wholesale price. In Model NN, by contrast, where the MNF does not participate in blockchain with any e-tailer, an increased quality image for e-tailer 1 intensifies competitive differentiation between the two e-tailers while reducing it between e-tailer 1 and the MNF's own retail division. This leads to

a lower wholesale price for two reasons: (i) Heightened competition between e-tailer 1 and the retail division forces the MNF to lower retail prices, which in turn pressures the MNF to reduce the wholesale price; and (ii) e-tailer 2's competitiveness diminishes as ρ increases, limiting the wholesale price it can afford to pay.

Second, regarding the effect of tax disparity, Figure 7 shows that the wholesale price decreases with τ across Models NN, NP, PN, and PP, which is consistent with Corollary 3.

Third, regarding the ranking of wholesale prices, Figure 7 reveals a stable ordering over the parameter range: $w^{NN} < w^{PN} < w^{NP} < w^{PP}$. In the NN model, neither e-tailer obtains blockchain trust endorsement. Limited consumer willingness-to-pay for online channels compels the MNF to adopt the lowest wholesale price to maintain e-tailers' participation constraints. In the PN and NP single-chain scenarios, only one e-tailer gains blockchain-driven quality improvement. The arm's-length principle requires a uniform wholesale price for both e-tailers, and the uncertified e-tailer exerts downward pressure on the wholesale price. Therefore, wholesale prices under single-chain settings lie between the no-chain and dual-chain benchmarks. Compared with PN, the NP model yields a slightly higher wholesale price because the certified e-tailer possesses stronger market attractiveness. In the PP dual-chain model, both e-tailers are equipped with blockchain trust endorsement. Blockchain simultaneously elevates consumers' valuation for both online channels, and there exists no low-trust e-tailer to suppress the wholesale price. Accordingly, the MNF can set the highest wholesale price to capture the trust-induced value increment from two online channels.

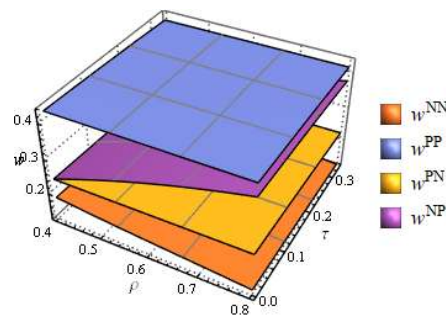


Figure 7. Wholesale price with ρ and τ .

Figure 8 shows the retail prices of the e-tailer 1, e-tailer 2 and the MNF's retail division with the e-tailer 1's quality image (ρ) and tax disparity (τ), respectively.

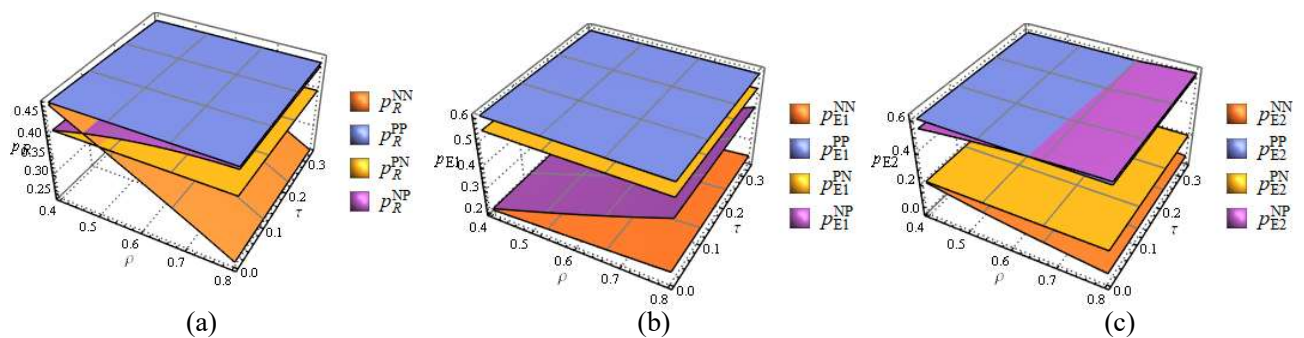


Figure 8. Retail price of the MNF's retail division, the e-tailer 1 and the e-tailer 2 with ρ and τ .

As shown in Figure 8(a-c), the retail prices of the MNF's retail division, the e-tailer 1 and e-tailer 2 will increase simultaneously in Model NP with the increase of e-tailer 1's quality image ρ . This is because when the MNF participates in blockchain with the e-tailer 2 but not with the e-tailer 1, the e-tailer 2's quality image is close to 1, and the increased quality image of the e-tailer 1 (ρ) improves the MNF's overall product reputation, allowing the MNF to set a higher wholesale price. In Model NN, with the increase of the e-tailer 1's quality image, the retail prices of the MNF's retail division and the e-tailer 2 will decrease, while the e-tailer 1's retail price will increase. The reason for this is that e-tailer 1's quality image becomes closer to the MNF's retail division with the increased ρ , which intensifies the market competition between the MNF's retail division and the e-tailers, so the MNF's retail division and the e-tailer 2 choose to decrease their retail prices.

Figure 8(a) indicates that the MNF's retail division can make a higher retail price in most cases in Model PP than in the other models. However, when the e-tailer 1's quality image is similar to the MNF's retail division together with a large tax disparity, the retail price of the MNF's retail division will be the highest in Model NP. On the one hand, the MNF will charge a higher wholesale price in Model PP, which encourages the MNF's retail division to make a higher retail price; on the other hand, when the e-tailer 1's quality image is similar to the MNF's retail division and the tax disparity is large in Model NP, the increased tax disparity decreases the retail division's sales price more significantly in Model PP than in Model NP.

From Figure 8(b), we can derive that there always exists $p_{E1}^{PP} > p_{E1}^{PN} > p_{E1}^{NP} > p_{E1}^{NN}$, which implies that the e-tailer 1's retail price is not only affected by the wholesale price but also by the quality image of the e-tailer 1. Moreover, the e-tailer 2's participation in blockchain is more conducive to improving the e-tailer 1's retail price than when the e-tailer 2 does not participate in blockchain.

Similar to the analysis in Figure 8(b), Figure 8(c) also shows that the e-tailer 2's prices are not only affected by the wholesale price but also by the quality image of the e-tailer 1. Additionally, there exists $p_{E2}^{PP}, p_{E2}^{NP} > p_{E2}^{PN} > p_{E2}^{NN}$, so, $p_{E2}^{PP} > p_{E2}^{NP}$ in most cases except when the tax disparity τ is relatively large.

Figure 9 shows the sales quantities of the e-tailer 1, e-tailer 2 and the MNF's retail division with the e-tailer's quality image (ρ) and tax disparity (τ), respectively.

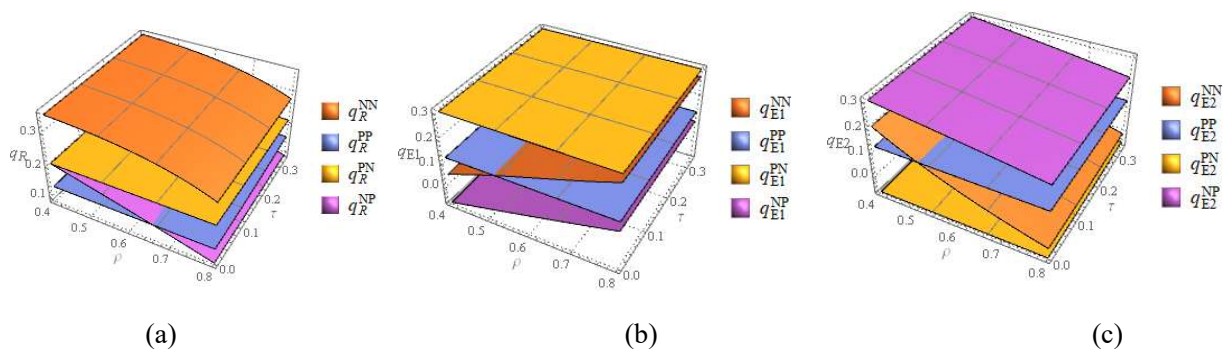


Figure 9. Sales quantities of the MNF's retail division, the e-tailer 1 and 2 with ρ and τ .

Figure 9(a-c) shows that in Models NN and NP, with the improvement of e-tailer 1's quality image (i.e., the increased ρ), e-tailer 1's sales quantities are increased, while the sales quantities of

the MNF's retail division and e-tailer 2 are decreased because of the fierce market competition caused by the increased quality image of the e-tailer 1.

In Figure 9(a), the sales quantities of the MNF's retail division are the highest in Model NN because of the market advantage of the MNF's retail division in the offline market, which provides a higher quality image to consumers.

In Figure 9(b), the sales quantities of e-tailer 1 are the highest in Model PN, because the e-tailer 1 can sell more products with an improving quality image, which captures market share from e-tailer 2 and the MNF's retail division. Moreover, it is more convenient for consumers to purchase the product from e-tailer 1 in the online market than from the offline market.

The explanation of the results in Figure 9(c) is similar to that in Figure 9(b).

Figure 10 describes the optimal profits of the MNF's retail division, e-tailer 1, and e-tailer 2 with the e-tailer's quality image (ρ), fixed cost to participate in blockchain (F), and tax disparity (τ), respectively.

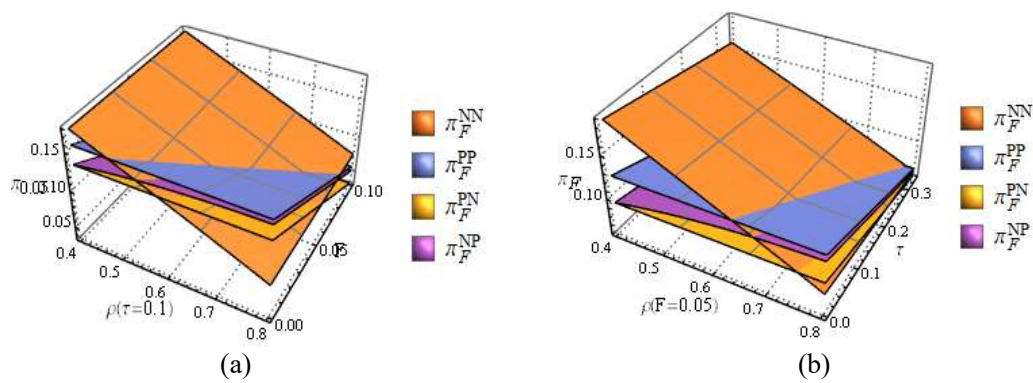


Figure 10. Profits of MNF's retail division with ρ , F , and τ .

Figure 10 indicates that the MNF's profits will decrease with the e-tailer 1's quality image (ρ) in Model NN, because the increased quality image of the e-tailer 1 intensifies the MNF's retail division's market competition, which decreases the profits of the MNF's retail division. Even though the increased quality image of the e-tailer 1 permits the MNF to obtain a higher wholesaling profit, the losses caused by the fierce market competition are even greater for the MNF's retail division in Model NN.

Figure 10(a) shows that the profits of Model NP, PN, and PP all rise as e-tailer 1's quality image ρ increases. When ρ is relatively low, π_F^{NN} yields the highest profit among all four strategies. When ρ becomes sufficiently large with smaller F and τ , π_F^{PP} turning into the globally optimal solution.

From Figure 10(b), we can derive that the MNF's profits will decrease the tax disparity (τ). A higher tax disparity implies a higher tax rate in the high-tax country. Without loss of generality, the higher the tax rate, the lower the profits the firms can obtain.

According to the above analysis, the MNF's profit comprises wholesale profit, retail profit from its internal retail division, tax-planning benefit, and the fixed cost associated with blockchain adoption. Figure 10 demonstrates that the MNF's blockchain-participation decision is jointly driven by the e-tailers' quality image, blockchain fixed cost, and tax disparity. Elevated fixed cost or large tax disparity weakens the MNF's incentive to adopt blockchain. As illustrated in Figure 10, Model NN is the preferred strategy when e-tailer 1's quality image is relatively low, whereas Model PP emerges as the globally optimal solution under sufficiently high e-tailer-1 quality image and low tax disparity.

Three underlying reasons account for this pattern. First, when e-tailer 1's quality image is low (marginally higher than that of e-tailer 2, yet substantially lower than the MNF's retail division), the MNF's internal retail division retains a competitive edge under Model NN. It can sell larger quantities at higher retail prices and secure considerable retail profit, which discourages the MNF from adopting blockchain. Second, when e-tailer 1's quality image is high, simultaneous blockchain participation by both e-tailers (Model PP) greatly enhances the quality images of the two downstream e-tailers. Even though this choice erodes tax-planning gains and retail profit, it substantially raises the MNF's wholesale profit, making PP attractive. Third, rising tax disparity or blockchain fixed cost suppresses the profit gains brought by Model PP. In such circumstances, the profit superiority of PP disappears, and Model NN becomes more attractive for the MNF.

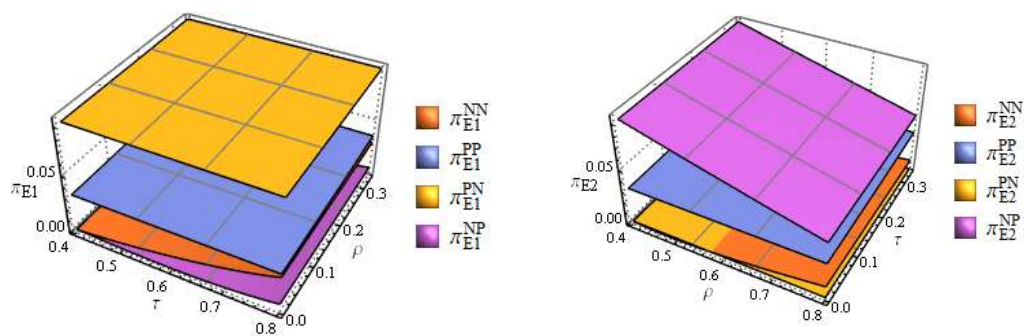


Figure 11. Profits of e-tailer 1 with ρ and τ . **Figure 12.** Profits of e-tailer 2 with ρ and τ .

Figure 11 indicates that the e-tailer 1's profits will increase in its quality image (ρ) in Model NN and NP, because of its increased market competitiveness with ρ . Moreover, from Figure 11, we can obtain that $\pi_{E1}^{PN} > \pi_{E1}^{PP} > \pi_{E1}^{NN} > \pi_{E1}^{NP}$. In Model PN, e-tailer 1's profit is the highest; however, e-tailer 1's profit is the lowest in Model NP, which provides some insights regarding e-tailer 1's decision on its preferences for joining in the blockchain. On the one hand, the MNF's participation in blockchain with e-tailer 1 but not with e-tailer 2 can increase e-tailer 1's market potential significantly, which helps e-tailer 1 place a large sales quantity with a higher retail price. Such a benefit is more conducive to improving e-tailer 1's profit margin even if the MNF increases the wholesale price. On the other hand, the MNF's participation in blockchain with e-tailer 2 but not with e-tailer 1 not only decreases e-tailer 1's market potential significantly, but also increases e-tailer 1's wholesale price, which decreases e-tailer 1's profits.

The explanation of e-tailer 2's profits in Figure 12 is similar to that of e-tailer 1 in Figure 11; therefore, we omit the specific analysis. Figures 11 and 12 reveal two key insights regarding e-tailers' blockchain participation incentives.

First, e-tailers always benefit from the MNF's decision to participate in blockchain, especially when the MNF participates with only a single e-tailer (i.e., Model NP or PN). This implies that e-tailers will always choose to join blockchain once the MNF decides to participate, so blockchain adoption is determined solely by the MNF. Second, the MNF's choice of which e-tailer to join with has asymmetric effects. According to Figure 10, when e-tailer 1's quality image is higher and close to that of the MNF's retail division, the MNF prefers to participate in blockchain with the weaker e-tailer (e-tailer 2) rather than with the stronger one (e-tailer 1). This significantly benefits e-tailer 2 (as shown in Figure 12) but hurts e-tailer 1 (as shown in Figure 11).

The above results provide a managerial insight: From a practical perspective, our equilibrium results imply that when the MNF chooses to adopt blockchain only for the weaker e-tailer, the stronger e-tailer suffers profit losses. Although our model does not endogenously incorporate incentive or subsidy instruments as decision variables, this observation points to a potential practical managerial direction: The MNF may consider designing supportive incentive arrangements for the stronger e-tailer in real-world operations.

6. Concluding remarks

6.1. Conclusions

Consumers in global markets often possess limited product information of the multinational firms on the cross-border e-commerce platforms. Blockchain has been practically deployed on cross-border e-commerce platforms to provide quality verification for consumers, such as JD.com, eBay, AliExpress, and Tmall Global. Moreover, the utilization of blockchain needs the participation of the brand-owner and the e-tailers on the supply chain, while it will fail if one of the supply chain members refuses to engage in blockchain. Therefore, we need research related to the utilization of blockchain from perspectives of the brand-owner and the e-tailers, respectively. We note that the brand-owners with the cross-border business are usually MNFs who have a manufacturing division and a retail division, and the MNF will sell products through its retail division and the e-tailers on the cross-border e-commerce platforms in low-tax countries. Furthermore, even though the utilization of blockchain induces more wholesaling profit for the MNF, no-participation maintains the quality advantage of the MNF's retail division. Moreover, there may be one or more e-tailers on different cross-border e-commerce platforms, which makes the firms' incentives to participate in blockchain sophisticated. Furthermore, the MNF's decisions related to participating in blockchain are also influenced by the tax disparity, the fixed adoption cost of blockchain and the e-tailers' quality image levels. Therefore, the MNFs and e-tailers need to carefully evaluate the tradeoffs when making the participation decisions under different market structures.

According to our results, we show that, first, when all e-tailers in the online market participate in blockchain, the market evolves into a highly coordinated and fully competitive cross-channel environment. When only part of e-tailers in the online market participate in blockchain, the market exhibits an asymmetric channel structure. When no e-tailer in the online market participate in blockchain, the competition structure becomes dominated by the MNF's retail division. In summary, different blockchain adoption patterns shape distinct channel competition structures, thereby directly affecting the MNF's pricing strategy and responsiveness to tax disparity by altering the degree of competitive equilibrium and channel symmetry. These modeling outcomes are consistent with prior empirical observations that blockchain traceability reshapes channel power and inter-firm competition in global retail markets [2]; yet, our work further quantifies how such structural changes interact with cross-border tax-planning motives.

Second, we show that the utilization of blockchain is a double-edged sword for the MNF. The utilization of blockchain increases the MNF's wholesaling profit, while it reduces the MNF's retailing and tax-planning profits. Moreover, e-tailers will choose to join blockchain once the MNF makes the decision to participate in blockchain; therefore, the utilization of blockchain is always determined only by the MNF. Moreover, whether the MNF is willing to participate in blockchain depends on the overall profits from wholesaling, retailing, and tax-planning profits.

Specifically, we show that: (i) Under e-tailer monopoly, the MNF rarely benefits from blockchain adoption. It will choose to participate only under narrow conditions: Sufficiently low fixed adoption cost, low tax disparity, and when the dominant e-tailer's quality image is close to that of the MNF's retail division. When the MNF joins blockchain, higher wholesale prices and improved e-tailer quality image boost wholesaling profit; nevertheless, profit losses from retailing and tax-planning dominate, discouraging adoption. (ii) In a duopoly setting with two competing e-tailers selling the MNF's products: When the stronger e-tailer's quality image is substantially lower than that of the MNF's retail division, the MNF refuses blockchain participation with either e-tailer. When the stronger e-tailer possesses a high-quality image, the MNF prefers joint blockchain adoption with both e-tailers. Under this circumstance, the incremental wholesaling profit outweighs losses in retailing and tax-planning profits. Furthermore, intensified channel competition, together with the ALP rule, enables the MNF to set higher wholesale prices and capture larger wholesaling revenues from both e-tailers. (iii) Without blockchain adoption, improvements in e-tailers' quality-image intensify competition between e-tailers and the MNF's retail division, accelerating declines in retailing and tax-planning profits and reducing the MNF's total profit. Hence, the MNF's propensity to adopt blockchain rises as e-tailers' quality-image improves. (iv) Lower fixed blockchain-adoption cost and lower tax disparity promote the MNF's blockchain participation. A larger tax disparity motivates the MNF to reduce wholesale prices to secure higher retail-side profit.

Combined with empirical evidence on multinational transfer pricing and blockchain investment, our numerical results complement real-world case findings: Many global brand owners remain hesitant to fully roll out blockchain verification across third-party online channels, because blockchain may erode their internal retail and tax-planning benefits even with growing wholesale revenue [35].

6.2. Managerial insights

Blockchain enables quality verification for e-tailers' products, expands e-commerce market demand, and intensifies competition between the MNF's retail division and third-party e-tailers. Our findings offer practical implications for MNFs operating overseas that evaluate blockchain participation under alternative market structures. In particular, these managerial guidelines can be finely differentiated across typical cross-border industries, with distinct decision logics for luxury goods and fast-moving consumer goods (FMCG). The MNF's overall profit (aggregating tax-planning, retailing, and wholesaling profit) varies with the co-opetition relationship between the MNF and e-tailers. We derive the following managerial insights that corroborate and extend the literature.

First, although the e-tailer's quality image and market potential improve when the MNF adopts blockchain, this intensifies market competition and reduces the MNF's tax-planning and retailing profits. On the one hand, blockchain adoption enables the MNF to set higher wholesale prices and increase sales quantities to the e-tailer, thereby boosting its wholesaling profits. On the other hand, the e-tailer's enhanced quality image weakens the MNF's retail division's market advantage, leading to significantly reduced order quantities and lower retailing profits. Moreover, the higher wholesale price also diminishes the MNF's tax-planning profits. These results suggest that the MNF's blockchain adoption decision depends on the net effect on its overall profits, which integrates tax-planning, retailing, and wholesaling components. For luxury goods industries where product authenticity dominates consumer purchase decisions, the quality verification value of blockchain is highly prominent. Luxury MNFs can tolerate moderate retail and tax-planning profit losses to capture long-term brand credibility and wholesale revenue growth. By contrast, Fast-Moving Consumer Goods

(FMCG) industries feature low product differentiation and price-sensitive consumers, so the marginal demand improvement brought by blockchain is limited.

Second, the MNF's blockchain-adoption strategies differ substantially between monopoly and duopoly cross-border e-commerce markets. Researchers, including those in [2,35,49], investigated blockchain applications in e-commerce. For instance, Niu et al. [2] showed that under e-tailer monopoly, the MNF rejects blockchain when tax disparity and channel substitutability are high. Our work differs from Niu et al. [2] in two major respects: (i) Under monopoly, our results show that the MNF generally resists blockchain participation, which contrasts with Niu et al. [2], who predicted MNF adoption under small tax disparity or low channel substitutability. This divergence originates from different modeling frameworks: Our demand function is built upon consumer utility and explicitly incorporates channel-specific quality-image perceptions, whereas Niu et al. [2] adopted a reduced-form linear competition demand model. In our setup, consumers favor e-tailer channels under blockchain due to online shopping convenience and time-saving benefits, which enhances model realism. (ii) We further examine the duopoly market with multiple competing e-tailers, a scenario unexplored in Niu et al. [2]. We find that high quality-image of the leading e-tailer favors blockchain adoption under duopoly. Notably, the MNF tends to reject blockchain under monopoly with a high-quality-image e-tailer but chooses participation under duopoly. The underlying logic is as follows: Without blockchain, strong e-tailer quality intensifies competition and generates severe retail-profit losses for the MNF when facing multiple e-tailers. With blockchain, the ALP rule enables the MNF to raise wholesale prices and benefit from expanded order volumes from multiple e-tailers, lifting wholesaling profit. This duopoly-preferred adoption strategy is more applicable to luxury cross-border markets with prominent channel quality differentiation. For homogeneous FMCG markets, intensified multi-retailer competition greatly weakens blockchain's marginal benefits; thus, MNFs in FMCG industries are advised to focus on tax and pricing optimization rather than proactive blockchain cooperation with multiple e-tailers.

Third, we analyze the impacts of market factors-including consumers' willingness-to-pay, tax disparity, the e-tailer's quality image, and the fixed cost of blockchain adoption on firms' optimal decisions and profits. (i) Higher consumer willingness-to-pay induces the MNF and e-tailers to set higher product prices and benefits all parties. Nevertheless, rising consumer willingness-to-pay yields larger marginal profit gains for the MNF's retail division in Model N, whereas the e-tailer captures larger marginal profit gains in Model P. (ii) To exploit cross-jurisdictional tax differences, the MNF lowers wholesale prices in Model N and Model P. This price reduction is more substantial in Model N, strengthening the market position of the MNF's retail division without blockchain. Accordingly, greater tax disparity weakens the MNF's incentive for blockchain adoption. (iii) When blockchain is absent, higher e-tailer quality image accelerates profit erosion for the MNF's retail and tax-planning segments and reduces total profit. Consequently, the MNF becomes more willing to adopt blockchain as e-tailer quality-image increases. (iv) Lower fixed blockchain-adoption cost encourages the MNF to participate in blockchain. In terms of industrial heterogeneity, the positive linkage between e-tailer quality image and blockchain adoption intention is much stronger for luxury products, as quality credibility directly determines consumer premium willingness. In comparison, FMCG MNFs are far more sensitive to fixed adoption costs and tax disparities, and their blockchain decisions are primarily driven by cost-benefit tradeoffs rather than quality improvement effects.

6.3. Limitation and future research directions

Despite these findings, this study has several notable limitations. First, we assume a single MNF as the upstream supplier and do not consider competition among multiple multinational manufacturers. Second, we do not conduct comprehensive multi-dimensional sensitivity analyses over the full parameter space to verify the robustness of equilibrium outcomes. Third, our core results rely heavily on numerical simulation under given parameter sets, which cannot provide fully closed-form analytical solutions for all equilibrium boundaries. Fourth, we do not model government subsidy mechanisms for blockchain adoption. To extend the understanding of firm interactions in cross-border e-commerce (particularly under scenarios of blockchain technology adoption or non-adoption), we propose the following promising research directions based on the aforementioned limitations:

First, although we assume deterministic consumer valuations for analytical tractability, researchers could incorporate stochastic elements into the model. Drawing on the stochastic control literature advanced by [50] regarding uncertainty in dynamic systems, subsequent studies could model consumer preferences or exchange rates as stochastic processes. Moreover, investigating how random fluctuations in tax rates or market demand interact with blockchain adoption would provide deeper insights into the risk management strategies of multinational firms. Furthermore, while we focus on a non-cooperative setting, researchers could explore cooperative game-theoretic solutions [39] to examine how blockchain facilitates coalition formation and profit distribution among supply chain members. Second, researchers can carry out complete multi-dimensional sensitivity tests across broader parameter ranges, such as: blockchain effectiveness, adoption costs, quality differences, and channel preferences [51,52]. Such robustness checks can further validate the reliability of our equilibrium results and extend the generalizability of the model conclusions. Third, since key equilibrium boundaries are obtained via numerical simulation, follow-up work can attempt to derive more closed-form analytical solutions. Moreover, our model treats blockchain-adoption cost as an exogenous lump-sum parameter, while it could be incorporated for future extended analysis [53]. In addition, we assume a uniform valuation distribution for tractability, and other distributions could be tested in future research. Fourth, formal modeling of subsidy mechanisms represents a promising avenue for future investigation. Since blockchain adoption can enhance consumer surplus and potentially improve total social welfare, researchers could explore how government-led subsidy schemes affect blockchain adoption decisions, pricing strategies, and channel competition among cross-border e-commerce participants. Moreover, advanced optimization-oriented modeling frameworks from studies can be adapted to enrich the above-mentioned future research avenues [45,54].

Author contributions

Fei Yan: Writing - Original Draft\ Writing - Review & Editing; Xiao-ping Wang: Supervision; Zhi-chao Zhang: Supervision.

Acknowledgments

All funding sources supporting this study are disclosed below: National Natural Science Foundation of China (Grant No. 72402003); Humanities and Social Sciences Research Project of the Ministry of Education (Grant No. 24YJC630307); Anhui Provincial Natural Science Foundation (Grant No. 2408085QG225).

Declarations

This is a purely game-theoretic analytical study that involves no human participants, human-related data or biological samples. Therefore, formal ethical approval is not applicable.

Use of Generative-AI tools declaration

Generative AI tools were used only for English language polishing and grammar checking during manuscript preparation. The AI tool did not participate in research design, data analysis, result interpretation or manuscript writing. All authors are responsible for the content of this work.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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