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Optimized Combination of e-commerce Platform Sales Model and Blockchain Anti-Counterfeit Traceability Service Strategy

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ABSTRACT In the e-commerce market, many e-commerce platforms act as resellers when selling products, and act as agents when selling other products. In the sales process, e-commerce platforms can either build their own blockchain anti-counterfeit traceability platforms or cooperate with third-party blockchain anti-counterfeit traceability platforms. This will generate four scenarios: 1) reseller, building its own platform (RE); 2) reseller, cooperating with a third-party platform (RO); 3) agent, building its own platform (ME); 4) agent, cooperating with a third-party platform (MO). Therefore, this paper constructs a differential game model under four modes to explore the interaction between the choice of sales mode and the choice of anti-counterfeit traceability service strategy. The results show that suppliers' profits are influenced by various aspects. On the one hand, in small-scale markets, the situation in which suppliers can realize higher profits evolves from ME to RO as the wholesale price increases, and in large-scale markets, suppliers are more profitable in the ME mode. On the other hand, with the increase of market scale and the decrease of unit price of anti-counterfeit traceability service of third-party platform, the situation that suppliers can achieve higher profit evolves from RE to RO and then to RE. For e-commerce platform, self-built platform is a better choice. In the small-scale market, as the market size increases, the cost performance of anti-counterfeit traceability service decreases, and the best choice for e-commerce platform evolves from resale to agency sales, and in the large-scale market, the best choice for e-commerce platform is resale.

INDEX TERMS Blockchain anti-counterfeit traceability platform (BATP), differential game, sales model selection.

I. INTRODUCTION

Along with the accelerated pace of consumer upgrading, the e-commerce market is expanding rapidly at an alarming rate [1]–[4]. The 2021 Global Payments Report, published by Worldpay, shows that China has become the largest e-commerce market in the world, with the e-commerce market expected to be worth $3.17 trillion by 2024. In previous e-commerce markets, e-commerce platforms operated primarily as resellers, reselling products purchased from upstream suppliers (e.g., Amazon resells music under iTunes), and in this model, the e-commerce platform owns the product [2], [3]. With the development of the e-commerce market, some retail giants such as Amazon and Walmart have broken with traditional sales methods and turned to agency sales (e.g., Amazon Marketplace, iBook Store), where e-commerce platforms act as agents, allowing suppliers to make decisions on key factors such as retail prices and sell products directly to consumers, but with a percentage fee paid to the e-commerce platform [5]–[8]. Due to more open and transparent retail prices, many e-commerce platforms are keen to adopt the agency sales format (e.g. Chinese smartphone manufacturer Xiaomi, well-known brand Sephora sells its products through Jingdong Mall, etc.) Despite the growing momentum of agency sales, some industries still use the resale sales model [9], [10]. The second annual "SME Impact Report" released by Amazon 2021 shows that revenue from reselling products amounted to $114.8 billion and total sales from agency selling exceeded $160 billion. As a result, the issue of choosing a sales model for e-commerce platforms has become a hot topic in recent years [2], [10]–[13].

In recent years, a wide range of products on the mall, the enterprise brand marketing efforts to increase the entire e-commerce field has brought a huge impact, some industry

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pain points have also emerged. Fierce competition among brands, the market is flooded with counterfeit goods, counterfeiting, and the sale of counterfeit problems are repeatedly prohibited [1], [14]–[17]. In Asia, counterfeit medicines are up to 60%, the fashion luxury industry is no exception [18]. According to the Harvard Business Review [19], the total trade in counterfeit goods is estimated to be as high as \$4.5 trillion in 2019, with counterfeit luxury goods totaling more than \$270 million and 40% of luxury counterfeit sales taking place online. How to solve these pain points becomes a difficult issue for companies, on the one hand, suppliers need to take action and be responsible for the quality improvement of their products (product innovation), continuous improvement of quality can positively contribute to goodwill [20]. On the other hand, e-commerce platforms use their own advantages, based on a large number of consumer transactions and behavior data, based on data-driven analysis of marketing activities, consumer demographic insights, advertising precision targeting and other data marketing services across the chain, that is, data-driven marketing (DDM), can also stimulate demand [21], [22]. In addition, counterfeit products seriously harm the interests of brands and consumers [23]–[25], damage the reputation of the entire consumer market, and are not conducive to the sustainable development of the market, product anti-counterfeiting has been pushed to the forefront of the times [14], [26], and the blockchain anti-counterfeiting traceability system was born [1], [27]. The product anti-counterfeiting traceability based on blockchain technology can realize the full traceability of products through the combination of its unique distributed ledger record characteristics and technologies such as Internet of Things [28], [29], including the information collection records of product sources, raw material source traceability, production and processing links, logistics information, anti-counterfeiting authentication, etc., realizing one code for one thing [15]. On the other hand, the chain of anti-counterfeit codes plays a supervisory role in tracing and discovering the illegal circulation and use of anti-counterfeit codes, and meets the actual demand of consumers for commodity traceability, which not only enhances the trust of the brand, but also improves the image of the brand, and the rights and interests of both enterprises and consumers can be protected, causing the resonance between enterprises and consumers [1], [30]. According to the 2020 Blockchain Traceability Service Innovation and Application Report, the sales of nutrition and health care and maternal and infant milk powder products have relatively increased by 29.4% and 10.0%, respectively, and the sales of other products have also increased after brands have launched blockchain anti-counterfeiting traceability services. Therefore, anti-counterfeit traceability service, as one of the most expensive operations of e-commerce platforms, is a key factor in promoting consumer demand and improving brand goodwill. In order to fully guarantee the quality of goods and enhance user experience, some platforms take advantage of their own blockchain technology to build "Blockchain Anti-counterfeit Traceability Platform" (BATP), such as Jingdong Zhizhen Chain, while some platforms provide anti-counterfeit traceability services for consumers by cooperating with third-party blockchain anti-counterfeit traceability platforms, such as the strategic cooperation between the famous brand "Baby Lattice" and the CQC code on the world anti-counterfeiting traceability platform.

It is well known that different service models (self-built and outsourced) have their own advantages and disadvantages, and can have different impacts on the company itself and on consumers due to different service efficiencies and costs. Some studies have also indicated that platforms implement different sales models for products with different service efficiencies/costs [10]. Therefore, in practice, the interaction of sales model selection and anti-counterfeit traceability service strategy results in four scenarios: (a) the e-commerce platform acts as a reseller and builds its own BATP to provide anti-counterfeit traceability service, namely, the RE scenario; (b) the e-commerce platform acts as a reseller and cooperates with a third-party BATP, which provides anti-counterfeit traceability service, namely, the RO scenario; (c) the platform acts as an agent and builds its own BATP to provide anti-counterfeit traceability service, namely, the ME scenario; and (d) the platform acts as an agent and cooperates with a third-party BATP, which provides anti-counterfeit traceability service, namely, the MO scenario.

On this basis, this paper aims to explore how the sales model selection of e-commerce platforms interacts with anti-counterfeit traceability service strategies. Specifically, we address the following questions.

(1) Under different models, how should suppliers, e-commerce platforms and third-party BATPs develop optimal strategies? What factors will be influenced by?

(2) Which scenario yields the highest retail price or the highest level of anti-counterfeit traceability service?

(3) What is the profitability of companies under different models? What factors will be affected?

(4) If we consider the interaction between the sales model of the e-commerce platform and the anti-counterfeit traceability service strategy, which case is optimal?

By solving problem (1) and analyzing four different models (i.e., RE/RO/ME/MO), we are able to obtain each optimal strategy for suppliers and e-commerce platforms under different scenarios and determine the optimal combination of sales model and blockchain anti-counterfeit traceability service strategy under different conditions.

By solving problem (2), we analyze which situation produces the highest retail price or the highest level of anti-counterfeit traceability service. The problem is considered not only from the perspective of the e-commerce platform, but also from the perspective of the consumer (because the higher the level of anti-counterfeit traceability service, the more it can protect the interests of the consumer).

By solving problem (3), we study in which case the e-commerce platform generates higher profits. It provides a reference for the managers of e-commerce platform companies in the selection of sales model and blockchain anti-counterfeit traceability service strategy.

Regarding question (4), we are interested in the optimal combination between e-commerce platform sales model and anti-counterfeit traceability service strategy, which has not been portrayed by mathematical theoretical models in previous literature. We investigate the key role played by the cost effectiveness of anti-counterfeit traceability services and further analyze how the different costs of anti-counterfeit traceability services on e-commerce platforms and third-party BATP anti-counterfeit traceability services affect the results in a more realistic way.

To solve the above problems, this paper considers a distribution channel consisting of an upstream supplier supplying products, a downstream e-commerce platform coordinating sales and anti-counterfeit traceability services, and continuous consumers. Then, we constructed differential game models under four modes of RE/RO/ME/MO, described the product innovation degree and brand goodwill with state equations, and examined how the sales mode choice of e-commerce platforms interacted with the anti-counterfeit traceability service strategy. The innovations of this paper are: (1) from a dynamic perspective, the evolution of product innovation degree and brand goodwill is portrayed under the addition of technology investment by suppliers and blockchain anti-counterfeit traceability service strategy provided by e-commerce platforms. (2) The differential game model is constructed by considering the choice of sales model of e-commerce platform and the choice of blockchain anti-counterfeiting and traceability service strategy. This problem has not been portrayed by mathematical theoretical models in previous literature. Some important findings are mainly presented below.

First, we solve for the degree of product innovation, brand goodwill, each optimal strategy and corporate profit under the four models, and conduct sensitivity analysis on the key parameters, and find that each strategy of the company is affected by different factors under different models. Under the RE model, the market size plays a positive influence on the supplier's technology investment level, but whether the market size and wholesale price have a positive studio or negative influence on the anti-counterfeit traceability service strategy and DDM strategy of the e-commerce platform depends on their interactions. Under the RO model, the impact of market size on the DDM strategy of e-commerce platforms, the impact of wholesale price on the level of technology investment and DDM strategy, and the impact of the unit price of anti-counterfeit traceability services charged by third-party BATPs on the strategy of anti-counterfeit traceability services all depend on the pricing criteria of the unit price of anti-counterfeit traceability services of third-party BATPs. Under the ME model, the market size has a positive effect on the channel, and the commission rate will weaken the incentive of suppliers to invest in technology, but will enhance the anti-counterfeit traceability service strategy and DDM strategy of e-commerce platforms. Under the MO model, the impact of market size on the DDM strategy of e-commerce platforms depends on the unit price of anti-counterfeit traceability services charged by third-party BATPs.

Second, we compared the retail prices of the products under the four models. The analysis shows that the RO model yields higher retail prices on a resale basis, and the same retail prices under the ME and MO models on an agency sales basis. Further, under the four models, the RO model will yield the highest retail price, the theoretical basis of which depends on the double marginalization effect. In addition, by comparing the anti-counterfeit traceability service strategies under the four models, it is found that the results depend on the unit price of anti-counterfeit traceability services of the third-party BATP.

Third, suppliers' profits will be affected by several factors, on the one hand, the interaction of market size and wholesale prices. In small or medium-sized markets, the scenario in which suppliers can realize higher profits will change from ME to RO as wholesale prices increase. In large scale markets, the ME model will achieve higher margins. On the other hand, the interaction of market size and the unit price of anti-counterfeit traceability services of third-party BATPs, as the market size increases and the unit price of services decreases, the situation in which suppliers can achieve higher profits changes from RE to RO and then to RE.

Finally, by considering the strategic interaction of sales model and strategy choice of e-commerce platforms, we find that self-built BATP is a better choice for e-commerce platforms. The result of the choice of sales model depends on the interaction between market size and cost effectiveness of anti-counterfeit traceability services. As the market size increases and the cost effectiveness of anti-counterfeit traceability services decreases, the best choice for e-commerce platforms shifts from resale to agency sales, when the market size is at the medium level and above, the best choice for e-commerce platforms is resale.

The rest of the paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 provides the problem description and related assumptions. Section 4 develops differential game models for the four models and performs the solution and sensitivity analysis. Section 5 presents a comparative analysis. Section 6 provides numerical examples. Finally, conclusions are drawn in Section 7.

II. LITERATURE REVIEW

In this section, we review the relevant literature from the following three streams: (1) sales model selection (2) blockchain anti-counterfeit traceability (3) platform strategy selection (self-built or cooperation with third-party platforms).

A. SALES MODEL SELECTION

Sales model selection has been a popular research topic in recent years, and much of the existing literature has focused on the trade-offs between resale and agency models for supply chain members under different conditions [2], [5]–[7], [12], [31], and many scholars have also revealed the key drivers that influence sales model selection [32]–[35]. Abhishe *et al.* [9] studied the impact of online on brick-and-mortar demand spillover effects, among others, on the choice of platform sales model and found that the preference of platforms for resale or agency sales depends on whether electronic channel sales have a positive or negative impact on the demand for traditional channels. Wei *et al.* [4] investigated the effect of information sharing on suppliers' sales model choice in a supply chain consisting of one supplier and one e-tailer and found that for a given information sharing strategy, suppliers used resale and agency sales models when production costs were relatively low and resale only when production costs were relatively large. Liu *et al.* [22] studied the impact of market size and data-driven marketing on platform sales model choice and found that as data-driven marketing becomes more efficient, platforms are more willing to adopt resale models. Some scholars, however, have considered the choice of sales model under the influence of market competition. Tian *et al.* [36] examined the impact of channel operating costs and the degree of competition from upstream suppliers on e-commerce sales models. Liu *et al.* [13] study the sales model choice of a monopoly manufacturer facing two competing downstream platform firms and find that for a given level of order fulfillment costs, the manufacturer's choice evolves from selling as an agent for both platforms, to a hybrid model, and then to reselling for both platforms due to the increase in order fulfillment costs. Chen *et al.* [8] studied how platforms should use both resale and agency sales business models in promotions in the presence of competition and found that a hybrid sales model (one resale, one agency sales model) yields Pareto improvements. However, in practice, the interaction between the choice of platform sales model and the operational decisions of supply chain members is an inevitable issue to be considered [11]. Geng *et al.* [37] examined the interaction between upstream firms' pricing strategies for add-on products and downstream online platform sales model choices and found that firms tend to bundle add-on and core products together in the resale model and retail add-on products separately in the marketplace model. Zhang and Zhang [3] examine the interaction between sales model choices and information sharing strategies between e-retailers and suppliers who establish brick-and-mortar stores. Wei *et al.* [38] constructed a model of competition between platforms to study the choice of platform sales model by considering the channel roles, and market share differences of e-retailers. Qin *et al.* [10] studied the interaction between sales model choice and logistics service strategy in e-commerce marketplace and found that for platforms, as the cost effectiveness of logistics service improves, the preferred scenario for platforms evolves from "marketplace model-platform provides logistics service" to "marketplace model-supplier provides logistics service", and then evolves to "reseller model-platform provides logistics service". This paper investigates the interaction between sales model selection and anti-counterfeit traceability service strategy of e-commerce platforms in the context of blockchain anti-counterfeit traceability, which is a further addition to the above literature.

B. BLOCKCHAIN ANTI-COUNTERFEITING TRACEABILITY

Due to the prevalence of counterfeit products in various industries, product security and anti-counterfeiting have become a major concern for companies and have received increasing academic attention in recent years [23], [24], [39]. In response to the proliferation of counterfeit products in e-commerce markets, Meraviglia [18] considers an innovative product monitoring approach to combat counterfeiting by controlling the entire production and distribution chain. Chin *et al.* [25] studied the decision problem of counterfeit goods in e-commerce transactions based on machine learning and IoT, and proposed anti-counterfeiting system ideas and methods from the perspectives of machine learning, IoT anti-counterfeiting sharing and anti-counterfeiting penalties. However, the traditional product anti-counterfeiting technology is difficult to realize the open and transparent information of production and sales chain, which leads to the product anti-counterfeiting cannot be truly realized [14], [40]. However, product anti-counterfeiting traceability based on blockchain technology can ensure product data security, tamper-proof and traceability, and effectively solve the problem of product counterfeiting [29], [30], [41]–[44]. Dutta *et al.* [28] collected 178 studies on the use of blockchain in supply chain operations, exploring industries where blockchain traceability technology can be successfully implemented, including agriculture, food, e-commerce, and more. Choi [45] shows that blockchain is widely recognized as an innovative, decentralized, distributed, "state-of-the-art" technology as a shared, open and distributed ledger that helps businesses store and record data and guarantees the confidentiality, integrity and availability of all transactions and data. Fan *et al.* [46] showed that blockchain technology has a powerful information traceability function and plays an important role in quality control and responding to product safety issues. Liu *et al.* [1] constructed an evaluation model based on customer needs in the project management of a blockchain traceability and anti-counterfeiting platform, showing that to use blockchain technology for anti-counterfeiting requires the synergy of consumer awareness, legal regulation, and other aspects. Alzahrani and Bulusu [15] constructed a decentralized anti-counterfeiting supply chain using NFC and blockchain technologies and proposed a new decentralized consensus protocol based on this. Liu and Li [27] constructed a blockchain-based framework for cross-border e-commerce supply chains and proposed corresponding techniques and methods to achieve product and transaction traceability in supply chain management. The difference between our paper and this series of literature is that we consider the rights of consumers. That is, our model sets the e-commerce platform to provide blockchain anti-counterfeiting traceability service strategy for consumers, so that consumers can get more specific product information, inspection and quarantine information and distribution and storage information, etc. through the traceability code of goods and the corresponding blockchain code, so that illegal transactions and fraudulent counterfeiting are nowhere to be found and consumers' rights and interests can be effectively ensured. For example, Jingdong's intelligent supply chain ecosystem is open to the "Jingdong Blockchain Anti-counterfeit Traceability Platform", which protects goods through information security sharing, tamper-proof and traceable blockchain technology, so that consumers can buy authentic products. At the same time, we also take into account the interests of e-commerce platforms, i.e. we build a model to analyze which option would be more profitable for e-commerce platforms to build their own BATP or cooperate with third-party BATPs. This is also the innovation of this paper.

C. PLATFORM STRATEGY SELECTION (SELF-BUILT OR COOPERATION WITH THIRD-PARTY PLATFORMS)

Due to the rise of blockchain anti-counterfeit traceability technology, many companies seize the opportunity to introduce blockchain anti-counterfeit traceability technology in the marketing process to provide consumers with anti-counterfeit traceability services. Consumers can scan the code to verify and obtain information about the whole process of the product in production, sales, etc., which improves consumers' trust [47]. Therefore the third research area closely related to the study of this paper is the question of strategy choice of the platform, i.e., for some services, whether to build its own system to provide or to cooperate with third parties. Liu and Liu [48] summarize the current development of self-built logistics and analyze the impact of self-built platforms on product price, sales volume, price and sales variance from the consumer's perspective. Niu *et al.* [49] constructed an analytical game model to investigate whether an e-commerce platform B without logistic advantage cooperates with a competitor A with logistic advantage and found that B benefits from cooperating with A when the product competition intensity is in the medium range. Qin *et al.* [50] constructed a supply chain consisting of an e-commerce platform and a seller, where the platform chooses whether to share the logistics service system with the seller, and the seller chooses whether to outsource the logistics service to a third-party platform. They found that as the level of logistics services and market potential increased, the platform and sellers cooperated as a balanced model. Previous related studies have mostly focused on the selection of logistics service strategies, while some scholars have also conducted research in other areas. Du *et al.* [51] studied merchants' optimal selection strategies for online-to-offline (O2O) food delivery models, showing that merchants should choose self-built platforms and self-production models when the advertising effect generated by self-delivery is larger and the consumer benefits from third-party platform promotion are smaller. Zhang *et al.* [52] developed a model consisting of manufacturers and third-party sharing platforms, showing that manufacturers will build their own sharing platforms when the cost of consumer inconvenience is relatively low but the marginal cost is relatively high, while manufacturers will partner with third-party sharing platforms when the cost of consumer inconvenience is relatively high but the marginal cost is relatively low.

As mentioned above, the choice of sales model in the e-commerce market has been the focus of attention of the business and academic circles. Blockchain anti-counterfeit traceability can directly hit the pain point of the industry of the proliferation of counterfeit and shoddy products in the e-commerce market, and gradually attracts the attention of academia. Considering the impact of strategies such as sales model selection and anti-counterfeit traceability services on the future profitability and sustainable development of enterprises, the differential game model can better portray the continuous timeliness and dynamic changes of strategies, which is more in line with the actual operation process. Therefore, this paper discusses the interaction between the choice of sales model and anti-counterfeit traceability service strategy of e-commerce platform from a dynamic perspective with the help of differential game theory.

III. MODEL DESCRIPTION AND ASSUMPTION

A. MODEL DESCRIPTION

We consider a distribution channel consisting of a supplier, an e-commerce platforms and a continuum of consumers. The supplier sells a particular brand of product to consumers through the e-commerce platform, and according to industry practice, the e-commerce platform can choose to sell the product as a reseller (resale model, e.g., Jingdong and Huawei) or an agent (agency sales model, e.g., Jingdong and Sephora). Under the resale model (denoted by R), the e-commerce platform buys the product from the upstream supplier at a fixed wholesale price w and determines the retail price p to the consumer [2], [3]. In contrast, under the agency sales model (denoted by M), the supplier determines the retail price p and sells its product directly to the consumer while paying a percentage of the fee to the platform, which we call the commission rate ε.[1] This structure is used in many marketplaces, such as Amazon Marketplace, iBook Store. Without loss of generality, we normalize the marginal cost of the product to zero, an assumption that has been adopted in much of the literature [10], [50].

In this process, suppliers invest in technology to improve the quality of their products by continuously developing innovations and improving production processes, thus increasing the innovation of their products [20]. e-commerce platforms, on the other hand, conduct marketing campaigns

[1] Depending on the situation, there are several interchangeable terms for commission rate, agency fee rate, revenue share ratio, etc. [37]. Note that in this paper, we set the commission rate as a fixed exogenous parameter, because in real life, e-commerce platforms usually charge the same commission rate to suppliers of the same product category. This assumption has also been adopted in many literatures [6], [37], [50], [53].

based on data-driven analysis, i.e., data-driven marketing (DDM), to stimulate demand while increasing consumer utility [22]. At the same time, in order to achieve product anti-counterfeiting and improve the brand goodwill of products, e-commerce platforms can build their own Blockchain Anti-counterfeiting Traceability Platform (BATP) to provide consumers with anti-counterfeiting traceability services, or they can choose to cooperate with a third-party anti-counterfeiting traceability platform and pay the unit price of anti-counterfeiting traceability services τ[2] to the third-party BATP to better protect consumers' rights and interests.

Table 1 summarizes the parameters and decision variables of our model.

In practice, anti-counterfeit traceability of goods based on blockchain technology can effectively solve the trust problem in traditional traceability and avoid counterfeit and shoddy products in the process of circulation. Therefore, blockchain anti-counterfeit traceability has become one of the key businesses of e-commerce platforms as an effective tool to combat counterfeit and shoddy products. e-commerce platforms commonly provide anti-counterfeiting traceability service strategy in the form of self-built and cooperation with third parties. Therefore, considering the choice of sales model of e-commerce platform and the strategy choice of e-commerce platform between self-built BATP model and cooperation model with third-party BATP, there are four possible scenarios, as shown in Fig. 1, and the game order in each scenario is conducted as follows.

(1) Reseller - e-commerce platform self-built model (RE): the e-commerce platform acts as a reseller and builds its own blockchain anti-counterfeit traceability platform

(2) Reseller - e-commerce platform and third-party platform cooperation model (RO): the e-commerce platform acts as a reseller and cooperates with a third-party blockchain anti-counterfeit traceability platform.

(3) Agent - e-commerce platform self-built model (ME): the e-commerce platform acts as an agent and builds its own blockchain anti-counterfeit traceability platform to provide anti-counterfeit traceability services to consumers.

(4) Agent - e-commerce platform and third-party platform cooperation model (MO): The e-commerce platform acts as an agent and cooperates with the third-party blockchain anti-counterfeit traceability platform.

B. MODEL ASSUMPTION

The current consumer market environment is becoming increasingly rational and consumers' choices are gradually expanding, and a single common product is no longer competitive. The degree of product innovation is a key factor influencing consumers' purchasing behavior, and suppliers have to continuously develop and innovate their products to improve the degree of product innovation and meet individualized market needs [20]. In a sense, product innovation is referred to as an operational tool, so it is a dynamic change process, and following the literature [20], the dynamics equation of product innovativeness can be described as

$$\dot{Q}(t) = \sigma T(t) - \gamma Q(t), \quad Q(0) = Q_0 \tag{1}$$

As an effective tool to combat counterfeit products, anti-counterfeit traceability services based on blockchain technology can meet the practical needs of consumers for product

[2]In this paper, we set the unit price of anti-counterfeit traceability services charged by third-party BATPs as a fixed exogenous parameter. Because in practice, third-party BATPs charge the same unit price of service for e-commerce platforms of the same product category, a similar assumption appears in the literature [10].

TABLE 1. Parameters and variables.

Symbol	Descescriptions
Parameter	
$x = S, E, O$	market players, where S represents suppliers, E represents e-commerce platforms, and O represents third-party anti-counterfeit traceability platforms
$y = RE, RO, ME, MO$	alternative solution, which are the combinations of two sales models and two anti-counterfeit traceability service strategies
π_x^y	firm x's profit under scenario y
D	market demand
D_0	the market size
w	the wholesale price
τ	unit price of anti-counterfeit traceability services charged by third-party BATP, $\tau > 0$
ε	commission rates charged by e-commerce platforms, $0 < \varepsilon < 1$
σ	coefficient of impact of technology investment level on product innovation degree, $\sigma > 0$
α	impact factor of anti-counterfeit traceability service on goodwill, $\alpha > 0$
β	coefficient of the effect of DDM on goodwill, $\beta > 0$
ξ	marginal contribution of product innovation to goodwill, $\xi > 0$
γ, δ	decay rate of product innovation and brand goodwill, $\gamma > 0, \delta > 0$
ϕ	supplier's cost-sharing percentage for DDM on e-commerce platforms, $0 < \phi < 1$
λ	coefficient of influence of product price on market demand, $\lambda > 0$
μ, θ	consumer sensitivity to product innovation and goodwill, $\mu > 0, \theta > 0$
k_T, k_I, k_A	cost factors for technology investment, anti-counterfeit traceability services and DDM, $k_T > 0, k_I > 0, k_A > 0$
r	the discount rate
Decision variables	
$p(t)$	retail price of the product
$T(t)$	the technology investment level of the supplier
$I(t)$	the anti-counterfeit traceability service strategy of the e-commerce platform
$A(t)$	the data-driven marketing strategy (DDM) of the e-commerce platform
State variables	
$Q(t)$	The degree of innovation of the product, where $Q_0 > 0$ is the initial degree of innovation
$G(t)$	The brand goodwill of the product, where $G_0 > 0$ is the initial brand goodwill

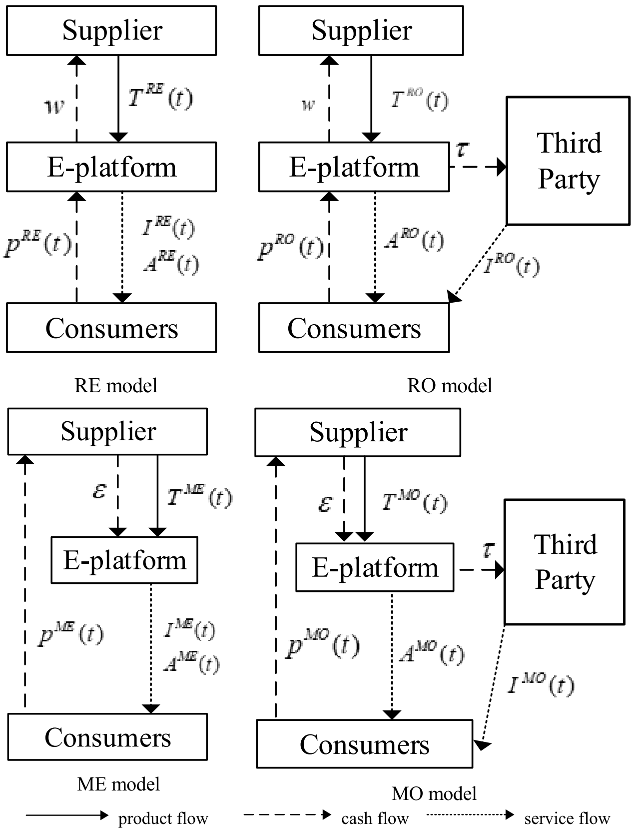


FIGURE 1. **Model structure.**

traceability and improve consumer trust, effectively increasing brand goodwill [1], [30]. And e-commerce platforms take advantage of their natural data acquisition, and marketing campaigns implemented based on data-driven analytics can improve consumer utility and promote higher goodwill [21], [22]. Moreover, the goal of supplier product innovation is to satisfy consumer needs, and the degree of product innovation always plays a positive contribution in accumulating product goodwill [20]. If anti-counterfeit traceability services, data-driven marketing, and product innovativeness are absent, goodwill decays exponentially over time at a rate of δ. According to the model of Liu *et al.* [20], the kinetic equation of goodwill can be described as

$$\dot{G}(t) = \lambda T(t) + \eta U(t) - \delta G(t), \quad G(0) = G_0 \tag{2}$$

The technology investment cost is assumed to be related to the level of technology investment as $C_T(t) = k_T T^2/2$, with a quadratic representation of the diminishing returns of such expenditures. Similarly, the anti-counterfeit traceability service and DDM costs are $C_I(t) = k_I I^2/2$ and $C_A(t) = k_A A^2/2$, respectively, and similar cost construction methods have been widely adopted in the literature [10], [20], [50].

Market demand depends on the pricing decisions of product owners, the degree of innovation of the product, and the brand goodwill of the product. This is manifested in the following aspects: (1) demand decreases as product price increases; (2) suppliers' technology investment indirectly affects market demand through innovation degree; and (3) e-commerce platforms indirectly affect market demand through product anti-counterfeit traceability services and DDM through brand goodwill. Specifically, the price function is assumed to be linearly decreasing, and, the innovation degree goodwill function is assumed to be a linearly separable additive function. Drawing on Liu *et al.* [20], the demand function is constructed using separable multiplication of price and non-price factors, so that the market demand function can be described as

$$D(t) = [D_0 - \lambda p(t)]\,[\mu Q(t) + \theta G(t)] \tag{3}$$

In the RE model, the supplier sells the product to the e-commerce platform at wholesale price w. At the same time, to better encourage the e-commerce platform to conduct data-driven marketing, it will share ϕ proportion of the DDM cost for the e-commerce platform, which builds its own BATP to provide anti-counterfeit traceability service. Therefore, the revenue function of the supplier is $\pi_S^{RE} = w(t)D(t) - \phi C_A(t) - C_T(t)$, and the revenue function of the e-commerce platform is $\pi_E^{RE} = [p(t) - w(t)]\,D(t) - (1-\phi)C_A(t) - C_I(t)$. In the RO model, the supplier sells the product to the e-commerce platform at the wholesale price w and shares ϕ proportion of the DDM cost for the e-commerce platform, and the e-commerce platform cooperates with the third-party BATP and pays the unit price τ to the third-party BATP, which provides anti-counterfeit traceability service. Therefore, the revenue function of the supplier is $\pi_S^{RO} = w(t)D(t) - \phi C_A(t) - C_T(t)$, the revenue function of the e-commerce platform is $\pi_E^{RO} = [p(t) - w(t)]\,D(t) - \tau D(t) - (1-\phi)C_A(t)$, and to ensure the normal operation of the e-commerce platform, $p(t) - w(t) - \tau > 0$ needs to be assumed, and the revenue function of the third-party blockchain anti-counterfeiting traceability platform is $\pi_O^{RO} = \tau D(t) - C_I(t)$. In particular, it should be noted that the wholesale price of the product will not fluctuate significantly within a certain period of time, unless there are irresistible factors, and it is assumed that the wholesale price of the product is a fixed constant to better focus on the choice of the sales model of the e-commerce platform, namely $w(t) = w$ (Basak *et al.*, 2017; Qin *et al.*, 2021). In the ME model, the supplier decides the retail price p of the product, sells it directly to the consumer, pays a certain percentage of the cost to the e-commerce platform, and shares ϕ percentage of the DDM cost for the e-commerce platform, which provides anti-counterfeit traceability service by building its own BATP. Therefore, the revenue function of the supplier is $\pi_S^{ME} = (1-\varepsilon)p(t)D(t) - \phi C_A(t) - C_T(t)$, and the revenue function of the e-commerce platform is $\pi_E^{ME} = \varepsilon p(t)D(t) - (1-\phi)C_A(t) - C_I(t)$. In the MO model, the supplier sets the price and pays a certain percentage of the fee to the e-commerce platform, while sharing ϕ proportion of the DDM cost for the e-commerce platform, and the e-commerce platform cooperates with the third-party BATP and pays a unit price τ to the third-party BATP. Therefore, the revenue function of the supplier is $\pi_S^{MO} = (1-\varepsilon)p(t)D(t) - \phi C_A(t) - C_T(t)$, and the revenue function of the e-commerce platform is $\pi_E^{MO} = \varepsilon p(t)D(t) - \tau D(t) - (1-\phi)C_A(t)$, and the revenue function of the third-party BATP is $\pi_O^{MO} = \tau D(t) - C_I(t)$.

Suppliers, e-commerce platforms and third-party anti-counterfeit traceability platforms all operate over an infinite plan period, seeking to maximize profits and having the same positive discount rate r.

IV. MODEL ANALYSIS

Based on the previous model description and assumptions, this section discusses the optimal pricing of products, the optimal strategies of suppliers, e-commerce platforms, and third-party BATPs, the degree of product innovation, brand goodwill, and firm profits under the four models. It also further analyzes the impact of key exogenous parameters on strategy and profit. For the clarity of the model, superscripts RE, RO, ME, and MO denote different decision models, and subscripts S, E, and O denote key channel members. All relevant proofs are shown in the Appendix.

A. MODEL-RE

In the RE model, the e-commerce platform acts as a reseller and builds its own BATP to provide anti-counterfeit traceability services. First, the supplier decides the wholesale price w and the technology investment level $T^{RE}(t)$ of the product, and then the e-commerce platform decides the retail price $p^{RE}(t)$, the anti-counterfeit traceability service strategy $I^{RE}(t)$ and the DDM strategy $A^{RE}(t)$. Therefore, the decision problem faced by the supply chain members can be summarized as

$$\max_{T(\cdot)} \left\{ J_S = \int_0^\infty e^{-rt} \begin{bmatrix} w\,[D_0 - \lambda p(t)]\,[\mu Q(t) + \theta G(t)] \\ -\frac{1}{2}\phi k_A A^2(t) - \frac{1}{2}k_T T^2(t) \end{bmatrix} dt \right\} \tag{4}$$

$$\max_{p(\cdot),I(\cdot),A(\cdot)} \left\{ J_E = \int_0^\infty e^{-rt} \begin{bmatrix} (p(t)-w)\,[D_0 - \lambda p(t)] \\ [\mu Q(t) + \theta G(t)] \\ -\frac{1}{2}(1-\phi)k_A A^2(t) - \frac{1}{2}k_I I^2(t) \end{bmatrix} dt \right\} \tag{5}$$

$$\text{s.t.} \begin{cases} \dot{Q}(t) = \sigma T(t) - \gamma Q(t),\ Q(0) = Q_0 \\ \dot{G}(t) = \alpha I(t) + \beta A(t) + \xi Q(t) - \delta G(t),\ G(0) = G_0 \end{cases} \tag{6}$$

Proposition 1: The optimal level of technology investment for the supplier is

$$T^{RE} = \frac{2\sigma w(D_0 - \lambda w)\,[\mu(r+\delta) + \xi\theta]}{4k_T(r+\gamma)(r+\delta)} \tag{7}$$

The retail price of the product is

$$p^{RE} = \frac{D_0 + \lambda w}{2\lambda} \tag{8}$$

The optimal anti-counterfeit traceability service strategy and optimal DDM strategy for e-commerce platform are

$$I^{RE} = \frac{\alpha\theta(D_0 - \lambda w)^2}{4k_I\lambda(r+\delta)} \tag{9}$$

and

$$A^{RE} = \frac{\beta\theta(D_0 - \lambda w)^2}{4k_A(1-\phi)\lambda(r+\delta)} \tag{10}$$

The dynamic evolution of the product innovation degree is

$$Q^{RE}(t) = Q_\infty^{RE} + \left(Q_0 - Q_\infty^{RE}\right)e^{-\gamma t} \tag{11}$$

where

$$Q_\infty^{RE} = \frac{2\sigma^2 w(D_0 - \lambda w)\,[\mu(r+\delta) + \xi\theta]}{4\gamma k_T(r+\gamma)(r+\delta)} \tag{12}$$

The dynamic evolution of brand goodwill is

$$\begin{aligned} G^{RE}(t) &= G_\infty^{RE} + \frac{\xi}{\delta-\gamma}\left(Q_0 - \frac{2\sigma^2 w(D_0 - \lambda w)\,[\mu(r+\delta)+\xi\theta]}{4\gamma k_T(r+\gamma)(r+\delta)}\right) \\ &\quad \times e^{-\gamma t} + \left[G_0 - G_\infty^{RE} - \frac{\xi}{\delta-\gamma}\right. \\ &\quad \left. \times \left(Q_0 - \frac{2\sigma^2 w(D_0 - \lambda w)\,[\mu(r+\delta)+\xi\theta]}{4\gamma k_T(r+\gamma)(r+\delta)}\right)\right] e^{-\delta t} \end{aligned} \tag{13}$$

where

$$\begin{aligned} G_\infty^{RE} &= \frac{\alpha^2\theta(D_0-\lambda w)^2}{4\delta k_I\lambda(r+\delta)} + \frac{\beta^2\theta(D_0-\lambda w)^2}{4\delta k_A(1-\phi)\lambda(r+\delta)} \\ &\quad + \frac{2\xi\sigma^2 w(D_0-\lambda w)\,[\mu(r+\delta)+\xi\theta]}{4\delta\gamma k_T(r+\gamma)(r+\delta)} \end{aligned} \tag{14}$$

The profits of suppliers and e-commerce platforms are

$$V_S^{RE} = f_1^{RE}Q^{RE} + f_2^{RE}G^{RE} + f_3^{RE} \tag{15}$$

and

$$V_E^{RE} = g_1^{RE}Q^{RE} + g_2^{RE}G^{RE} + g_3^{RE} \tag{16}$$

where

$$\begin{aligned} f_1^{RE} &= \frac{2w(D_0-\lambda w)\,[\mu(r+\delta)+\xi\theta]}{4(r+\gamma)(r+\delta)}, \\ f_2^{RE} &= \frac{w(D_0-\lambda w)\theta}{2(r+\delta)}, \\ f_3^{RE} &= \frac{1}{r}\left[\frac{(\sigma f_1^{RE})^2}{2k_T} + \frac{\alpha^2 f_2^{RE} g_2^{RE}}{k_I}\right. \\ &\quad \left. + \frac{\beta^2 g_2^{RE}\left[2(1-\phi)f_2^{RE} - \phi g_2^{RE}\right]}{2k_A(1-\phi)^2}\right] \\ g_1^{RE} &= \frac{(D_0-\lambda w)^2\,[\mu(r+\delta)+\xi\theta]}{4\lambda(r+\delta)(r+\gamma)},\quad g_2^{RE} = \frac{\theta(D_0-\lambda w)^2}{4\lambda(r+\delta)}, \\ g_3^{RE} &= \frac{1}{r}\left[\frac{\sigma^2 g_1^{RE} f_1^{RE}}{k_T} + \frac{(\alpha g_2^{RE})^2}{2k_I} + \frac{(\beta g_2^{RE})^2}{2k_A(1-\phi)}\right] \end{aligned}$$

Corollary 1: Table 2 shows the relationship between the optimal technology investment level, anti-counterfeit traceability service strategy, DDM strategy, product innovation degree, brand goodwill and each key parameter under the RE model.

TABLE 2. Sensitivity analysis in the RE model.

	D_0	λ	w	ϕ
p^{RE}	↗	↘	↗	—
T^{RE}	↗	↘	$D_0-2\lambda w>0$ ↗ $D_0-2\lambda w<0$ ↘	—
Q_∞^{RE}	↗	↘	$D_0-2\lambda w>0$ ↗ $D_0-2\lambda w<0$ ↘	—
I^{RE}	$D_0-\lambda w>0$ ↗ $D_0-\lambda w<0$ ↘	$D_0-\lambda w<0$ ↗ $D_0-\lambda w>0$ ↘	$D_0-\lambda w<0$ ↗ $D_0-\lambda w>0$ ↘	—
A^{RE}	$D_0-\lambda w>0$ ↗ $D_0-\lambda w<0$ ↘	$D_0-\lambda w<0$ ↗ $D_0-\lambda w>0$ ↘	$D_0-\lambda w<0$ ↗ $D_0-\lambda w>0$ ↘	↗
G_∞^{RE}	$D_0-\lambda w>0$ ↗ $D_0-\lambda w<0$ ↘	*	*	—

Note: ↗ indicates positive correlation, ↘ indicates negative correlation, — indicates no correlation, and * indicates pending..

Corollary 1 shows that, first, the pricing strategy of the product and the technology investment strategy of the supplier are positively related to the market size. A larger market size implies a higher probability of profitability for the firm and a greater incentive for suppliers to invest more in technology and increase product innovation. At this point, suppliers will get a higher return on investment by increasing wholesale prices, and thus product prices will be higher. Suppliers' technology investment initiatives are more than enough to give consumers access to higher quality products and mitigate the negative impact of higher product prices on demand. Second, when the market size and wholesale price meet certain conditions ($D_0 - 2\lambda w > 0$), the supplier technology investment strategy will be positively correlated with the wholesale price, the higher the wholesale price will incentivize suppliers to improve the level of technology investment, otherwise it is negatively correlated. This indicates that setting a reasonable wholesale price is crucial for suppliers. Furthermore, there is a correlation between the anti-counterfeit traceability service strategy and DDM strategy of e-commerce platforms and market size and wholesale price. When $D_0 - \lambda w > 0$ is satisfied, the anti-counterfeit traceability service strategy is positively influenced by market size, and e-commerce platforms are more interested in investing in blockchain technology to better realize one-thing quality protection product traceability and make the sales market stable and sustainable. At the same time, e-commerce platforms are more motivated to use their own advantages to fully collect customer information, accurately place advertisements and increase marketing efforts. Under the same conditions, anti-counterfeit traceability service and DDM strategy are negatively correlated with wholesale price. It can be seen that higher wholesale prices will weaken the enthusiasm of e-commerce platforms for anti-counterfeit traceability services and DDM, which is not conducive to the sustainable development of the sales market, while lower wholesale prices tend to make the suppliers' revenue insufficient to meet the technical costs, reduce their enthusiasm for technological innovation, and are not conducive to product innovation. Therefore, enterprises should pay more attention to the changes in market scale, the impact of product prices on market demand and other factors, and seek a reasonable wholesale price, which is the way to long-term profitability. Finally, the relationship between goodwill and wholesale price is shown in the numerical analysis section.

B. MODEL-RO

In the RO model, the e-commerce platform acts as a reseller and cooperates with a third-party BATP to provide anti-counterfeit traceability services. First, the supplier decides the wholesale price w and the technology investment level $T^{RO}(t)$, then the e-commerce platform decides the retail price $p^{RO}(t)$ and the DDM strategy $A^{RO}(t)$, and the third-party BATP decides the unit price τ and the anti-counterfeit traceability service strategy $I^{RO}(t)$. Therefore, the decision problem faced by the supply chain members can be summarized in (17)–(20), as shown at the bottom of the next page.

Proposition 2: The optimal level of technology investment for the supplier is

$$T^{RO} = \frac{\sigma w\,(D_0 - \lambda(w+\tau))\,[\mu(r+\delta)+\xi\theta]}{2k_T(r+\delta)(r+\gamma)} \tag{21}$$

The retail price of the product is

$$p^{RO} = \frac{D_0 + \lambda(w+\tau)}{2\lambda} \tag{22}$$

The optimal anti-counterfeit traceability service strategy is

$$I^{RO} = \frac{\alpha\tau\theta\,(D_0 - \lambda(w+\tau))}{2k_I(r+\delta)} \tag{23}$$

The optimal DDM strategy for e-commerce platforms is

$$A^{RO} = \frac{\beta\theta\,(D_0 - \lambda(w+\tau))^2}{4k_A(1-\phi)\lambda(r+\delta)} \tag{24}$$

The dynamic evolution of the product innovation degree is

$$Q^{RO}(t) = Q_\infty^{RO} + \left(Q_0 - Q_\infty^{RO}\right)e^{-\gamma t} \tag{25}$$

where

$$Q_\infty^{RO} = \frac{\sigma^2 w\,(D_0 - \lambda(w+\tau))\,[\mu(r+\delta)+\xi\theta]}{2\gamma k_T(r+\delta)(r+\gamma)} \tag{26}$$

The dynamic evolution of brand goodwill is

$$G^{RO}(t) = G_\infty^{RO} + \frac{\xi}{\delta-\gamma} \times \left(Q_0 - \frac{\sigma^2 w\,(D_0 - \lambda(w+\tau))\,[\mu(r+\delta)+\xi\theta]}{2\gamma k_T(r+\delta)(r+\gamma)}\right)e^{-\gamma t}$$

$$
+\begin{bmatrix} G_0 - G_\infty^{RO} \\ -\frac{\xi}{\delta-\gamma}\left(Q_0 - \frac{\sigma^2 w(D_0-\lambda(w+\tau))[\mu(r+\delta)+\xi\theta]}{2\gamma k_T(r+\delta)(r+\gamma)}\right) \end{bmatrix} e^{-\delta t} \tag{27}
$$

where

$$
\begin{aligned}
G_\infty^{RO} &= \frac{\alpha^2\tau\theta\,(D_0-\lambda(w+\tau))}{2\delta k_I(r+\delta)} + \frac{\beta^2\theta\,(D_0-\lambda(w+\tau))^2}{4\delta k_A(1-\phi)\lambda(r+\delta)} \\
&\quad + \frac{\xi\sigma^2 w\,(D_0-\lambda(w+\tau))\,[\mu(r+\delta)+\xi\theta]}{2\delta\gamma k_T(r+\delta)(r+\gamma)}
\end{aligned} \tag{28}
$$

The profit of supplier, e-commerce platform and third party BATP are

$$
V_S^{RO} = f_1^{RO}Q^{RO} + f_2^{RO}G^{RO} + f_3^{RO} \tag{29}
$$

and

$$
V_E^{RO} = g_1^{RO}Q^{RO} + g_2^{RO}G^{RO} + g_3^{RO} \tag{30}
$$

and

$$
V_O^{RO} = h_1^{RO}Q + h_2^{RO}G + h_3^{RO} \tag{31}
$$

where

$$
\begin{aligned}
f_1^{RO} &= \frac{w\,(D_0-\lambda(w+\tau))\,[\mu(r+\delta)+\xi\theta]}{2(r+\delta)(r+\gamma)}, \\
f_2^{RO} &= \frac{w\theta\,(D_0-\lambda(w+\tau))}{2(r+\delta)}, \\
f_3^{RO} &= \frac{1}{r}\begin{bmatrix} \frac{(\sigma f_1^{RO})^2}{2k_T} + \frac{\alpha^2 f_2^{RO}h_2^{RO}}{k_I} \\ + \frac{\beta^2 g_2^{RO}[2(1-\phi)f_2^{RO}-\phi g_2^{RO}]}{2k_A(1-\phi)^2} \end{bmatrix} \\
g_1^{RO} &= \frac{(D_0-\lambda(w+\tau))^2\,[\mu(r+\delta)+\xi\theta]}{4\lambda(r+\delta)(r+\gamma)}, \\
g_2^{RO} &= \frac{\theta\,(D_0-\lambda(w+\tau))^2}{4\lambda(r+\delta)}, \\
g_3^{RO} &= \frac{1}{r}\left[\frac{\sigma^2 g_1^{RO}f_1^{RO}}{k_T} + \frac{\alpha^2 g_2^{RO}h_2^{RO}}{k_I} + \frac{(\beta g_2^{RO})^2}{2k_A(1-\phi)}\right] \\
h_1^{RO} &= \frac{(D_0-\lambda(w+\tau))\,\tau\,[\mu(r+\delta)+\theta\xi]}{2(r+\delta)(r+\gamma)}, \\
h_2^{RO} &= \frac{\tau\theta\,(D_0-\lambda(w+\tau))}{2(r+\delta)}, \\
h_3^{RO} &= \frac{1}{r}\left[\frac{\sigma^2 h_1^{RO}f_1^{RO}}{k_T} + \frac{(\alpha h_2^{RO})^2}{2k_I} + \frac{\beta^2 h_2^{RO}g_2^{RO}}{k_A(1-\phi)}\right]
\end{aligned}
$$

Corollary 2: Table 3 shows the relationship between the optimal technology investment level, anti-counterfeit traceability service strategy, DDM strategy, product innovation degree, brand goodwill and each key parameter under the RO model.

TABLE 3. **Sensitivity analysis in the RO model.**

	D_0	λ	w	ϕ	τ
p^{RO}	↗	↘	↗	—	↗
T^{RO}	↗	↘	$0<\tau<\underset{\sim}{\tau}$ ↗ $\tau>\underset{\sim}{\tau}$ ↘	—	↗
Q_∞^{RO}	↗	↘	$0<\tau<\underset{\sim}{\tau}$ ↗ $\tau>\underset{\sim}{\tau}$ ↘	—	↗
I^{RO}	↗	↘	↘	—	$0<\tau<\hat{\tau}$ ↗ $\tau>\hat{\tau}$ ↘
A^{RO}	$0<\tau<\tilde{\tau}$ ↗ $\tau>\tilde{\tau}$ ↘	$\tau>\tilde{\tau}$ ↗ $0<\tau<\tilde{\tau}$ ↘	$\tau>\tilde{\tau}$ ↗ $0<\tau<\tilde{\tau}$ ↘	↗	$\tau>\tilde{\tau}$ ↗ $0<\tau<\tilde{\tau}$ ↘
G_∞^{RO}	↗	*	*	↗	*

Note: ↗ indicates positive correlation, ↘ indicates negative correlation, — indicates no correlation, and ∗ indicates pending. Where, $\tilde{\tau}=\frac{D_0-\lambda w}{\lambda}$, $\underset{\sim}{\tau}=\frac{D_0-2\lambda w}{\lambda}$, $\hat{\tau}=\frac{D_0-\lambda w}{2\lambda}$.

Corollary 2 shows that, firstly, market size, wholesale price and unit price of anti-counterfeit traceability services charged by third-party BATPs create positive incentives for the pricing strategy of products. Second, subject to certain conditions, the relationship between market size, wholesale price and unit price of anti-counterfeit traceability services charged by third-party BATP satisfies $D_0 - 2\lambda w - \lambda\tau > 0$, with higher wholesale price, suppliers have more working capital and higher technology investment level; when it satisfies $D_0 - 2\lambda w - \lambda\tau < 0$, higher wholesale price will discourage suppliers' technology investment. This is because, the higher the wholesale price, the e-commerce platform will compensate for the negative impact of high wholesale price by increasing the retail price of the product to maintain its

$$
\max_{T(\cdot)}\left\{J_S = \int_0^\infty e^{-rt}\begin{pmatrix} w\,[D_0-\lambda p(t)]\,[\mu Q(t)+\theta G(t)] \\ -\frac{1}{2}\phi k_A A^2(t) - \frac{1}{2}k_T T^2(t)\end{pmatrix}\mathrm{d}t\right\} \tag{17}
$$

$$
\max_{p(\cdot),A(\cdot)}\left\{J_E = \int_0^\infty e^{-rt}\begin{bmatrix} (p-w)\,[D_0-\lambda p(t)]\,[\mu Q(t)+\theta G(t)] \\ -\tau\,[D_0-\lambda p(t)]\,[\mu Q(t)+\theta G(t)] \\ -\frac{1}{2}(1-\phi)k_A A^2(t)\end{bmatrix}\mathrm{d}t\right\} \tag{18}
$$

$$
\max_{I(\cdot)}\left\{J_O = \int_0^\infty e^{-rt}\left[\tau\,[D_0-\lambda p(t)]\,[\mu Q(t)+\theta G(t)] - \frac{1}{2}k_I I^2(t)\right]\mathrm{d}t\right\} \tag{19}
$$

$$
\text{s.t.}\quad \begin{cases} \dot{Q}(t) = \sigma T(t) - \gamma Q(t), & Q(0) = Q_0 \\ \dot{G}(t) = \alpha I(t) + \beta A(t) + \xi Q(t) - \delta G(t), & G(0) = G_0 \end{cases} \tag{20}
$$

economic efficiency, which will discourage consumers from buying the product, so the supplier will also reduce the technical investment in the product accordingly. Furthermore, third-party BATPs charge a certain unit price for anti-counterfeit traceability services can motivate third-party BATPs to provide anti-counterfeit traceability services, but if the service price exceeds a certain range, it is easy to make the retail price of products soar, which reduces consumers' desire to purchase and discourages third-party BATPs from providing anti-counterfeit traceability services. Similarly, when the unit price of anti-counterfeit traceability services is within a reasonable range, e-commerce platforms will focus their strategies on cooperation with third-party BATPs. When the service price exceeds a certain range, leading to a lower anti-counterfeit traceability service strategy, then e-commerce platforms can only shift their strategies to reduce the negative impact of a lower anti-counterfeit traceability service strategy by increasing their DDM strategies. In the rest of this paper, we will discuss the important parameter range where the unit price of anti-counterfeit traceability services is not too high, namely $0 < \tau < \frac{D_0-\lambda w}{\lambda}$. Finally, the relationship between goodwill and wholesale price is shown in the numerical analysis section.

C. MODEL-ME

In the ME model, the e-commerce platform acts as an agent and builds its own BATP to provide anti-counterfeit traceability services. First, the e-commerce platform decides the commission rate ε, the anti-counterfeit traceability service strategy $I^{ME}(t)$ and the DDM strategy $A^{ME}(t)$, and then the supplier decides the retail price $p^{ME}(t)$ of the product and the level of technology investment $T^{ME}(t)$. Therefore, the decision problem faced by the supply chain members can be summarized as

$$\max_{T(\cdot),p(\cdot)} \left\{ J_S = \int_0^{\infty} e^{-rt} \times \begin{pmatrix} (1-\varepsilon)p\left[D_0-\lambda p(t)\right]\left[\mu Q(t)+\theta G(t)\right] \\ -\frac{1}{2}\phi k_A A^2(t)-\frac{1}{2}k_T T^2(t) \end{pmatrix} \mathrm{d}t \right\} \tag{32}$$

$$\max_{I(\cdot),A(\cdot)} \left\{ J_E = \int_0^{\infty} e^{-rt} \times \begin{bmatrix} \varepsilon p\left[D_0-\lambda p(t)\right]\left[\mu Q(t)+\theta G(t)\right] \\ -\frac{1}{2}(1-\phi)k_A A^2(t)-\frac{1}{2}k_I I^2(t) \end{bmatrix} \mathrm{d}t \right\} \tag{33}$$

$$\text{s.t.} \begin{cases} \dot{Q}(t)=\sigma T(t)-\gamma Q(t),\ Q(0)=Q_0 \\ \dot{G}(t)=\alpha I(t)+\beta A(t)+\xi Q(t)-\delta G(t),\ G(0)=G_0 \end{cases} \tag{34}$$

Proposition 3: The optimal level of technology investment for the supplier is

$$T^{ME}=\frac{\sigma D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\xi\theta\right]}{4k_T\lambda(r+\delta)(r+\gamma)} \tag{35}$$

The retail price of the product is

$$p^{ME}=\frac{D_0}{2\lambda} \tag{36}$$

The optimal anti-counterfeit traceability service strategy and optimal DDM strategy for e-commerce platform are

$$I^{ME}=\frac{\alpha D_0^2\varepsilon\theta}{4k_I\lambda(r+\delta)} \tag{37}$$

and

$$A^{ME}=\frac{\beta D_0^2\varepsilon\theta}{4k_A(1-\phi)\lambda(r+\delta)} \tag{38}$$

The dynamic evolution of the product innovation degree is

$$Q^{ME}(t)=Q_\infty^{ME}+\left(Q_0-Q_\infty^{ME}\right)e^{-\gamma t} \tag{39}$$

where

$$Q_\infty^{ME}=\frac{\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\xi\theta\right]}{4\gamma k_T\lambda(r+\delta)(r+\gamma)} \tag{40}$$

The dynamic evolution of brand goodwill is

$$\begin{aligned} G^{ME}(t) &= G_\infty^{ME}+\frac{\xi}{\delta-\gamma}\left(Q_0-\frac{\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\xi\theta\right]}{4\gamma k_T\lambda(r+\delta)(r+\gamma)}\right)e^{-\gamma t} \\ &+\left[G_0-G_\infty^{ME}-\frac{\xi}{\delta-\gamma}\right. \\ &\times\left.\left(Q_0-\frac{\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\xi\theta\right]}{4\gamma k_T\lambda(r+\delta)(r+\gamma)}\right)\right]e^{-\delta t} \end{aligned} \tag{41}$$

where

$$\begin{aligned} G_\infty^{ME} &= \frac{\alpha^2 D_0^2\varepsilon\theta}{4\delta k_I\lambda(r+\delta)}+\frac{\beta^2 D_0^2\varepsilon\theta}{4\delta k_A(1-\phi)\lambda(r+\delta)} \\ &+\frac{\xi\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\xi\theta\right]}{4\delta\gamma k_T\lambda(r+\delta)(r+\gamma)} \end{aligned} \tag{42}$$

The profits of suppliers and e-commerce platforms are

$$V_S^{ME}=f_1^{ME}Q^{ME}+f_2^{ME}G^{ME}+f_3^{ME} \tag{43}$$

and

$$V_E^{ME}=g_1^{ME}Q^{ME}+g_2^{ME}G^{ME}+g_3^{ME} \tag{44}$$

where

$$f_1^{ME}=\frac{D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\xi\theta\right]}{4\lambda(r+\delta)(r+\gamma)},\quad f_2^{ME}=\frac{D_0^2\theta(1-\varepsilon)}{4\lambda(r+\delta)},$$

$$f_3^{RO}=\frac{1}{r}\left[\frac{(\sigma f_1)^2}{2k_T}+\frac{\alpha^2 f_2 g_2}{k_I}+\frac{\beta^2 g_2\left[2(1-\phi)f_2-\phi g_2\right]}{2k_A(1-\phi)^2}\right]$$

$$g_1^{ME}=\frac{D_0^2\varepsilon\left[\mu(r+\delta)+\xi\theta\right]}{4\lambda(r+\delta)(r+\gamma)},\quad g_2^{ME}=\frac{D_0^2\varepsilon\theta}{4\lambda(r+\delta)},$$

$$g_3^{ME}=\frac{1}{r}\left[\frac{\sigma^2 g_1 f_1}{k_T}+\frac{(\alpha g_2)^2}{2k_I}+\frac{(\beta g_2)^2}{2k_A(1-\phi)}\right]$$

Corollary 3: Table 4 shows the relationship between the optimal technology investment level, anti-counterfeit traceability service strategy, DDM strategy, product innovation

TABLE 4. Sensitivity analysis in the ME model.

	D_0	λ	ε	ϕ
p^{ME}	↗	↘	—	—
T^{ME}	↗	↘	↘	—
Q_∞^{ME}	↗	↘	↘	—
I^{ME}	↗	↘	↗	—
A^{ME}	↗	↘	↗	↗
G_∞^{ME}	↗	↘	*	↗

Note: ↗ indicates positive correlation, ↘ indicates negative correlation, — indicates no correlation, and * indicates pending..

degree, brand goodwill and each key parameter under the ME model.

Corollary 3 suggests that, first, as market size increases, suppliers have an incentive to raise the retail price of their products, as well as an incentive to increase the level of technological investment and further improve product innovation as a way to boost profits. The anti-counterfeit traceability service strategy of e-commerce platforms is positively correlated with market size; the larger the market size, the higher the likelihood of profitability of the firm and the more incentive the e-commerce platform has to improve anti-counterfeit traceability services. Similarly, the larger the market size, the higher the DDM strategy of the e-commerce platform to promote higher brand goodwill. Second, commission rates do not affect suppliers' pricing strategies, but negatively affect technology investment strategies, meaning that excessive commission rates discourage suppliers' technology investment activities and discourage product innovation. The commission rate, on the other hand, positively affects the anti-counterfeit traceability service strategy and DDM strategy of e-commerce platforms. A higher commission rate means that a higher revenue goes to the platform, and the platform has more incentive to improve its anti-counterfeit traceability strategy when it has financial assurance. Finally, the impact of commission rate on brand goodwill is shown in the numerical analysis section.

D. MODEL-MO

In the MO model, the e-commerce platform acts as an agent and cooperates with the third-party BATP to provide anti-counterfeit traceability services. First, the e-commerce platform decides the commission rate ε and DDM strategy $A^{MO}(t)$, and the third-party BATP decides the unit price τ and the anti-counterfeit traceability service strategy $I^{MO}(t)$. Then the supplier decides the retail price $p^{MO}(t)$ and the technology investment level $T^{MO}(t)$ of the product. Therefore, the decision problem faced by the supply chain members can be summarized in (45)–(48), as shown at the bottom of the next page.

Proposition 4: The optimal level of technology investment for the supplier is

$$T^{MO} = \frac{\sigma D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\theta\xi\right]}{4k_T\lambda(r+\delta)(r+\gamma)} \tag{49}$$

The retail price of the product is

$$p^{MO} = \frac{D_0}{2\lambda} \tag{50}$$

The optimal anti-counterfeit traceability service strategy is

$$I^{MO} = \frac{\alpha D_0\tau\theta}{2k_I(r+\delta)} \tag{51}$$

The optimal DDM strategy for e-commerce platforms is

$$A^{MO} = \frac{\beta D_0\theta(\varepsilon D_0 - 2\lambda\tau)}{4k_A(1-\phi)\lambda(r+\delta)} \tag{52}$$

The dynamic evolution of the product innovation degree is

$$Q^{MO}(t) = Q_\infty^{MO} + \left(Q_0 - Q_\infty^{MO}\right)e^{-\gamma t} \tag{53}$$

where

$$Q_\infty^{MO} = \frac{\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\theta\xi\right]}{4\gamma k_T\lambda(r+\delta)(r+\gamma)} \tag{54}$$

The dynamic evolution of brand goodwill is

$$\begin{aligned} G^{MO}(t) &= G_\infty^{MO} \\ &+ \frac{\xi}{\delta-\gamma}\left(Q_0 - \frac{\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\theta\xi\right]}{4\gamma k_T\lambda(r+\delta)(r+\gamma)}\right)e^{-\gamma t} \\ &+ \left[\begin{array}{l} G_0 - G_\infty^{MO} \\ -\frac{\xi}{\delta-\gamma}\left(Q_0 - \frac{\sigma^2 D_0^2(1-\varepsilon)[\mu(r+\delta)+\theta\xi]}{4\gamma k_T\lambda(r+\delta)(r+\gamma)}\right)\end{array}\right]e^{-\delta t} \end{aligned} \tag{55}$$

where

$$\begin{aligned} G_\infty^{MO} = \frac{\alpha^2 D_0\tau\theta}{2\delta k_I(r+\delta)} + \frac{\beta^2 D_0\theta(\varepsilon D_0 - 2\lambda\tau)}{4\delta k_A(1-\phi)\lambda(r+\delta)} \\ + \frac{\xi\sigma^2 D_0^2(1-\varepsilon)\left[\mu(r+\delta)+\theta\xi\right]}{4\delta\gamma k_T\lambda(r+\delta)(r+\gamma)} \end{aligned} \tag{56}$$

The profit of supplier, e-commerce platform and third party BATP are

$$V_S^{MO} = f_1^{MO}Q^{MO} + f_2^{MO}G^{MO} + f_3^{MO} \tag{57}$$

and

$$V_E^{MO} = g_1^{MO}Q^{MO} + g_2^{MO}G^{MO} + g_3^{MO} \tag{58}$$

and

$$V_O^{MO} = h_1^{MO}Q + h_2^{MO}G + h_3^{MO} \tag{59}$$

where

$$f_1^{MO} = \frac{(1-\varepsilon)D_0^2\left[\mu(r+\delta)+\theta\xi\right]}{4\lambda(r+\delta)(r+\gamma)}, \quad f_2^{MO} = \frac{(1-\varepsilon)\theta D_0^2}{4\lambda(r+\delta)},$$

$$f_3^{MO} = \frac{1}{r}\left[\frac{(\sigma f_1)^2}{2k_T} + \frac{\alpha^2 f_2 h_2}{k_I} + \frac{\beta^2 g_2\left[2f_2(1-\phi)-\phi g_2\right]}{2k_A(1-\phi)^2}\right]$$

$$g_1^{MO} = \frac{D_0(\varepsilon D_0 - 2\lambda\tau)\left[\mu(r+\delta)+\xi\theta\right]}{4\lambda(r+\delta)(r+\gamma)},$$

$$g_2^{MO} = \frac{(\varepsilon D_0 - 2\lambda\tau)\theta D_0}{4\lambda(r+\delta)},$$

$$g_3^{MO} = \frac{1}{r}\left[\frac{\sigma^2 g_1 f_1}{k_T} + \frac{\alpha^2 g_2 h_2}{k_I} + \frac{(\beta g_2)^2}{2k_A(1-\phi)}\right]$$

$$h_1^{MO} = \frac{\tau D_0\left[\mu(r+\delta)+\xi\theta\right]}{2(r+\delta)(r+\gamma)}, \quad h_1^{MO} = \frac{\tau\theta D_0}{2(r+\delta)},$$
$$h_1^{MO} = \frac{1}{r}\left[\frac{\sigma^2 h_1 f_1}{k_T} + \frac{(\alpha h_2)^2}{2k_I} + \frac{\beta^2 h_2 g_2}{k_A(1-\phi)}\right]$$

Corollary 4: Table 5 shows the relationship between the optimal technology investment level, anti-counterfeit traceability service strategy, DDM strategy, product innovation degree, brand goodwill and each key parameter under the MO model.

TABLE 5. Sensitivity analysis in the MO model.

	D_0	λ	ε	ϕ	τ
p^{MO}	$\nearrow$	$\searrow$	—	—	—
T^{MO}	$\nearrow$	$\searrow$	$\searrow$	—	—
Q_∞^{MO}	$\nearrow$	$\searrow$	$\searrow$	—	—
I^{MO}	$\nearrow$	—	—	—	$\nearrow$
A^{MO}	$0<\tau<\underset{\smile}{\tau}$ $\nearrow$ $\tau>\underset{\smile}{\tau}$ $\searrow$	$\searrow$	$\nearrow$	$\nearrow$	$\searrow$
G_∞^{MO}	$0<\tau<\underset{\smile}{\tau}$ $\nearrow$ $\tau>\underset{\smile}{\tau}$ $\searrow$	$\searrow$	*	$\nearrow$	*

Note: $\nearrow$ indicates positive correlation, $\searrow$ indicates negative correlation, — indicates no correlation, and $*$ indicates pending. Where $\underset{\smile}{\tau} = \frac{\varepsilon D_0}{\lambda}$.

Corollary 4 shows that market size positively affects the pricing strategy of suppliers, technology investment strategy, and anti-counterfeit traceability service strategy of third-party BATPs. The influence of market size on the DDM strategy of e-commerce platforms is determined by the unit price of anti-counterfeit traceability services charged by third-party BATPs, and in a reasonable range, (i.e., $0 < \tau < \underset{\smile}{\tau}$) the market size will have a positive influence on the DDM strategy of e-commerce platforms. If the unit price of anti-counterfeit traceability services charged by the third-party BATP exceeds a certain range, it will make the e-commerce platform have no extra funds for DDM, and in such an unfavorable environment, the e-commerce platform will reduce its DDM strategy as the market scale expands. In the MO model, the commission rate will not affect the third-party BATP anti-counterfeit traceability strategy.

V. COMPARATIVE ANALYSIS

Based on the above model analysis, we compare the retail price, technology investment level, anti-counterfeit traceability service strategy, and DDM strategy of the products under the four different models.

Proposition 5: By comparing the optimal product retail prices in the four scenarios, we have

(1) When the e-commerce platform acts as a reseller, the relationship between the optimal retail price of the product is $p^{RO} > p^{RE}$.

(2) When the e-commerce platform acts as an agent, the relationship of the optimal retail price of the product is $p^{MO} = p^{ME}$.

(3) When the e-commerce platform builds its own BATP, the relationship of the optimal retail price of the product is $p^{RE} > p^{ME}$.

(4) When an e-commerce platform cooperates with a third-party BATP, the relationship between the optimal retail price of the product is $p^{RO} > p^{MO}$.

Proposition 5 shows that: (1) when an e-commerce platform acts as a reseller, the retail price depends on whether the e-commerce platform builds its own BATP or cooperates with a third-party BATP. Since the investment cost of self-built BATP is high and the cycle time is relatively long, the e-commerce platform can only choose to raise the retail price to make up for the capital gap, so the retail price of products when self-built BATP is higher than the retail price of products when cooperating with third-party BATP. (2) When the e-commerce platform acts as an agent, the supplier decides the retail price of the product and supplies it directly to the consumer, avoiding the double marginal effect, and the retail price will not be affected whether the e-commerce platform builds its own BATP or cooperates with a third-party BATP. (3) When the e-commerce platform builds its own BATP, the retail price in resale mode is higher than the retail price in agency mode. The reason is that the e-commerce platform has the power to control the price of the product when acting as a reseller, and will raise the retail price due to the existence

$$\max_{T(\cdot),p(\cdot)}\left\{J_S = \int_0^\infty e^{-rt}\begin{pmatrix}(1-\varepsilon)p\left[D_0-\lambda p(t)\right]\left[\mu Q(t)+\theta G(t)\right]\\ -\frac{1}{2}\phi k_A A^2(t)-\frac{1}{2}k_T T^2(t)\end{pmatrix}\mathrm{d}t\right\} \tag{45}$$

$$\max_{A(\cdot)}\left\{J_E = \int_0^\infty e^{-rt}\begin{bmatrix}\varepsilon p\left[D_0-\lambda p(t)\right]\left[\mu Q(t)+\theta G(t)\right]\\ -\tau\left[D_0-\lambda p(t)\right]\left[\mu Q(t)+\theta G(t)\right]\\ -\frac{1}{2}(1-\phi)k_A A^2(t)\end{bmatrix}\mathrm{d}t\right\} \tag{46}$$

$$\max_{I(\cdot)}\left\{J_O = \int_0^\infty e^{-rt}\left[\tau\left[D_0-\lambda p(t)\right]\left[\mu Q(t)+\theta G(t)\right]-\frac{1}{2}k_I I^2(t)\right]\mathrm{d}t\right\} \tag{47}$$

$$\text{s.t.}\begin{cases}\dot{Q}(t)=\sigma T(t)-\gamma Q(t), & Q(0)=Q_0\\ \dot{G}(t)=\alpha I(t)+\beta A(t)+\xi Q(t)-\delta G(t), & G(0)=G_0\end{cases} \tag{48}$$

of the double marginal effect and in order to ensure that more funds are available to support the BATP operation. (4) When the e-commerce platform cooperates with the third-party BATP, on the one hand, due to the existence of the double marginal effect, on the other hand, the e-commerce platform has to pay the unit price of anti-counterfeit traceability service to the third-party BATP, which costs money. Therefore, when the e-commerce platform has the pricing power, it will increase the product price accordingly.

Proposition 6: By comparing the optimal anti-counterfeiting traceability strategies in four scenarios, we have

(1) When the e-commerce platform acts as a reseller, the relationship of the optimal anti-counterfeit traceability strategy is $I^{RE} > I^{RO}$ if $D_0 - 2\lambda w - 2\lambda\tau > 0$, otherwise $I^{RE} < I^{RO}$.

(2) When the e-commerce platform acts as an agent, the relationship of the optimal anti-counterfeiting traceability strategy is $I^{ME} > I^{MO}$ if $0 < \tau < \frac{D_0\varepsilon}{2\lambda}$, otherwise, $I^{ME} < I^{MO}$.

(3) When the e-commerce platform builds its own BATP, the relationship of the optimal anti-counterfeiting traceability strategy is $I^{ME} > I^{RE}$ if $2D_0 - \lambda w > 0$, otherwise, $I^{ME} < I^{RE}$.

(4) When the e-commerce platform cooperates with the third-party BATP, the relationship of the optimal anti-counterfeit traceability strategy is $I^{MO} > I^{RO}$.

Proposition 6 shows that: (1) when the e-commerce platform acts as a reseller, the relationship between the optimal anti-counterfeit traceability service strategy under different scenarios depends on the interaction between wholesale price, unit price of service and market size, and when the three satisfy certain conditions ($D_0 - 2\lambda w - 2\lambda\tau > 0$), the e-commerce platform's self-built BATP will produce a higher level of anti-counterfeit traceability. (2) When the e-commerce platform acts as an agent, the relationship between the optimal anti-counterfeit traceability service strategy under different scenarios is highly correlated with the unit price of the service. When the unit price of the service is within a certain range, the e-commerce platform's self-built BATP will produce a higher level of anti-counterfeit traceability service. When the unit price of service is too high, the third-party BATP makes more profit and will produce a higher level of anti-counterfeit traceability service. (3) When the e-commerce platform builds its own BATP, the agency model will generate higher anti-counterfeit traceability service level when the wholesale price and market scale meet certain conditions. The reason is that the e-commerce platform charges a certain commission from suppliers under the agency model, which can have more sufficient capital flow to the operation of BATP. Otherwise, the resale sale generates a higher level of anti-counterfeit traceability service. (4) When the e-commerce platform cooperates with the third-party BATP, the anti-counterfeit traceability strategy under the MO model is higher than that under the RO model.

Proposition 7: By comparing the optimal DDM strategies for the four scenarios, we have

(1) When the e-commerce platform acts as a reseller, the relationship of the optimal DDM strategy is $A^{RE} > A^{RO}$ if $2D_0 - \lambda\tau - 2\lambda^2 > 0$, otherwise $A^{RE} < A^{RO}$.

(2) When the e-commerce platform acts as an agent, the relationship of the optimal DDM strategy is $A^{ME} > A^{MO}$.

(3) When the e-commerce platform builds its own BATP, the relationship of the optimal DDM strategy is $A^{RE} > A^{ME}$ if $\lambda w - 2D_0 > 0$, otherwise $A^{RE} < A^{ME}$.

(4) When the e-commerce platform cooperates with the third-party BATP, the relationship of the optimal DDM strategy is $A^{RO} > A^{MO}$ if $\lambda w - 2D_0 > 0$, otherwise $A^{RO} < A^{MO}$.

Proposition 7 shows that: (1) when the e-commerce platform acts as a reseller, the relationship of the optimal DDM strategy under different scenarios depends on the market size and the unit price of the third-party BATP anti-counterfeiting traceability service charge. (2) When the e-commerce platform acts as a reseller, the relationship of the size of the optimal DDM strategy under different scenarios is not affected by external factors, and the DDM strategy in the ME mode is higher than that in the MO mode, which is because when the e-commerce platform builds its own BATP, it does not need to pay external fees and has sufficient funds to run itself, and the DDM strategy is higher. (3) When the e-commerce platform builds its own BATP, the relationship between the size of the optimal DDM strategy under different scenarios depends on the influence of wholesale price and market size. (4) When the e-commerce platform cooperates with the third-party BATP, the relationship between the size of the optimal DDM strategy under different scenarios also depends on the influence of wholesale price and market size. Thus, it can be seen that the choice of sales model of e-commerce platform affects the operation strategy of enterprises, and external factors such as market scale, wholesale price and the unit price of anti-counterfeit traceability service of third-party BATP also affect the strategy. Therefore, from the supplier's point of view, it is important to set reasonable wholesale prices. From the perspective of a company's investment, it is vital for the company to keep an eye on the changes in market size and set reasonable rates.

Proposition 8: By comparing the optimal level of technology investment in the four scenarios, we have

(1) When the e-commerce platform acts as a reseller, the relationship of the optimal technology investment level is $T^{RE} > T^{RO}$.

(2) When the e-commerce platform acts as an agent, the relationship of the optimal technology investment level is $T^{ME} = T^{MO}$.

(3) When the e-commerce platform builds its own BATP, the relationship of the optimal technology investment level is $T^{ME} > T^{RE}$ if $(1 - \varepsilon)D_0^2 - 2w(D_0 - \lambda w) > 0$, otherwise $T^{ME} > T^{RE}$.

(4) When the e-commerce platform cooperates with the third-party BATP, the relationship of the optimal DDM strategy is $T^{MO} > T^{RO}$ if $(1-\varepsilon)D_0^2 - 2\lambda w\,(D_0 - \lambda(w+\tau)) > 0$, otherwise $T^{MO} > T^{RO}$.

Proposition 8 shows that: (1) the level of technology investment of suppliers under the RE model is higher when the e-commerce platform acts as a reseller, because the pricing power and anti-counterfeit traceability service strategy are jointly controlled by the e-commerce platform under the RE model compared to the RO model, leading to less double marginalization effect. (2) When the e-commerce platform acts as an agent, the technology investment level of suppliers under ME model is the same as that under MO model. (3) When the e-commerce platform builds its own BATP, the relationship between the optimal technology investment level of suppliers is influenced by external factors such as commission rate, market size and wholesale price. (4) When the e-commerce platform cooperates with the third-party BATP, the relationship of the optimal technical investment level of suppliers is influenced by multiple factors such as commission rate, market scale, wholesale price, and the unit price of anti-counterfeit traceability service charged by the third-party BATP.

VI. NUMERICAL ANALYSIS

Considering the complexity of the model, some comparative results are difficult to obtain. This section validates the previous findings through numerical analysis and further analyzes the impact of market size, wholesale price, and unit price of anti-counterfeit traceability services charged by third-party BATPs on the strategy. Then, we also explore the impact of key parameters on channel members' profits. According to the assumptions of the literature [54], [55] and the actual situation, the parameters are set as follows:

$$r = 0.1,\ \sigma = 1,\ \alpha = 1,\ \beta = 1,\ \gamma = 0.5,\ \delta = 0.6,\ \lambda = 1,\ \mu = 1,\ \theta = 1,\ \xi = 1,\ D_0 = 10,\ k_T = 2,\ k_I = 2,\ k_A = 2,\ \phi = 0.3$$

A. TYPES OF GRAPHICS EFFECT ANALYSIS OF THE DECISION MODE AND TIME

The initial innovation degrees $Q_0 = 0 < Q_\infty^i$ and $Q_0 = 80 > Q_\infty^i$, $G_0 = 0 < G_\infty^i$ and $G_0 = 200 > G_\infty^i$, respectively, where, $i \in \{RE, RO, ME, MO\}$, the sales channel operation time is set to $t \in [0, 15]$, and the wholesale price, commission rate, and unit price of anti-counterfeit traceability service charged by the third-party BATP are set within a reasonable range, $w = 2, \varepsilon = 0.5, \tau = 0.5$. The time evolution trajectories of innovation degree and brand goodwill under the four models are shown in Fig. 2 and Fig.3.

It can be observed from Fig. 2 that the initial value of innovation does not affect the final steady-state results, and the system has a steady-state equilibrium in all four modes; moreover, when the initial innovation degree is the same, the time trajectory of innovation degree in all three modes is always $Q_\infty^{ME} = Q_\infty^{MO} > Q_\infty^{RE} > Q_\infty^{RO}$. This indicates that

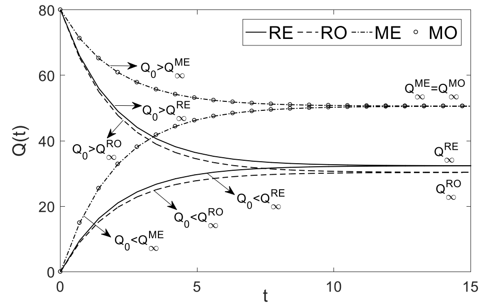


FIGURE 2. Time trajectories of innovation degree.

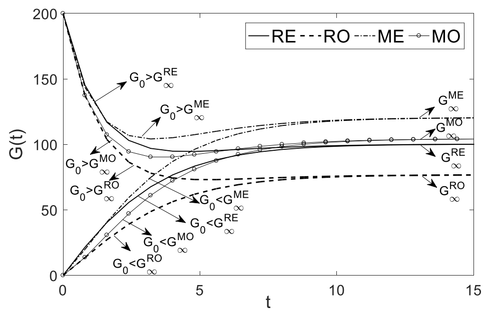


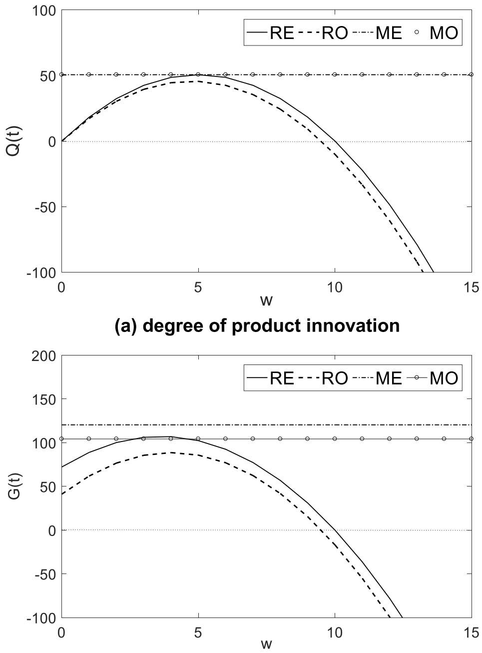
FIGURE 3. Time trajectories of brand goodwill.

the sales mode of the e-commerce platform affects the degree of product innovation, and the choice of agency mode is more favorable to product innovation. As can be observed from Fig. 3, initial brand goodwill does not affect the final steady-state results, and this scale relationship is equally robust, and the time trajectory of brand goodwill is always $G_\infty^{ME} > G_\infty^{MO} > G_\infty^{RE} > G_\infty^{RO}$ for all four modes when the initial brand goodwill is the same. This indicates that the sales model and strategy choice of the e-commerce platform also affects brand goodwill, with the highest value of brand goodwill under the ME model. Since the size of the initial innovation value does not affect the relationship between the size of the innovation degree under the four modes, the initial innovation degree is set to $Q_0 = 0$ in the later paper, and similarly the initial brand goodwill is set to $G_0 = 0$.

B. IMPACT ANALYSIS OF KEY PARAMETERS ON PRODUCT INNOVATION, BRAND GOODWILL AND CORPORATE PROFIT

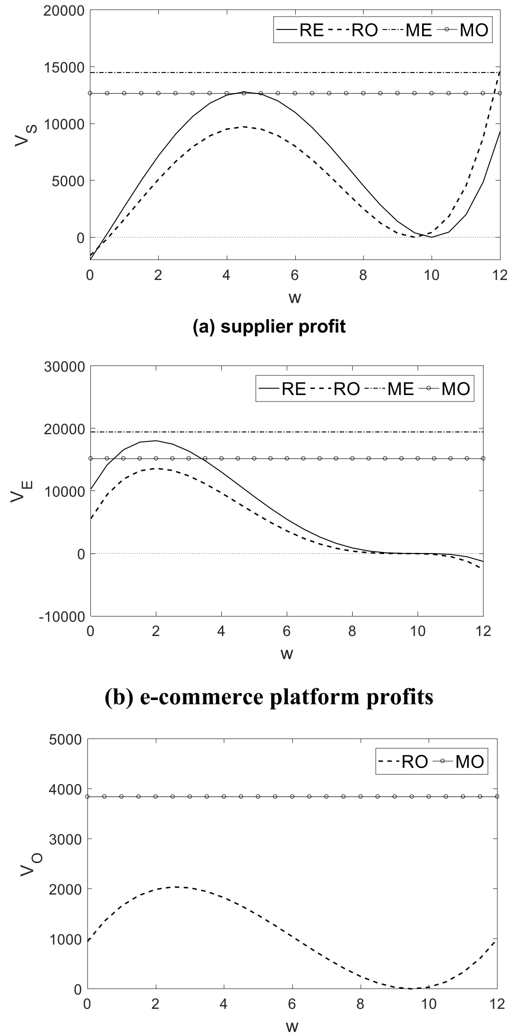
1) WHOLESALE PRICE

Fig. 4 shows that product innovation and brand goodwill show a trend of increasing and then decreasing in both RE and RO models. This indicates that reasonable wholesale prices play a positive role in improving product innovation and brand goodwill, while if the wholesale prices are too high, they can be detrimental to product innovation. Similarly, when the wholesale price is too high, the cost of ordering products on e-commerce platforms becomes higher, and their anti-counterfeit traceability service and DDM will be less



(a) degree of product innovation
(b) brand goodwill

FIGURE 4. The impact of wholesale price on product innovation and brand goodwill.



(a) supplier profit
(b) e-commerce platform profits
(c) third-party BATP profits

FIGURE 5. The impact of wholesale price on profit.

active at this time as the wholesale price increases, thus damaging brand goodwill as well.

Fig. 5(a) shows that when e-commerce platforms choose the resale model, charging wholesale prices becomes the main way for suppliers to benefit, and the increase in wholesale prices can improve suppliers' profits. However, if the wholesale price exceeds a certain range, resulting in low product innovation and brand goodwill, it can lead to a large number of consumers lost, which leads to a decrease in supplier profits. It is worth noting that when the wholesale price is very high, the supplier's profit appears to recover because the higher wholesale price can compensate for the loss caused by lower product innovation and lower brand goodwill, so the profit appears to rebound.

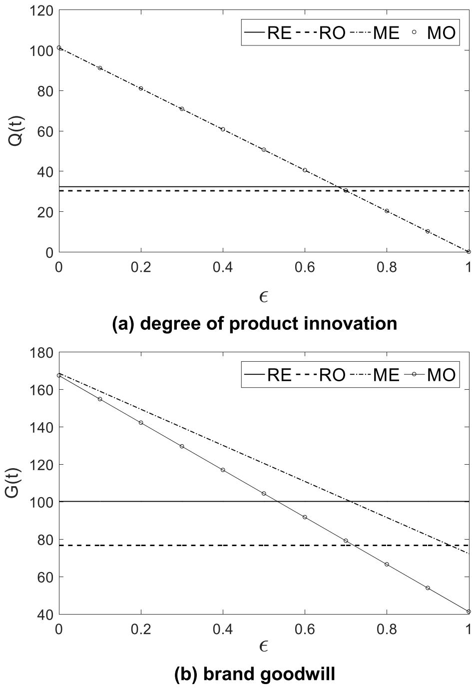
Fig. 5(b) shows that with this numerical arithmetic, the e-commerce platform chooses to act as a distributor and builds its own BATP, which is a better choice for itself. And when the e-commerce platform acts as a distributor, if the wholesale price is within a certain reasonable range, it can help the e-commerce platform achieve high profitability, but if the wholesale price keeps increasing, it will put a lot of cost pressure on the e-commerce platform, leading to a significant drop in its profit, or even difficult to maintain a break-even.

Fig. 5(c) shows that when the e-commerce platform acts as a reseller, for the third-party BATP, although it does not need to pay the supplier, the wholesale price set by the supplier still has an indirect impact on the third-party BATP. When the wholesale price is within a reasonable range, the profit of the third-party BATP gets increased, and the wholesale price is too high, which will cause damage to the third-party BATP getting profit.

2) COMMISSION RATE

Fig. 6 shows that in the resale model, product innovation and brand goodwill are independent of the commission rate. In contrast, in the agency sales model, the supplier pays a certain percentage of commission to the e-commerce platform. The higher the commission rate, the smaller the share of profit the supplier receives and the less motivated he is to invest in product technology, leading to lower product innovation, which indirectly damages brand goodwill.

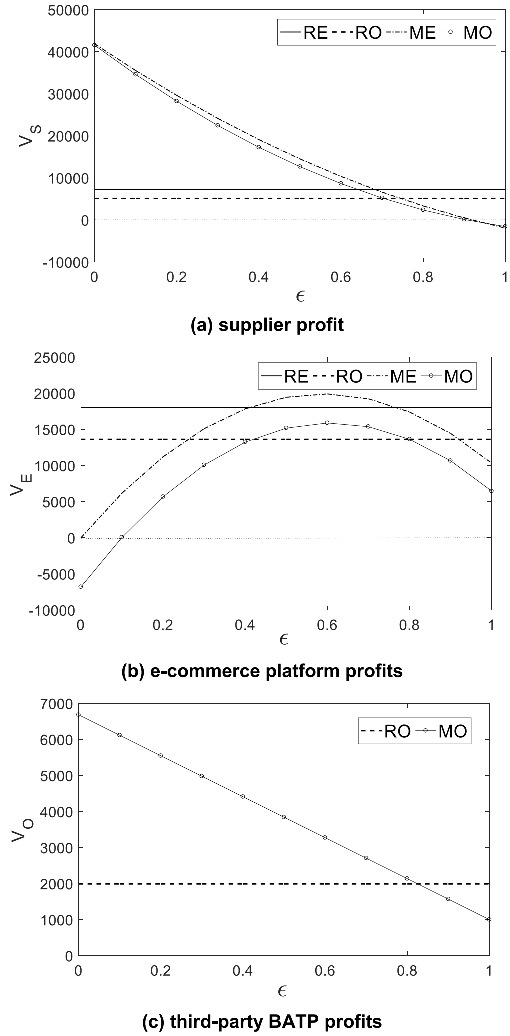
Fig. 7(a) shows that as the commission rate increases, the supplier's profit gradually decreases and is even lower than the profit level under the resale model. The reason for this is that, on the one hand, the commission rate increases and the supplier's cost expenses increase. On the other hand, with the increase in commission rate, suppliers lose their incentive to invest in product technology, which leads to a decrease in product innovation and brand goodwill, a decrease in consumer demand, and thus a decrease in profits.



(a) degree of product innovation

(b) brand goodwill

FIGURE 6. The impact of commission rate on product innovation and brand goodwill.



(a) supplier profit

(b) e-commerce platform profits

(c) third-party BATP profits

FIGURE 7. Impact of commission rate on profit.

Fig. 7(b) shows that: the fee rate of e-commerce platform directly determines the size of its own profit. With the increasing commission rate, the profit of e-commerce platform in agency mode will increase significantly, and may even exceed the profit level in resale mode. However, the e-commerce platform should not blindly increase the commission rate in order to obtain high profits. Excessive commission rate will not only lead to the loss of suppliers, but also cause the decrease of product innovation and brand goodwill, and the decrease of market sales, resulting in the decrease of profits of the e-commerce platform, which is not conducive to the market environment and the sustainable development of the e-commerce platform. In a market environment with unstable commission rates, e-commerce platforms pursuing stable revenue will tend to choose the resale model, while e-commerce platforms pursuing high risk, but high revenue will prefer the agency sales model.

Fig. 7(c) shows that the commission rate not only changes the revenue distribution of the parties involved, but also has an indirect effect on the third-party BATP. The profit of the third-party BATP decreases with the increase of commission rate in MO model, which is due to the decrease of sales volume caused by high commission rate and also indirectly affects the profit of the third-party BATP.

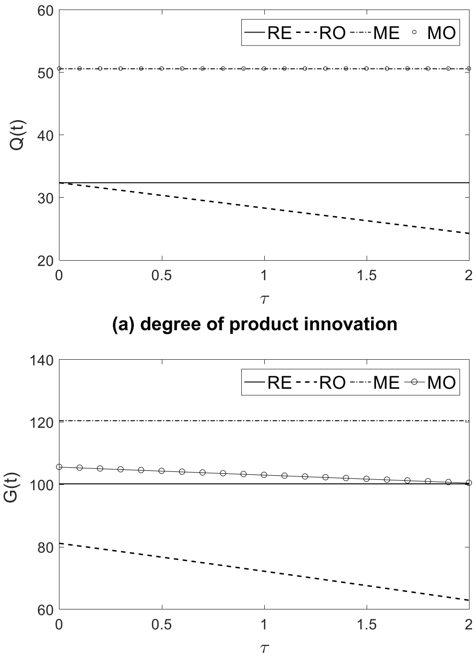
3) UNIT PRICE OF ANTI-COUNTERFEIT TRACEABILITY SERVICES CHARGED BY THIRD-PARTY BATP

Fig. 8(a) shows that the unit price of anti-counterfeit traceability services charged by the third-party BATP under the RO model has a negative impact on the degree of product innovation. The higher the unit price of anti-counterfeit traceability services charged by the third-party BATP, the greater the cost pressure on the e-commerce platform, which will increase the retail price of the product and damage the product sales, which also leads to a lower motivation of suppliers to invest in technology and is not conducive to product innovation.

Fig. 8(b) shows that when an e-commerce platform chooses to cooperate with a third-party BATP, the unit price of anti-counterfeit traceability charged by the third-party BATP will have a negative impact on the brand goodwill regardless of whether it chooses to resell or resell, and the negative impact is even greater in the RO model.

Fig. 9(a) shows that when e-commerce platforms cooperate with the third-party BATP, the supplier's profit is affected by the unit price of anti-counterfeit traceability service charged by the third-party BATP, and the profit is slightly affected in the MO mode and more affected in the RO mode.

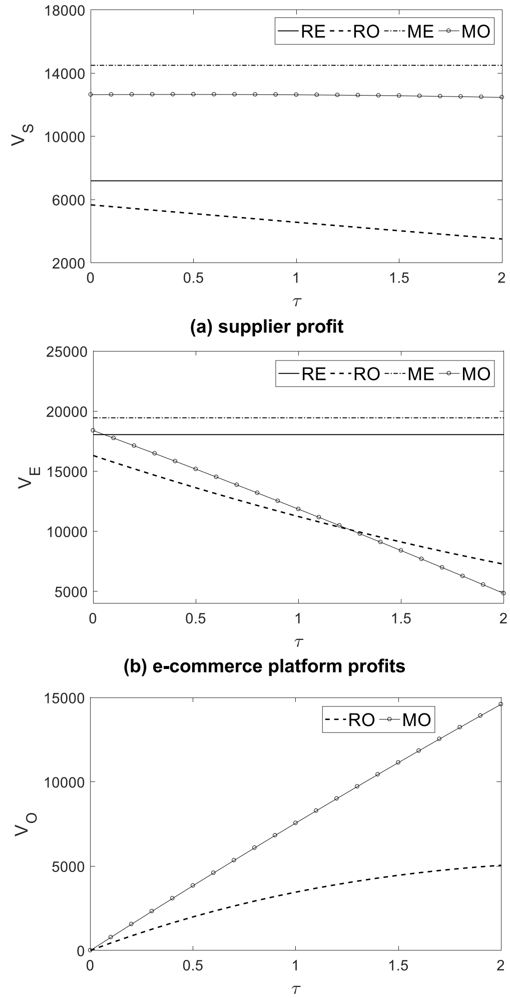
Fig. 9(b) shows that when an e-commerce platform cooperates with a third-party BATP, the fee rate of the third-party BATP will directly determine the size of the e-commerce platform's profit, thus affecting the choice of the e-commerce



(a) degree of product innovation

(b) brand goodwill

FIGURE 8. The impact of unit price of anti-counterfeit traceability service charged by third-party BATP on product innovation degree and brand goodwill.



(a) supplier profit

(b) e-commerce platform profits

(c) third-party BATP profits

FIGURE 9. Impact of unit price of anti-counterfeit traceability service charged by third-party BATP on profit.

platform's sales model. With the increasing fees of third-party BATPs, the profits of e-commerce platforms are significantly reduced. Therefore, under the conditions of fixed market size, wholesale price and commission rate, many e-commerce platforms prefer to build their own BATP platforms.

Fig. 9(c) shows that the unit price of anti-counterfeit traceability service charged by the third-party BATP will determine the size of its own profit, and its own profit will increase with the increase of the fee rate, which is less affected in the RO mode and more affected in the MO mode.

C. THE INTERACTION OF KEY PARAMETERS ON SUPPLIER PROFITABILITY

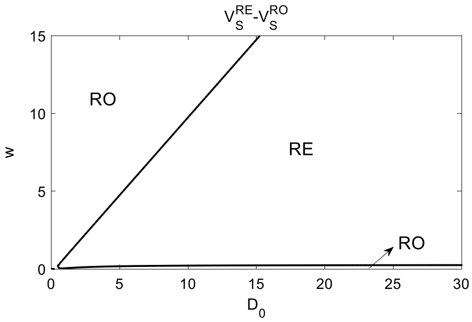
1) THE INTERACTION OF THE WHOLESALE PRICE AND MARKET SIZE

Fig. 10(a) shows that when the market size remains at or below the medium level, the scenario in which suppliers achieve higher profits with higher wholesale prices is RE→RO. When the market size is moderate and above, suppliers achieve higher profits in the RE model. Fig. 10(b) shows that suppliers achieve higher profits in the ME model. Fig. 10(c) shows that the scenario in which suppliers achieve higher profits with higher wholesale prices when the market size is maintained at or below the medium level is ME→RE. When the market size is maintained at a medium level and above, suppliers achieve higher profits in the ME model. Figure 10(d) shows that when the market size is maintained at medium level and below, the scenario in which suppliers achieve higher profits as the wholesale price increases is MO→RO. When the market size is maintained at the medium level and above, suppliers achieve higher profits in the MO model.

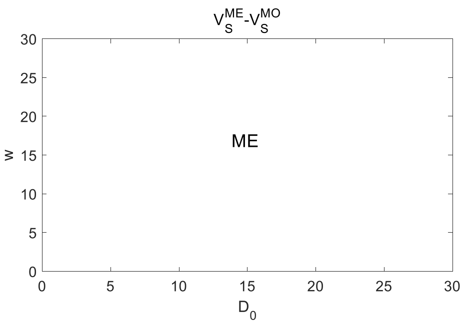
In summary, when the market size is maintained at a medium level and below, the scenario of higher profitability for suppliers with higher wholesale prices would be, when the market size is maintained at a medium level and above, suppliers achieve higher profitability in the ME model.

2) THE INTERACTION OF MARKET SIZE AND UNIT PRICE OF ANTI-COUNTERFEIT TRACEABILITY SERVICES CHARGED BY THE THIRD-PARTY BATP

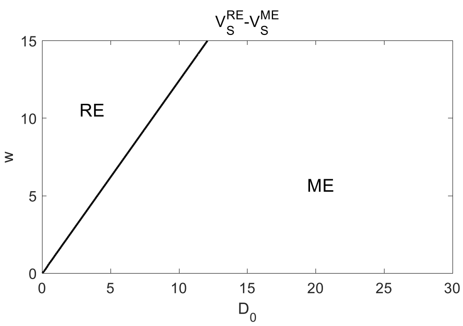
Comprehensive Fig. 11(a)-(b): 1) When the market size is small and the unit price of anti-counterfeit traceability service charged by the third-party BATP is high, it is the wisest choice for the e-commerce platform to build its own BATP; this is also beneficial to the suppliers, otherwise the e-commerce platform faces the risk of losing profits due to the high unit price of anti-counterfeit traceability service, which may



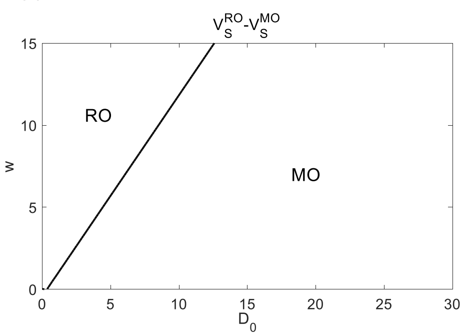
(a) the e-commerce platform acts as a reseller



(b) the e-commerce platform acts as an agent

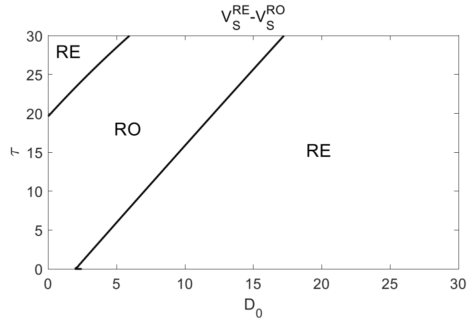


(c) the e-commerce platform builds its own BATP

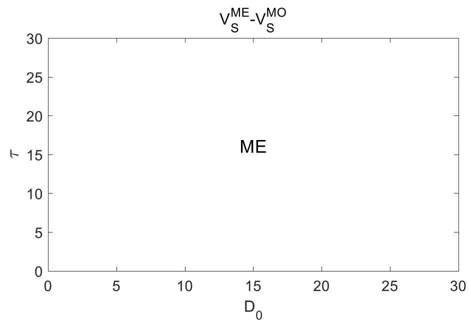


(d) the e-commerce platform cooperates with a third-party BATP

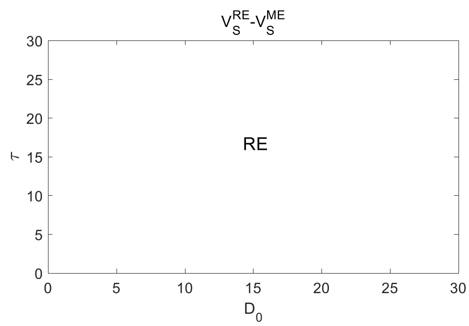
FIGURE 10. The interaction of the wholesale price and market size.



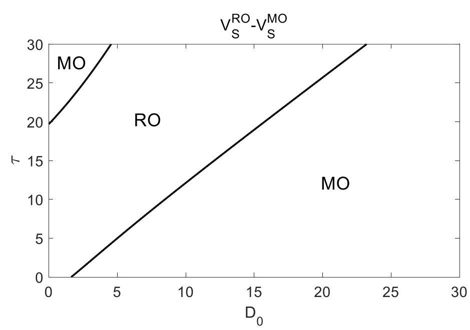
(a) the e-commerce platform acts as a reseller



(b) the e-commerce platform acts as an agent



(c) the e-commerce platform builds its own BATP

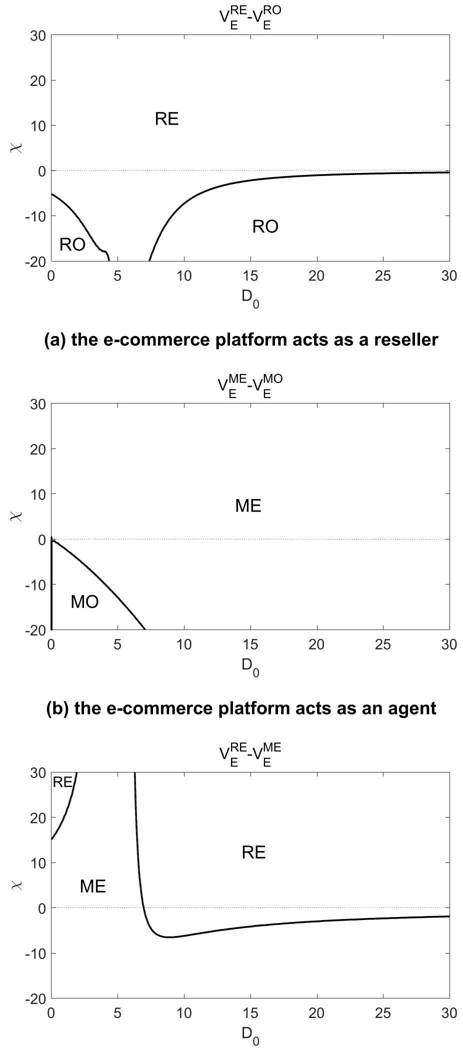


(d) the e-commerce platform cooperates with a third-party BATP

FIGURE 11. The interaction of market size and unit price of anti-counterfeit traceability services charged by the third-party BATP.

increase the retail price of the products and damage the market demand, thus it will indirectly affect suppliers' profits. Therefore, suppliers make more profit in the RE mode. 2) When the market size is at the lower middle level and the unit price of service is high, suppliers make more profit in the RO mode. 3) When the market size is at a high level, suppliers make more profit in the RE mode because the larger market size can compensate for the negative impact of the high unit price of anti-counterfeit traceability service.

In summary, as the market size increases and the unit price of services decreases, the scenarios in which suppliers can achieve higher profits are RE→RO→RE.



(a) the e-commerce platform acts as a reseller

(b) the e-commerce platform acts as an agent

(c) the e-commerce platform builds its own BATP

FIGURE 12. The interaction of market size and anti-counterfeit traceability cost effectiveness.

D. THE INTERACTION OF KEY PARAMETERS ON SUPPLIER PROFITABILITY THE INTERACTION OF KEY PARAMETERS ON THE PROFITABILITY OF e-commerce PLATFORMS

In this section, we examine the preferences of e-commerce platforms and analyze four scenarios by considering the strategic interaction between sales model and strategy choice. We consider the impact of two main factors on the model choice and strategy choice of e-commerce platforms - market size and cost effectiveness of anti-counterfeit traceability services (i.e. $\chi = \alpha^2/k$).[3]

1) THE INTERACTION OF MARKET SIZE AND ANTI-COUNTERFEIT TRACEABILITY COST EFFECTIVENESS

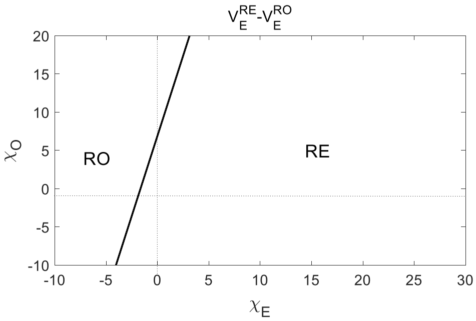
Fig. 12 shows that: 1) the area below the dotted line indicates a scenario with negative value for money, a situation that is not conducive to sustainable market development and will be eliminated from the market, so we only analyze the area above the dotted line. 2) Under the resale model, e-commerce platforms will realize higher profits under the RE model. The rationale depends on the fact that compared to the RO model, the e-commerce platform under the RE model has both pricing power and the right to develop anti-counterfeit traceability strategies, with less double marginalization effect, thus promoting higher profits. In contrast, under the agency model, e-commerce platforms earn higher profits under the ME model. This shows that self-built BATP is a better choice for e-commerce platforms. 3) Further, we observe in Fig. 12(c) that when e-commerce platforms build their own BATP, the best choice for e-commerce platforms is resale→agent sales as the market size increases and the cost effectiveness decreases, and when the market size is at the medium and above level, the best choice for e-commerce platforms becomes resale. As the market scale and the cost performance of anti-counterfeit traceability service gradually increase, the e-commerce platform will have obvious profit advantage in RE mode.

2) THE INTERACTION BETWEEN THE COST PERFORMANCE OF ANTI-COUNTERFEIT TRACEABILITY SERVICE OF E-COMMERCE PLATFORM AND THE COST PERFORMANCE OF THIRD-PARTY BATP ANTI-COUNTERFEIT TRACEABILITY SERVICE

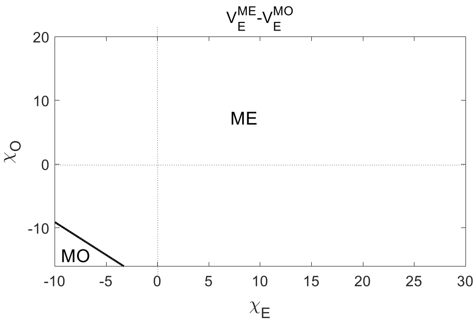
In the core model, we assume that the cost of anti-counterfeit traceability services for e-commerce platforms and third-party BATP anti-counterfeit traceability services are the same. However, according to the industry practice, the anti-counterfeit traceability services provided by different platforms may differ due to different technical levels and operational capabilities. To incorporate this situation, in this subsection we extend the model to consider the impact of different anti-counterfeit traceability service costs on the choice of e-commerce platforms. Specifically, we define $\chi_E = \alpha^2/k_E$ and $\chi_O = \alpha^2/k_O$ to represent the cost effectiveness of anti-counterfeit traceability services for e-commerce platforms and third-party BATPs, respectively.

Observing Fig. 13, when the cost performance ratio is negative, it will eventually be eliminated from the market, so we only focus on the upper right area of the dotted line. Fig. 13 shows that: on the basis of the e-commerce platform acting as a distributor, when the third-party BATP is more advantageous than the e-commerce platform in terms of cost performance of anti-counterfeiting traceability services, the e-commerce platform earns higher profits in the RO model. When the price of anti-counterfeit traceability service of the e-commerce platform is more advantageous, the e-commerce platform will choose to build its own BATP. On the basis of the e-commerce platform acting as an agent, the e-commerce platform earns higher profits under the model. On the basis of the e-commerce platform's self-built BATP, the e-commerce platform prefers to choose the resale sales model. The reason is that in the ME scenario, the e-commerce platform cedes

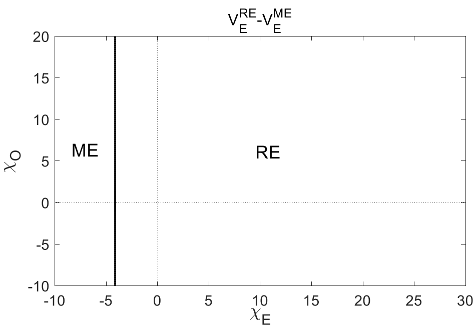
[3]The symbol χ indicates the efficiency of investment in anti-counterfeit traceability services, and a larger indicates that each unit of investment in anti-counterfeit traceability services boosts higher goodwill, which leads to more demand.



(a) the e-commerce platform acts as a reseller



(b) the e-commerce platform acts as an agent



(c) the e-commerce platform builds its own BATP

FIGURE 13. The interaction between the cost performance of anti-counterfeit traceability service of e-commerce platform and the cost performance of third-party BATP anti-counterfeit traceability service.

the channel right to the supplier and can only passively bear the market result. However, in the RE scenario, the platform can seize more channel power (i.e. pricing power). Intuitively, companies with a greater advantage in cost performance of anti-counterfeit traceability services have an incentive to provide a higher level of anti-counterfeit traceability services. Therefore, when the third-party BATP platform has a significant advantage in the cost performance of anti-counterfeit traceability services, the e-commerce platform will prefer the third-party BATP platform to undertake anti-counterfeit traceability services; otherwise, the e-commerce platform will prefer to provide anti-counterfeit traceability services itself. The underlying principle lies in the fact that companies with higher cost performance of anti-counterfeit traceability services have an incentive to provide higher service levels of anti-counterfeit traceability services and thus gain higher profits.

VII. DISCUSSION AND RESULTS

A. DISCUSSION

This paper considers a distribution channel consisting of suppliers, e-commerce platforms and continuous consumers, and solves the optimal strategy of members, product innovation, brand goodwill and corporate profit under four models with the help of Bellman's continuous dynamic programming theory, and analyzes them. Through comparative analysis, the magnitude of strategies under different models is studied. And the influence of key parameters on strategy and profit is further investigated by numerical arithmetic examples, and the influence of the interaction between sales model and strategy selection on profit is discussed. The following discussion are obtained:

In previous related studies, Qin *et al.* [10] considered the optimal combination of platform sales model selection and logistics service strategy, focusing on the impact of cost-effectiveness of logistics service on the equilibrium scenario. However, in real life, some force majeure factors can have an important impact on firms' strategies. Therefore, unlike the study by Qin *et al.* [10] we also examined the impact of important factors such as market size, wholesale price, and unit price of anti-counterfeit traceability services charged by third-party BATPs on each strategy. We find that market size promotes higher retail prices for products and increases the incentive for suppliers to invest in technology. Interestingly, the impact of market size, wholesale price, and unit price of anti-counterfeit traceability services charged by third-party BATPs on anti-counterfeit traceability strategy and DDM strategy under different models is determined by different conditions. In the RE model, the effects of market size and wholesale price on anti-counterfeit traceability service strategy and DDM strategy of e-commerce platform depend on their interactions. In the RO model, market size will always incentivize the third-party BATP to improve the anti-counterfeit traceability service strategy, and the wholesale price will inhibit this strategy. the influence of market size and wholesale price on the DDM strategy of e-commerce platform depends on the unit price of anti-counterfeit traceability service of the third-party BATP. In the ME model, market size will promote the anti-counterfeit traceability service strategy and DDM strategy of e-commerce platform, and promote higher brand goodwill. The increase in commission rate will weaken suppliers' technology investment level, which is detrimental to product innovation degree, but will prompt e-commerce platforms to improve anti-counterfeit traceability service strategy and DDM strategy to reduce the negative impact of impaired product innovation degree on demand. In the MO model, market size and the unit price of anti-counterfeit traceability service charged by third-party BATPs consistently motivate third-party BATPs to improve anti-counterfeit traceability service strategy, and market size has an The impact of market size on DDM strategy of e-commerce platforms depends on the pricing of anti-counterfeit traceability services of third-party BATPs.

Second, Qin *et al.* [10] show that the "reseller-supplier" scenario generates lower sales prices when the logistics service is more cost-effective, and the "market-supplier" scenario generates lower sales prices when the logistics service is less cost-effective. In contrast to the results of Qin *et al.* [10], we find that the retail price of the product in the resale model is higher than that in the agency model due to the double marginal effect, and the RO model generates a higher retail price by comparing the retail price of the product in the four models. The retail prices of the products in ME and MO models are the same and the lowest.

Third, unlike previous studies, in this paper we analyze the effects of key factors on product innovation, brand goodwill, and firm profits from a dynamic perspective. In the resale model, an appropriate range of wholesale prices can lead to higher product innovation, brand goodwill, and profits of each firm, but too high wholesale prices can weaken product innovation, brand goodwill, and profits of each firm, which is not conducive to the sustainable development of the market. The increase of commission rate under agency model will damage the product innovation degree and brand goodwill, and lead to lower profits of suppliers and third-party BATPs. A reasonable commission rate will enhance the profit of the e-commerce platform, but if the commission rate is too high, it will damage the profit of the e-commerce platform. The unit price of anti-counterfeit traceability service set by the third-party BATP can improve its own profit, but otherwise, it will be detrimental to the degree of product innovation, brand goodwill, and the profit of suppliers and e-commerce platforms.

B. RESULTS

Based on the above analysis and conclusions, we draw the following management comments. First, the market size will promote the retail price of products and increase the motivation of suppliers to invest in technology. The impact of market size on anti-counterfeit traceability service strategy and DDM strategy under different models is determined by different conditions. Second, by comparing the retail prices of the products under the four models, it is found that the highest retail prices of the products under the RO model. By comparing the anti-counterfeit traceability service strategies under the four models, it was found that the results depend on the interaction between the wholesale price, the unit price of anti-counterfeit traceability service charged by the third-party BATP, and the market size. In addition, we found that suppliers' profitability under different models can be constrained by multiple factors. On the one hand, the interaction of market size and wholesale price, when the market size is maintained at a medium level or below, with the increase in wholesale price, the situation where suppliers can achieve higher profits will evolve from ME to RO. Higher profits are realized in the ME model when the market size is above the medium level. On the other hand, the interaction of market size and the unit price of anti-counterfeit traceability services of third-party BATPs, as the market size increases, the unit price of services decreases, and the scenarios in which suppliers can achieve higher profits are RE→RO→RE. Finally, we test the four models by considering the strategic interaction of sales model and strategy choice of e-commerce platforms. Self-built BATP is found to be a better choice for e-commerce platforms, and the outcome of the choice of sales model depends on the interaction between market size and cost effectiveness of anti-counterfeit traceability services. When the market size is at a below-medium level, the best choice for e-commerce platforms as the market size increases and the cost performance decreases is resale→agent sale. When the market size is at a medium and above level, the best choice for e-commerce platforms becomes resale. In addition, we extend the model that the cost performance of anti-counterfeit traceability services of e-commerce platform and third-party BATP are different. Only when the cost performance of anti-counterfeit traceability services of e-commerce platform is very low and the cost performance of anti-counterfeit traceability services of third-party BATP is very high, the e-commerce platform prefers the RO model, otherwise, it will prefer the RE model.

This paper also has the limitation of not including wholesale price as a decision variable for suppliers. Also, future research can consider consumer surplus and social welfare based on our model and analyze which case generates higher consumer surplus and social welfare.

APPENDIX

According to the Bellman continuum dynamic planning theory, the HJB (Hamilton-Jacobi-Bellman) equation for suppliers, e-commerce platforms are

$$rV_S^{RE} = \max_{T^{RE}} \left\{ \begin{array}{l} w(D_0 - \lambda p^{RE})(\mu Q^{RE} + \theta G^{RE}) - \frac{k_A \phi}{2}(A^{RE})^2 \\ - \frac{1}{2}k_T(T^{RE})^2 + \frac{\partial V_S^{RE}}{\partial Q^{RE}}\left(\sigma T^{RE} - \gamma Q^{RE}\right) \\ + \frac{\partial V_S^{RE}}{\partial G^{RE}}\left(\alpha I^{RE} + \beta A^{RE} + \xi Q^{RE} - \delta G^{RE}\right) \end{array} \right\} \tag{A-1}$$

$$rV_E^{RE} = \max_{p^{RE}, I^{RE}, A^{RE}} \left\{ \begin{array}{l} (p^{RE} - w)(D_0 - \lambda p^{RE})(\mu Q^{RE} + \theta G^{RE}) \\ - \frac{k_A(1-\phi)}{2}(A^{RE})^2 - \frac{1}{2}k_I(I^{RE})^2 \\ + \frac{\partial V_E^{RE}}{\partial Q^{RE}}\left(\sigma T^{RE} - \gamma Q^{RE}\right) \\ + \frac{\partial V_E^{RE}}{\partial G^{RE}}\left(\alpha I^{RE} + \beta A^{RE} + \xi Q^{RE} - \delta G^{RE}\right) \end{array} \right\} \tag{A-2}$$

where, V_S^{RE} and V_E^{RE} are the optimal value functions of the supplier and the e-commerce platform in the RE model.

According to the first-order optimality conditions on the right-hand side of equations (A-1) and (A-2), we can obtain

$$T^{RE} = \frac{\sigma}{k_T}\frac{\partial V_S^{RE}}{Q^{RE}}, \quad p^{RE} = \frac{D_0 + \lambda w}{2\lambda},$$
$$I^{RE} = \frac{\alpha}{k_I}\frac{\partial V_E^{RE}}{G^{RE}}, \quad A^{RE} = \frac{\beta}{k_A(1-\phi)}\frac{\partial V_E^{RE}}{G^{RE}} \tag{A-3}$$

Substituting (A-2) into (A-1) and (A-2), we can get

$$rV_S^{RE} = \left\{ \begin{array}{l} \left[\frac{w(D_0-\lambda w)}{2}\mu - \gamma\frac{\partial V_S^{RE}}{\partial Q^{RE}} + \xi\frac{\partial V_S^{RE}}{\partial G^{RE}}\right] Q^{RE} \\ + \left[\frac{w(D_0-\lambda w)}{2}\theta - \delta\frac{\partial V_S^{RE}}{\partial G^{RE}}\right] G^{RE} \\ + \frac{(\sigma\frac{\partial V_S^{RE}}{\partial Q^{RE}})^2}{2k_T} + \frac{\alpha^2\frac{\partial V_S^{RE}}{\partial G^{RE}}\frac{\partial V_E^{RE}}{\partial G^{RE}}}{k_I} \\ + \frac{\beta^2\frac{\partial V_E^{RE}}{\partial G^{RE}}\left[2(1-\phi)\frac{\partial V_S^{RE}}{\partial G^{RE}} - \phi\frac{\partial V_E^{RE}}{\partial G^{RE}}\right]}{2k_A(1-\phi)^2} \end{array} \right\} \tag{A-4}$$

$$rV_E^{RE} = \left\{ \begin{array}{l} \left[\frac{(D_0-\lambda w)^2\mu}{4\lambda} - \gamma\frac{\partial V_E^{RE}}{\partial Q^{RE}} + \xi\frac{\partial V_E^{RE}}{\partial G^{RE}}\right] Q^{RE} \\ + \left[\frac{(D_0-\lambda w)^2\theta}{4\lambda} - \delta\frac{\partial V_E^{RE}}{\partial G^{RE}}\right] G^{RE} \\ + \frac{\sigma^2\frac{\partial V_E^{RE}}{\partial Q^{RE}}\frac{\partial V_S^{RE}}{\partial Q^{RE}}}{k_T} + \frac{(\alpha\frac{\partial V_E^{RE}}{\partial G^{RE}})^2}{2k_I} + \frac{2(\beta\frac{\partial V_E^{RE}}{\partial G^{RE}})^2}{2k_A(1-\phi)} \end{array} \right\} \tag{A-5}$$

According to the structure of (A-4) and (A-5), the optimal value function of the supplier and the e-commerce platform can be assumed to be $V_S^{RE} = f_1^{RE}Q^{RE} + f_2^{RE}G^{RE} + f_3^{RE}$, $V_E = g_1^{RE}Q^{RE} + g_2^{RE}G^{RE} + g_3^{RE}$, where, $f_1^{RE}, f_2^{RE}, f_3^{RE}, g_1^{RE}, g_2^{RE}, g_3^{RE}$ are undetermined parameters. Substituting V_S^{RE}, V_E^{RE} and its derivative into (A-3) and (A-4), and the pending coefficients can be obtained according to the constant relationship:

$$f_1^{RE} = \frac{2w(D_0-\lambda w)\left[\mu(r+\delta)+\xi\theta\right]}{4(r+\gamma)(r+\delta)},$$
$$f_2^{RE} = \frac{w(D_0-\lambda w)\theta}{2(r+\delta)},$$
$$f_3^{RE} = \frac{1}{r}\left[\frac{(\sigma f_1^{RE})^2}{2k_T} + \frac{\alpha^2 f_2^{RE} g_2^{RE}}{k_I} + \frac{\beta^2 g_2^{RE}\left[2(1-\phi)f_2^{RE} - \phi g_2^{RE}\right]}{2k_A(1-\phi)^2}\right]$$
$$g_1^{RE} = \frac{(D_0-\lambda w)^2\left[\mu(r+\delta)+\xi\theta\right]}{4\lambda(r+\delta)(r+\gamma)}, \quad g_2^{RE} = \frac{\theta(D_0-\lambda w)^2}{4\lambda(r+\delta)},$$
$$g_3^{RE} = \frac{1}{r}\left[\frac{\sigma^2 g_1^{RE} f_1^{RE}}{k_T} + \frac{(\alpha g_2^{RE})^2}{2k_I} + \frac{(\beta g_2^{RE})^2}{2k_A(1-\phi)}\right] \tag{A-6}$$

Substituting (A-6) into (A-3) and the optimal value function, we can obtain the optimal strategy and profit function for the members in the RE model.

The proof of Proposition 2/3/4 is similar to Proposition 1, so we do not repeat it here.

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