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# Decisions of Knowledge Payment Product Supply Chain Considering Government Subsidies and Anti-Piracy Efforts: Based on China's Knowledge Payment Market

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**Abstract:** Knowledge payment is an emerging business mode that has developed in the era of social media. With the impact of Internet technology, the knowledge payment market is rapidly expanding, especially in China. However, piracy leads to more intense competition and affects the profits of knowledge providers and knowledge payment platforms. Government policies combined with the anti-piracy measures of these platforms have become effective methods to combat piracy. This paper investigates the impact of government subsidies and anti-piracy efforts on a knowledge provider's and platform's optimal decisions. We develop a two-stage knowledge payment product supply chain with a knowledge provider and a knowledge payment platform. The platform in the leader position of the supply chain has anti-piracy efforts and the government subsidizes the platform. Stackelberg game models are constructed and compared to examine the equilibrium solution in relation to three modes (no government subsidies and no anti-piracy efforts; only anti-piracy efforts; and both government subsidies and anti-piracy efforts). Our analysis shows that (1) both government subsidies and anti-piracy efforts increase the quality level and unit quality signing bonus of the knowledge payment product. Meanwhile, the product's retail price increases with anti-piracy efforts but decreases within a certain subsidy range. (2) The knowledge provider's profit always increases with the anti-piracy effort level, while the platform's profit is an inverted U-shaped relationship with the anti-piracy effort level. (3) Government subsidy behavior can always increase a knowledge provider's profit but may not necessarily increase the platform's profit. Moreover, there exists a certain threshold: when subsidies are lower (higher) than this threshold, it is more beneficial to the knowledge provider (platform). In addition, we also find that the method of high subsidies combined with a low anti-piracy effort level benefits both parties and that the subsidized party will be more sensitive. The results will provide knowledge providers and platforms with new market management insights from the perspective of government subsidies and anti-piracy efforts and guide them to make optimal decisions.

**Keywords:** government subsidies; anti-piracy efforts; knowledge payment; supply chain decisions

## 1. Introduction

### 1.1. Research Background

Online knowledge payment is a form of knowledge service in which consumers pay for a certain purpose. It combines Internet technology with traditional knowledge payment methods so that consumers can obtain high-quality knowledge content more conveniently and meet the needs of people to acquire knowledge in fragmented time [1]. Under the influence of the global shift toward a knowledge-sharing economy and the growing demand for knowledge products and services [2], it has developed rapidly as an effective method of knowledge sharing [3]. In particular, during the COVID-19 epidemic prevention and control period, the offline real economy suffered a huge impact, while the knowledge payment industry ushered in a new development opportunity [4]. The

development trend of this industry in China is particularly remarkable [5]. According to the "Report on the Current Situation and Development Prospect of China's Knowledge Payment Industry in 2023" announced by iiMedia Research, China's knowledge payment market size has reached 112.65 billion RMB in 2022 and is expected to reach 280.88 billion RMB in 2025. However, behind this booming development, there are still some problems in the knowledge payment industry, such as, in the practice of knowledge payments, the pirated knowledge made by methods of transcription, and that imitation and plagiarism are spread wantonly, which seriously hinders the stability and long-term development of the knowledge payment market. Piracy is the illegal act of copying and distributing products without the authorization of the copyright owner. The piracy problem in knowledge payments is different from that in traditional information products [6]. More specifically, the latter is mainly driven by profits, such as the low-price sale of authorized CDs after transcription, and the former is mainly driven by actions that are not for profit, such as unauthorized reprinting and giving paid audio to relatives and friends. These piracy behaviors not only hurt the incentive for knowledge providers to develop innovative knowledge products, so that then consumers cannot obtain high-quality knowledge content, but also undermine the benign cooperative relationship between the knowledge provider and the platform [7]. There are three main reasons why the piracy problem in the knowledge payment industry is so serious. First, the fixed and marginal production costs of knowledge products are almost zero [8]. Meanwhile, the digitization of knowledge products reduces the cost of communication and the technical barriers to piracy behavior. Second, knowledge products have the characteristic of being public goods [9], which makes pirates think that their piracy behavior is justified. Third, knowledge payment products have the characteristic of being lossless, wherein they will not produce losses or depreciation due to the increase in usage time and usage count [10]. At the same time, consumers only need to buy a product once in the life cycle of knowledge payment products. The threat of piracy has led some knowledge providers to take a variety of initiatives to protect their intellectual property. As an important subject connecting the consumer market, knowledge payment platforms are most aware of consumers' product preferences and the piracy phenomenon in the market, and they have also made some efforts to combat piracy. For example, "Qianliao Live" has adopted video content encryption and secondary verification of off-site logins to combat pirates stealing video content. "Xiaoe-tech" has launched an anti-recording screen running light, graphic anti-copy plans and other functions.

Although the anti-piracy effort behavior of knowledge payment platforms can effectively combat piracy, the implementation of anti-piracy measures also means that the platforms need to invest higher costs. In order to maximize their own profits, the platforms have to increase the retail price of authorized knowledge products, which will also drive consumers to seek relatively cheap pirated products through other channels, and eventually lead to the phenomenon of "bad money drives out good" in the market. This phenomenon not only easily causes the failure of market order, but also affects government revenue. Therefore, governments have strengthened the crackdown on piracy, and increased the risk of engaging in piracy through some policies (such as piracy control laws, fines, etc.), which has had a significant effect on intellectual property protection [11]. On the other hand, anti-piracy is not only the demand for knowledge payment platforms to protect their own profits, but also the responsibility of governments; thus, coordination and cooperation between the platform and government are needed. Therefore, while combating piracy a government should also consider the high cost of anti-piracy tactics that knowledge payment platforms or enterprises, are faced with so as to better incentivize the anti-piracy behavior of platforms and promote the sale of authorized knowledge products. In this situation, the regulatory role of a government must be brought into play, and government subsidies are an important approach. For instance, Logicreation (i.e., the parent company of "DeDao") sells authorized knowledge payment products through low-price sales, carrying out preferential activities and other actions. From 2017 to 2019, it made an average annual

profit of more than 30 million RMB, of which government subsidies accounted for one-third of its total sale profits.

The above examples and some studies have indicated that government anti-piracy polices, especially the subsidy strategy and the anti-piracy effort behavior of knowledge payment platforms, are effective ways to combat piracy. In the knowledge payment market, high-quality knowledge products are the core competitiveness of knowledge payment platforms. Generally speaking, the knowledge provider controls the quality level of knowledge products and the knowledge payment platform needs to set prices for the products: there is a contractual relationship between them. When there is piracy in the market, the behavior of consumers using pirated knowledge products will affect the profits of the knowledge provider and platform. Therefore, considering their own costs and profits, the platform and knowledge provider are bound to respond when making pricing and quality decisions. Under the joint action of government subsidies and a platform's anti-piracy efforts, the piracy in the market will be effectively curbed and consumers will be more recognized for using authorized knowledge products, thereby expanding the demand of authorized products. With the expansion of the authorized product market size, the knowledge provider and knowledge payment platform will change their own decision-making behavior to obtain more benefits. Therefore, when they make decisions on price and the quality level of knowledge products, it is necessary for them to consider the impact of government subsidies and anti-piracy efforts.

### 1.2. Research Questions and Content

Based on the above analysis, this paper will explore the optimal decision problems of a knowledge provider and knowledge payment platform from the perspective of government subsidies and the platform's anti-piracy efforts. Meanwhile, the following questions are expected to be addressed: (1) Can government subsidies and anti-piracy efforts effectively improve the quality level of knowledge payment products? (2) How does the government subsidy strategy affect the knowledge provider's quality decisions and the knowledge payment platform's pricing decisions? (3) How do government subsidies and anti-piracy efforts affect the knowledge provider's and knowledge payment platform's profits?

To answer these research questions, we consider a knowledge payment product supply chain where the knowledge provider signs with the knowledge payment platform and offers knowledge products, and then the platform sells them to end consumers. The government will subsidize the platform based on the sales volume of authorized knowledge products. The interactions between the knowledge provider and knowledge payment platform are modeled as a two-stage Stackelberg game in which the platform is the leader and the knowledge provider is the follower. The platform decides the retail price and signing bonus, and the knowledge provider decides the quality level of knowledge products. Three game models under three decision modes between the knowledge provider and the platform are constructed and compared: no government subsidies and no anti-piracy efforts (NN mode), only anti-piracy efforts (NA mode) and both government subsidies and anti-piracy efforts (SA mode). The impact of government subsidies and anti-piracy efforts on the optimal decisions and profits of supply chain members is studied.

### 1.3. Research Methods

In this paper, we mainly adopt four research methods: a literature analysis method, game theory, a comparative analysis and a numerical simulation method. The main research methods and their detailed descriptions are presented in Table 1.

**Table 1.** The main research methods in this paper and their detailed descriptions.

| Research Methods | Detailed Description |
|---|---|
| Literature analysis method | We collect the related literature on the piracy of information products and the effect of government subsidies in the supply chain and analyze and summarize current research to reflect our work's innovation. |
| Game theory | We construct Stackelberg game models in three modes, i.e., no government subsidies no anti-piracy efforts (NN mode), only anti-piracy efforts (NA mode) and both government subsidies and anti-piracy efforts (SA mode), and solve the optimal decisions and profits of knowledge provider and knowledge payment platform in different models. |
| Comparative analysis | We take the NN mode as a benchmark and let the NA mode and SA mode be compared with it, respectively. And we also analyze the impact of government subsidies and anti-piracy efforts on the optimal decisions and profits of supply chain members under different models. |
| Numerical simulation method | We assign values to the parameters involved in our work based on the parameter settings of the relevant literature and use Maple 2019 simulation software for numerical analysis to verify the relevant conclusions proposed in this paper. |

*1.4. Contributions and Paper Organization*

The main contributions of this paper are as follows. First, as mentioned before, government policies combined with the anti-piracy effort behavior of a firm/platform can help combat piracy and affect the decision-making behavior of market participants. Previous studies have studied product decision problems from the perspective of government punishment and regulation, but fewer works have discussed the role of government subsidies and none of them have taken both government subsidies and anti-piracy efforts into account. Different from them, our study will look at this from the perspective of government subsidies and a platform's anti-piracy efforts. Secondly, the government subsidy strategy is an effective way to solve the problems of supply chains. Many scholars have studied the effect of government subsidies on some supply chain industries, but not in the context of the knowledge payment industry. Our research will explore the impact of government subsidies in the context of piracy in the knowledge payment industry. Therefore, this paper will contribute to the application of the government subsidy strategy. To fill the research gaps, this paper considers a knowledge payment product supply chain where there are government subsidies and anti-piracy efforts and compares three decision models to explore the effect of the government subsidies and anti-piracy efforts on the knowledge provider's and platform's optimal decisions about pricing and quality level and their profits. This is also the most important innovation of our research.

The rest of this paper is organized as follows. In Section 2, we present a simple review of the related literature. In Section 3, we describe the model assumptions, notations and demand functions. After that, the three game models under three decision modes are formulated and solved in Section 4. In Section 5, we compare and analyze the effect of the government subsidies and anti-piracy efforts on the supply chain participants' optimal decisions and profits under the three models. In Section 6, we present a numerical analysis to illustrate some insights. Finally, we discuss the conclusions, managerial implications and limitations for this paper in Section 7. The proof process of all propositions and corollaries is shown in Appendix A.

**2. Literature Review**

This paper is closely related to two aspects of the literature: the piracy of information products and the effect of government subsidies on the supply chain. Next, we present a review and compare our work with these studies to highlight our innovations.

*2.1. The Piracy of Information Products*

In the face of the threat of information product piracy, there are usually two responses: first, pricing strategies and anti-piracy effort behavior by authorized firms, and second, government policies to protect intellectual property and combat piracy, such as improving

the legal system, stepping up crackdowns and imposing heavy fines. Correspondingly, scholars' studies on information product piracy chiefly focus on product pricing, copyright protection and government policies [12]. In terms of product pricing, Nascimento and Vanhonacker [13] found that the skimming pricing method is the best strategy in the absence of piracy. Lahiri and Dey [14] stated that reducing piracy efforts increases the incentive for firms to invest in the retail price and quality of their products. Sundararajan [15], King and Lampe [16] and Bhattacharjee et al. [17] pointed out that under the threat of piracy, authorized firms can increase profits through price discrimination strategies (such as combination pricing, version pricing, etc.) to achieve optimal pricing. Cremer and Pestieau [18] examined the impact of piracy on the price and welfare of information products and found that piracy may increase welfare. Jin et al. [19] discovered that bundled pricing strategies for information products can encourage piracy. Gopal and Gupta [20] noted that in the presence of piracy, product bundling pricing can achieve a win–win situation for both the buyers and the sellers. Nan et al. [21] reported that when the level of piracy enforcement is high, it is better for information product providers to adopt a free pricing strategy than a traditional pricing strategy. In addition, network externality also has an important impact on the pricing of information products. Zhu et al. [22] examined the impact of network externality on pricing and quality decisions of information products in the presence of piracy, and found that network externality helps to improve a product's quality and reduce its price. Zhao et al. [23] discussed the impact of network externality on the pricing of pirated products and the quality of legitimate products. They found that smaller network externalities have no effect on the pricing decision of information products, and larger network externalities will lead to piracy in the market. In terms of copyright protection, Vernik et al. [24] thought that when authorized firms do not adopt copyright protection, the number of pirated products in the market will instead decline. Jain [25] found that weaker copyright protection can serve to coordinate competition for pirated products and reduce the retail price. Bae and Choi [26] pointed out that the copyright protection behavior of a legitimate manufacturer will greatly increase the cost of replication and quality erosion at the same time. Ma et al. [27] analyzed the property rights protection strategies of knowledge providers in response to the piracy problem in knowledge payments and found that too high of a property rights protection intensity is instead detrimental. Moreover, Digital Rights Management (DRM) is an important technology in copyright protection, and some scholars have also carried out research related to it. Wu et al. [28] developed a theoretical model to examine the conditions of implementing DRM in a firm and found that the adoption of DRM will effectively curb piracy and increase a firm's profits when the level of DRM restrictions is high. Vernik et al. [24] believed that even if lacking DRM, competition among digital retailers, traditional retailers and pirates may reduce piracy and a product's retail price. In terms of government policy, Jaisingh [29] found that strict punishment policies may increase pirated products' retail price and decrease authorized products' quality in some ways. Zhang et al. [30] studied the impact of government regulatory strategies on the quality choices of authorized firms, and found that government penalties are directly proportional to the quality of authorized information products. Banerjee [31] constructed a game model between an authorized firm, a pirate firm and a government, finding that strengthening government supervision will change the pricing strategy of authorized firms and that it may not be the optimal strategy when considering the cost of supervision. Similarly, Deng and Zhang [32] built a game model of the same three subjects to study the coordination of anti-piracy between a government and an authorized firm, and discovered that the government will abandon (strengthen) supervision when authorized firms take a tough (tolerant) attitude on piracy behavior. Chen and Png [33] indicated that a government's consumption subsidy strategy for authorized products can enable firms to reduce prices, and that it is superior to the punitive measures.

The above-mentioned literature shows that pirated information products have both positive and negative effects on authorized products, and the reasonable choice of govern-

ment policy and the anti-piracy effort behavior of authorized firms have crucial impacts on them. Regarding a government's anti-piracy policies, most of the studies focus on the impact of the government's punishment and supervision strategies on the pricing and quality decisions of information products, However, for information products, especially knowledge payment products, few scholars put their research perspective on the government subsidy strategy. Although Chen and Png [33] have noted this, they did not consider the authorized firm's anti-piracy effort behavior. To fill this gap, our research will consider both government subsidies and anti-piracy efforts to explore their impact on the decision-making process of knowledge payment products.

*2.2. The Effect of Government Subsidies in the Supply Chain*

In the face of worsening environmental and social challenges, every modern supply chain inevitably encounters various problems in the process of development, which makes them have to explore a sustainable path [34]. Governments have been taking an important role in guiding the sustainable development of supply chains. Many scholars have studied the impact of government subsidy policies on supply chain operation and management. As a common and effective method to study the decision-making behavior of decision makers, game theory is widely applied to the field of supply chain management [35]. In the green industry, for the problem of green innovation, Ma et al. [36] established a game model between a government, manufacturers and retailers in the green supply chain to study the impact of government subsidies on the level of green innovation and profits in the supply chain. They believed that government subsidies to both manufacturers and retailers will increase the level of green innovation and promote enterprises to participate in green innovation activities. However, Meng et al. [37] found that in order for supply chain enterprises to consciously implement green innovations, governments should subsidize manufacturers rather than both manufacturers and retailers. For the problem of green technology investment, Li et al. [38] constructed three supply chain game models to explore the impact of two subsidy strategies on green technology investment, finding that government subsidies cannot guarantee green technology investment, which also depends on the range of investment costs. Wu et al. [39] considered a green closed-loop supply chain model to study the optimal technology investment decisions of the supply chain under different government subsidy rates, and found that government subsidies can effectively improve the supply chain's technology investment level. In terms of environmental effects, Khosroshahi et al. [40] developed a three-stage Stackelberg game model to study the impact of different subsidy strategies on green supply chain decisions and found that government subsidies can make manufacturers increase the transparency level and thereby help the environmental aspect of sustainability. Xu et al. [41] built a game model between a government, manufacturers and retailers when there is horizontal integration between manufacturers and retailers and analyzed the policy role between the carbon tax and green subsidies. They thought that both carbon taxes and green subsidies can limit greenhouse gas emissions. In addition, some scholars have also explored the effect of government subsidies in the context of a green product's optimal pricing [42–44]. For example, Xue et al. [43] analyzed the pricing and design of green products under different government subsidy strategies by adopting a game-theoretical approach and found that a product's price will decline but a product's demand will increase when a government provides a differentiated subsidy strategy. Barman et al. [44] analyzed and compared optimal pricing strategies that maximize the overall profit of the green supply chain with and without government subsidies through using the Stackelberg game approach. In the agricultural industry, aiming at the environmental problem in agriculture, Zhang et al. [45] introduced the government subsidy factor into the agricultural supply chain and found that a mixed subsidy scheme of an output quantity subsidy and environmental innovation subsidy can reduce agricultural pollution emissions and increase firm profits. He et al. [46] built a game model to study the impact of government subsidies on sustainable agriculture supply chain members' profits, technology inputs and environmental pollution. Aiming

at the poverty alleviation problem in agriculture, Kang et al. [47] explored the impact of government subsidies and fairness concerns on poverty alleviation supply chain decisions using game theory, and stated that reasonable government subsidies can eliminate market failures and promote profits of both the farmer enterprise and core enterprise. Ye and Deng [48] constructed a four-stage game model to study the optimal decision problem of the poverty alleviation supply chain and suggested that governments should formulate subsidy policies based on the performance of beneficiaries in poverty alleviation projects. Furthermore, some scholars also studied the financing problem of the agricultural supply chain from the perspective of government subsidies [49–51]. For example, Huang et al. [50] constructed a four-stage game model to analyze the design of the government subsidy mechanism in contract farming supply chain financing and found that the government subsidy mechanism is related to the price sensitivity of agricultural products. Lu et al. [51] explored the impact of a government loan interest subsidy and policy guarantees on the operation of the agricultural supply chain by the modeling method. They found that a higher subsidy rate can reduce the financing costs of farmers and promote farmers' profits. In the remanufacturing industry, aiming at the problem of recycling/sale channel selection, Huang and Liang [52] established three recycling modes in the manufacturing closed-loop supply chain model to study the impact of government subsidies on channel member's recycling mode selection. Wang et al. [53] considered the two sale channels (direct sale and indirect sale) of the remanufacturer and constructed a game model under different channels to study government subsidies' effects. They found that subsidies can stimulate remanufacturing activities no matter which channel the remanufacturer chooses. He et al. [54] explored the influence of government subsidies on the choice of three sales channel structures of manufacturers and found that a reasonable subsidy level can encourage manufacturers to choose the desired channels. Moreover, some scholars have also discussed carbon emissions [55–57], remanufacturing product sales [58], supply chain member competition [59–61] and other issues in the remanufacturing industry. For example, Shu et al. [56] constructed a closed-loop supply chain model of remanufacturing under carbon taxes and government subsidies and found that appropriate carbon taxes and government subsidies would improve corporate profits and reduce carbon emissions. Mitra and Webster [60] analyzed a two-period competitive game model and proposed that if the subsidy is distributed between a manufacturer and remanufacturer in a certain proportion, it will increase remanufacturing activities. In the information goods industry, Wang et al. [62] designed a game model to study the impact of government subsidies on the R&D partnership coordinated contract of the information goods supply chain, finding that government subsidies can make up for the lack of innovation externalities on the original innovation incentive and improve the supply chain system profits and social welfare.

From the literature reviewed here, it can be seen that most of the research presented studies the impact of government subsidies in different supply chain fields by constructing game models, and it was indicated that government subsidies are an effective way to solve some industry problems. Similarly, government intervention is also needed for problems in the knowledge payment industry, such as piracy behavior and the sale of authorized knowledge products. However, no scholars have yet applied government policies to the knowledge payment industry. Given the significant effect of government subsidies, we try to introduce the subsidy factor into the knowledge payment product supply chain and explore its impact on supply chain decision making.

## 3. The Model

### 3.1. Model Description and Assumption

This paper considers a two-stage knowledge payment product supply chain with a knowledge provider (denoted by $K$) and a knowledge payment platform (denoted by $P$). The knowledge provider offers a knowledge product with the quality level $q$ to the platform with the unit quality signing bonus $c$, and then the platform decides the retail price $p$. In this paper, the supply chain refers to the network chain structure formed by the participants

involved in the whole process, in which the knowledge provider provides the knowledge products to the consumers through the platform. Piracy exposes the knowledge product to a serious competitive threat, which leads the platform to take a variety of measures to combat piracy and defend its benefits. To inspire the platform's anti-piracy behavior, the government subsidizes the platform based on the sales volume of the authorized knowledge product; $s$ is the amount of subsidy per unit of knowledge product, and $e$ is the platform's anti-piracy effort level. Both the knowledge provider and the platform are completely rational and maximize expected profits. The structure of the knowledge payment product supply chain is shown in Figure 1.
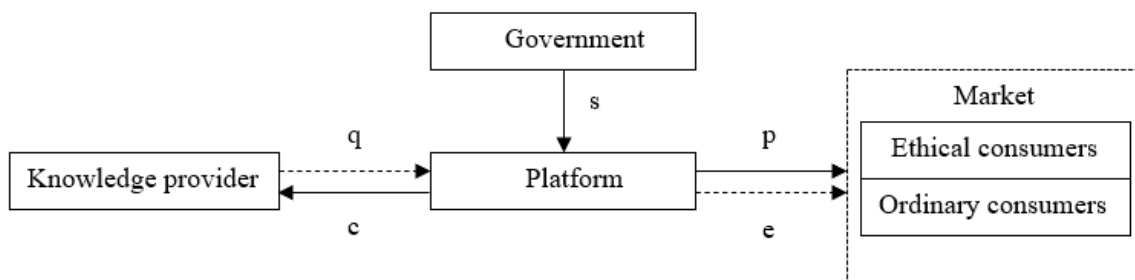


**Figure 1.** The structure of the knowledge payment product supply chain.

The mass of consumers in the market is normalized to 1. Each consumer buys at most one unit of either the authorized or pirated product. There are two types of consumers in the market, which we refer to as the ethical consumers (denoted by $E$) and the ordinary consumers (denoted by $O$), respectively [63]. The ratio is $\theta$ and $1 - \theta$ for the ethical consumers and the ordinary consumers, respectively, and $\theta \in [0, 1]$. Different types of consumers have a differentiated perceived value of knowledge products, which affects their purchase decision [64]. The two types of consumers differ from each other in two aspects. First, they have different attitudes regarding the pirated product. The ethical consumers have a sufficiently low value for the pirated product and therefore purchase only the authorized one. In contrast, the ordinary consumers have weak consciousness of intellectual property, and consider both the authorized and the pirated products as acceptable options. Second, the two types of consumers differ in their search costs, denoted as $t$. In particular, the ethical consumers must incur a positive search cost $t$ to be able to make a purchase decision and to be informed of the relevant characteristics of the authorized product (such as price and quality) [65]. Given that the search cost for the ordinary consumers is negligible, for simplicity, the ordinary consumers' search cost is normalized to 0 [27]. We focus on the case when the ethical consumers' search cost is positive but sufficiently small; therefore, we assume that $t$ satisfies $0 < t < 1/2$ [66].

Given the replicability and non-depletion of the knowledge product, without the loss of generality, the knowledge provider's fixed and marginal costs of production are normalized to 0 [67–69]. The product creation cost paid by the knowledge provider is affected by the quality level of product and increases exponentially. The higher the quality level of the product, the higher the cost of product creation. We assume that the product creation cost is $kq^2/2$ [70], where $k$ is the product creation cost coefficient and $k > 0$. Similarly, the anti-piracy effort cost paid by the platform is affected by the level of anti-piracy efforts and increases exponentially. The higher the level of anti-piracy efforts, the higher the cost of anti-piracy efforts. We assume that the anti-piracy effort cost is $\lambda e^2/2$ [71], where $\lambda$ is the anti-piracy effort cost coefficient, $\lambda > 0$.

Knowledge products that are regularly updated at the end of one certain period can be obtained at a transaction cost [72]. This provides consumers with a possible choice strategy, and their willingness to pay for authorized and pirated products is different. It is assumed that the consumers' willingness to pay for an authorized knowledge product is $v$, and $v$ is uniformly distributed on $[0, 1]$. The ordinary consumers generally are less willing to pay for an authorized product than for a pirated product. Assuming that the

ordinary consumers' acceptance for the pirated product is $\alpha$, and $\alpha \in [0, 1]$, the larger the $\alpha$, the greater the ordinary consumers' desire for the pirated product. Limited by the high price of the authorized knowledge product, ordinary consumers are more inclined to buy the pirated knowledge product. Although ethical consumers prefer authorized knowledge products, they will also make purchase decisions based on a comprehensive consideration of their own economic condition and the product's quality level [73], which means that their willingness to pay for authorized products may not always be high. Through relevant anti-piracy efforts (such as giving a certain concession to consumers who buy authorized knowledge products), the platform cannot completely prevent piracy, but it can improve consumers' recognition of authorized knowledge products and increase different consumers' willingness to pay [74]. Similar to Li and Wang [58], we assume that the willingness to pay of two types of consumers will increase $\alpha^2 e$ under the influence of the platform's anti-piracy efforts.

### 3.2. Demand Functions

#### 3.2.1. The Demand Functions under No Anti-Piracy Efforts

According to the above assumptions, we can obtain that the utilities of the authorized product for the ethical consumers and the ordinary consumers are $v - p + q - t$ and $v - p + q$, and the utilities of the pirated product for the ethical consumers and the ordinary consumers are $0$ and $\alpha(v + q)$. The ethical consumers choose to buy the authorized product only when $v \geq v_E = \min\{p - q + t, 1\}$, where $v_E$ represents the indifference point of the utility of ethical consumers from purchasing the authorized product and no consumption. Since $v$ is uniformly distributed, the market demand of ethical consumers under no anti-piracy efforts $D_{EN}$ can be expressed as follows:

$$D_{EN} = \theta \int_{p-q+t}^{1} dv = \theta(1 - p + q - t) \tag{1}$$

Similarly, the ordinary consumers choose to buy the authorized product when $v - p + q \geq \alpha(v + q)$ and the pirated product when $v - p + q < \alpha(v + q)$. Therefore, the indifference point of the utility of ordinary consumers from the authorized product and pirated product is represented by $v_O = \min\{\frac{p}{1-\alpha} - q, 1\}$, and the market demand of ordinary consumers under no anti-piracy efforts $D_{ON}$ can be expressed as follows:

$$D_{ON} = (1 - \theta) \int_{\frac{p}{1-\alpha} - q}^{1} dv = (1 - \theta)(1 - \frac{p}{1 - \alpha} + q) \tag{2}$$

#### 3.2.2. The Demand Functions under Anti-Piracy Efforts

In this situation, the consumers' willingness to pay will increase due to the platform's anti-piracy effort behavior. Based on the above assumptions, we can obtain that the utilities of the authorized product for the ethical consumers and the ordinary consumers are $v - p + q - t + \alpha^2 e$ and $v - p + q + \alpha^2 e$, and the utilities of the pirated product for the ethical consumers and the ordinary consumers are $0$ and $\alpha(v + q)$. Similar to the analysis process in Section 3.2.1, the market demand of ethical consumers under anti-piracy efforts $D_{EA}$ can be expressed as follows:

$$D_{EA} = \theta \int_{p-q+t-\alpha^2 e}^{1} dv = \theta(1 - p + q - t + \alpha^2 e) \tag{3}$$

The market demand of ordinary consumers under anti-piracy efforts $D_{OA}$ can be expressed as follows:

$$D_{OA} = (1 - \theta) \int_{\frac{p-\alpha^2 e}{1-\alpha} - q}^{1} dv = (1 - \theta)(1 - \frac{p - \alpha^2 e}{1 - \alpha} + q) \tag{4}$$

## 4. Model Construction and Solution

In this section, we model the interactions among the supply chain participants with the following two-stage Stackelberg game where the platform is the leader and the knowledge provider is the follower. At stage 1, the platform decides the retail price $p$ and the unit quality signing bonus $c$. And then, at stage 2, the knowledge provider decides the quality level of product $q$. Based on the above assumptions and demand functions, we construct the profit functions of the knowledge provider and the platform under three scenarios in turn, and solve for the optimal decisions and profits in each model, respectively.

### 4.1. No Government Subsidies No Anti-Piracy Efforts (NN Mode)

In the NN mode, the profit functions of the knowledge provider and the platform are as follows:

$$\pi_K^{NN} = cq - \frac{1}{2}kq^2 \tag{5}$$

$$\pi_P^{NN} = p[\theta(1 - p + q - t) + (1 - \theta)(1 - \frac{p}{1 - \alpha} + q)] - cq \tag{6}$$

**Proposition 1.** *In the NN mode, the optimal retail price and unit quality signing bonus set by the platform are as follows:*

$$p^{NN*} = \frac{2k(\theta t - 1)(1 - \alpha)}{4\theta k\alpha - \alpha - 4k + 1} \tag{7}$$

$$c^{NN*} = \frac{k(\theta t - 1)(1 - \alpha)}{4\theta k\alpha - \alpha - 4k + 1} \tag{8}$$

*The optimal quality level of the product set by the knowledge provider is as follows:*

$$q^{NN*} = \frac{(\theta t - 1)(1 - \alpha)}{4\theta k\alpha - \alpha - 4k + 1} \tag{9}$$

*The optimal profits of the knowledge provider and the platform are as follows:*

$$\pi_K^{NN*} = \frac{k[(\theta t - 1)(1 - \alpha)]^2}{2(4\theta k\alpha - \alpha - 4k + 1)^2} \tag{10}$$

$$\pi_P^{NN*} = \frac{k(\theta t - 1)^2(\alpha - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{11}$$

### 4.2. There Are Only Anti-Piracy Efforts (NA Mode)

In the NA mode, the profit functions of the knowledge provider and the platform are as follows:

$$\pi_K^{NA} = cq - \frac{1}{2}kq^2 \tag{12}$$

$$\pi_P^{NA} = p[\theta(1 - p + q - t + \alpha^2 e) + (1 - \theta)(1 - \frac{p - \alpha^2 e}{1 - \alpha} + q)] - cq - \frac{1}{2}\lambda e^2 \tag{13}$$

**Proposition 2.** *In the NA mode, the optimal retail price and unit quality signing bonus set by the platform are as follows:*

$$p^{NA*} = \frac{2k(\theta t - 1)(1 - \alpha) + 2\alpha^2 ek(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{14}$$

$$c^{NA*} = \frac{k(\theta t - 1)(1 - \alpha) + \alpha^2 ek(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{15}$$

*The optimal quality level of the product set by the knowledge provider is as follows:*

$$q^{NA*} = \frac{(\theta t - 1)(1 - \alpha) + \alpha^2 e(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{16}$$

*The optimal profits of the knowledge provider and the platform are as follows:*

$$\pi_K^{NA*} = \frac{k[(\theta t - 1)(1 - \alpha) + \alpha^2 e(\alpha\theta - 1)]^2}{2(4\theta k\alpha - \alpha - 4k + 1)^2} \tag{17}$$

$$\pi_P^{NA*} = \frac{k(A_1 - A_2 + A_3 + A_4 + A_5 + A_6 + A_7) + A_8}{2(\alpha - 1)(4\theta k\alpha - \alpha - 4k + 1)} \tag{18}$$

*In Equation (18),*

$$
\begin{aligned}
A_1 &= 2e^2\theta^2\alpha^6, \\
A_2 &= 4e^2\theta\alpha^5, \\
A_3 &= 2e\alpha^4(2\theta - 2t\theta^2 + e), \\
A_4 &= 4e\alpha^3(1 + \theta)(\theta t - 1), \\
A_5 &= \alpha^2[-4e^2\theta\lambda + (4 - 4\theta t)e + 2(\theta t - 1)^2], \\
A_6 &= \alpha[4\lambda e^2(1 + \theta) - 4(\theta t - 1)^2], \\
A_7 &= [2(\theta t - 1)^2 - 4\lambda e^2], \\
A_8 &= e^2\lambda(\alpha - 1)^2.
\end{aligned}
$$

### 4.3. There Are Both Government Subsidies and Anti-Piracy Efforts (SA Mode)

In the SA mode, the profit functions of the knowledge provider and the platform are as follows:

$$\pi_K^{SA} = cq - \frac{1}{2}kq^2 \tag{19}$$

$$\pi_P^{SA} = (p + s)[\theta(1 - p + q - t + \alpha^2 e) + (1 - \theta)(1 - \frac{p - \alpha^2 e}{1 - \alpha} + q)] - cq - \frac{1}{2}\lambda e^2 \tag{20}$$

**Proposition 3.** *In the SA mode, the optimal retail price and unit quality signing bonus set by the platform are as follows:*

$$p^{SA*} = \frac{2k(\alpha^2 e - s)(\alpha\theta - 1) + (2k\theta t - 2k - s)(1 - \alpha)}{4\theta k\alpha - \alpha - 4k + 1} \tag{21}$$

$$c^{SA*} = \frac{k(\theta t - 1)(1 - \alpha) + k(\alpha^2 e + s)(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{22}$$

*The optimal quality level of the product set by the knowledge provider is as follows:*

$$q^{SA*} = \frac{(\theta t - 1)(1 - \alpha) + (\alpha^2 e + s)(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{23}$$

*The optimal profits of the knowledge provider and the platform are as follows:*

$$\pi_K^{SA*} = \frac{k[(\theta t - 1)(1 - \alpha) + (\alpha^2 e + s)(\alpha\theta - 1)]^2}{2(4\theta k\alpha - \alpha - 4k + 1)^2} \tag{24}$$

$$\pi_P^{SA*} = \frac{k(A_1 - A_2 + B_1 - B_2 + B_3 + B_4 + B_5) + A_8}{2(\alpha - 1)(4\theta k\alpha - \alpha - 4k + 1)} \tag{25}$$

*In Equation (25),*

$$B_1 = 2e\alpha^4[(2s - 2t)\theta^2 + 2\theta + e],$$
$$B_2 = e\alpha^3[4 - 4\theta^2 t + (8s - 4t + 4)\theta],$$
$$B_3 = \alpha^2[2(s - t)^2\theta^2 + (-4\lambda e^2 - 4et + 4s - 4t)\theta + 2 + (4s + 4)e],$$
$$B_4 = \alpha[4t\theta^2(s - t) + (4\lambda e^2 - 4s^2 + 4st - 4s + 8t)\theta + 4\lambda e^2 - 4s - 4],$$
$$B_5 = 2t^2\theta^2 - 4t(1 + s)\theta - 4\lambda e^2 + 2(1 + s)^2.$$

## 5. Analysis and Comparison

Since there are many decision scenarios involved, in order to show more clearly the effect of government subsidies and anti-piracy efforts on each equilibrium strategy of the knowledge provider and platform, we perform the following work in this section. Firstly, the NN mode is used as the benchmark. Secondly, the equilibrium solutions in the NA mode and NN mode are compared, that is, we explore the effect of anti-piracy efforts on supply chain members' equilibrium strategies without government subsidies. And then, the equilibrium solutions in the SA mode and NN mode are compared, that is, we explore the effect of anti-piracy efforts on supply chain members' equilibrium strategies with government subsidies.

*5.1. The Impact of Anti-Piracy Efforts on Supply Chain without Government Subsidies*

**Corollary 1.** $p^{NA*} > p^{NN*}, c^{NA*} > c^{NN*}, q^{NA*} > q^{NN*}.$

Corollary 1 shows that when government subsidies are not considered, the optimal retail price, quality level and unit quality signing bonus of the knowledge payment product under anti-piracy efforts are all higher than those in the case without anti-piracy efforts. The reason is that when piracy is not effectively curbed, it will hurt the intellectual property of the knowledge provider and reduce their enthusiasm for creation. However, when the platform takes some anti-piracy measures to combat piracy, the scale of the piracy market will decrease and the consumers who purchase the authorized knowledge product will increase. This is conducive to motivating the initiative of the knowledge provider for product quality innovation. Therefore, the quality level of the knowledge product is higher under the effect of anti-piracy efforts. Correspondingly, if the quality level of the knowledge product is improved, the platform will increase the unit quality signing bonus to encourage the knowledge provider to produce more high-quality products. Moreover, in order to combat piracy and obtain consumers' recognition, the platform will improve the level of anti-piracy efforts actively, which will lead the platform to increase the retail price of the product to make up for the extra cost of improving the anti-piracy effort level.

**Corollary 2.** $\pi_K^{NA*} > \pi_K^{NN*}$; *when* $0 < e \leq \frac{(\alpha\theta - 1)(\theta t - 1)(\alpha - 1)}{2\alpha^4 k(\alpha - 1)^2 + \lambda(\alpha - 1)^2 + 4k\lambda(1 - \alpha\theta)(\alpha - 1)}$, $\pi_P^{NA*} \geq \pi_P^{NN*}$; *when* $e > \frac{(\alpha\theta - 1)(\theta t - 1)(\alpha - 1)}{2\alpha^4 k(\alpha - 1)^2 + \lambda(\alpha - 1)^2 + 4k\lambda(1 - \alpha\theta)(\alpha - 1)}$, $\pi_P^{NA*} < \pi_P^{NN*}.$

Corollary 2 shows that when government subsidies are not considered, the profit of the knowledge provider under anti-piracy efforts is always higher than that in the case without anti-piracy efforts. That is, there is not an anti-piracy effort level that maximizes the knowledge provider's profit. This is because the knowledge provider does not bear the

costs of anti-piracy efforts, and it can always obtain additional economic and reputation benefits through the "free-riding" effect (this refers to the efforts made by a member for the team so that all members may profit, but the cost is borne by the member themselves). For the platform, when the anti-piracy effort level is lower (higher) than a certain value, its profit under anti-piracy efforts is higher (lower) than that in the case without anti-piracy efforts (i.e., there is an optimal anti-piracy effort level that maximizes the platform's profit). The reason is that when the anti-piracy effort level is low, the platform will obtain more profits with lower anti-piracy effort costs. When the anti-piracy effort level is high, this means the platform needs to increase costs. If costs rise, the platform will raise the retail price, which will lead to a decrease in consumers' willingness to pay, especially ordinary consumers. In this situation, the cost expenditure of platform is greater than the sales revenue, that is, a high anti-piracy effort level hurts the platform's profit. The above phenomenon also shows that when there are no government subsidies the knowledge provider will become the biggest beneficiary of anti-piracy efforts in the supply chain.

*5.2. The Impact of Anti-Piracy Efforts on Supply Chain with Government Subsidies*

**Corollary 3.** *When* $s > \frac{2k\alpha^2 e(\alpha\theta - 1)}{2\theta k\alpha - \alpha - 2k + 1}$, $p^{SA*} < p^{NN*}$; $c^{SA*} > c^{NN*}$; $q^{SA*} > q^{NN*}$.

Corollary 3 shows that when considering government subsidies, the optimal quality level and unit quality signing bonus of the knowledge payment product under anti-piracy efforts are all higher than those in the case without anti-piracy efforts. Nevertheless, when the government subsidies are higher than a certain value, the optimal retail price under anti-piracy efforts is lower than that in the case without anti-piracy efforts. This is because government subsidies relieve the cost pressure of the platform's anti-piracy efforts, giving the platform the prerequisite to reduce the retail price. It is worth noting that the size of this value is closely related to the level of anti-piracy efforts: the larger the anti-piracy effort level, the larger the value. Therefore, when a government makes a subsidy strategy, it should consider not only its own financial situation, but also the platform's anti-piracy effort level. This is conducive to improving the enthusiasm of the platform's anti-piracy efforts and promoting the development of an authorized product market.

**Corollary 4.** *When* $s \geq \frac{2k(\alpha-1)(\theta t - 1) + 2\alpha^2 ek(\alpha\theta - 1) + \sqrt{8e^2 k^2 \lambda (1-\alpha)(1-\alpha\theta) + 2k(\alpha-1)^2 (2kt^2\theta^2 - e^2\lambda - 4kt\theta + 2k)}}{2k(1-\alpha\theta)}$, $\pi_P^{SA*} \geq \pi_P^{NN*}$; $\pi_K^{SA*} > \pi_K^{NN*}$.

Corollary 4 shows that when considering government subsidies, the profit of the knowledge provider under anti-piracy efforts is always higher than that in the case without anti-piracy efforts. And for the platform, only when the government subsidies are higher than a certain value, its profit under anti-piracy efforts is higher than that in the case without anti-piracy efforts. This can be explained in two ways. On the one hand, as mentioned before, high government subsidies can reduce the retail price, which means that for both ethical and ordinary consumers, it is conducive to improving their value evaluation and willingness to pay for the authorized knowledge product, thereby increasing the profit of the platform. On the other hand, high subsidies make up for the platform's anti-piracy effort cost expenditure. At the same time, the above results also show that as the platform is the direct object of government subsidies, its profit is more sensitive to the amount of subsidies. When the government provides higher subsidies, it is beneficial for all participants of the supply chain.

## 6. Numerical Analysis

In this section, we conduct a numerical analysis to assess the robustness of the corollaries derived by Maple 2019, and select the equilibrium strategies in the SA mode as the numerical analysis object. To satisfy the constraints in the model, we define the range of $e$ in $[0, 10]$ and the range of $s$ in $[0, 1]$. More precisely, $e = 0$ indicates no anti-piracy efforts, and $s = 0$ indicates no government subsidies. Meanwhile, based on the values presented in Zhao et al. [23] and Haruvy et al. [71], we also set the model parameters as $\alpha = 0.5$, $t = 0.2$, $\theta = 0.5$, $k = 0.38$ and $\lambda = 1$. These parameters ensure $(4\theta k - 1)\alpha < 4k - 1$ and $0 < t < 1/2$ to guarantee that the optimal decisions and profits

are bigger than zero. The effect of government subsidies and anti-piracy effort level on the optimal decisions and profits is shown in Figure 2.
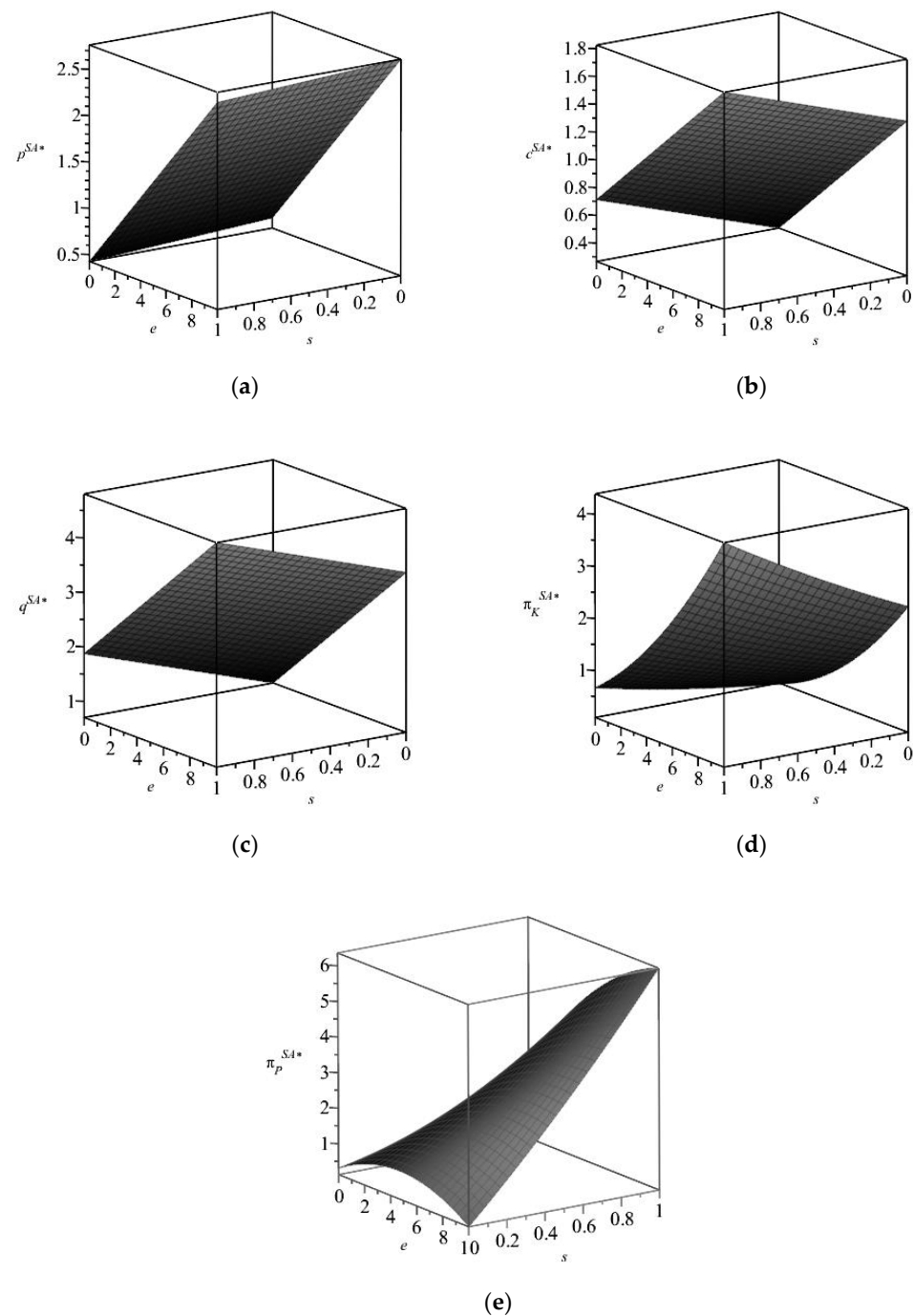


(a)

(b)

(c)

(d)

(e)

**Figure 2.** The effect of government subsidies $s$ and anti-piracy effort level $e$ on the optimal decisions and profits: (**a**) effect of $e$ and $s$ on the retail price; (**b**) effect of $e$ and $s$ on the unit quality signing bonus; (**c**) effect of $e$ and $s$ on the quality level; (**d**) effect of $e$ and $s$ on the knowledge provider's profit; (**e**) effect of $e$ and $s$ on the platform's profit.

Figure 2a–c plot the impact of government subsidies and anti-piracy efforts on the retail price, unit quality signing bonus and quality level of the knowledge product, respectively. It can be seen from Figure 2a–c that, whether there are government subsidies or not, the quality level and unit quality signing bonus of the knowledge product all increase with the level of anti-piracy efforts. However, the retail price has different change trends, which increase with the level of anti-piracy efforts but decrease with government subsidies. Furthermore, when the government subsidies reach

a certain value, the retail price of the knowledge product is lower than that without anti-piracy efforts, which indicates that government subsidies can effectively curb the rise in retail prices. This verifies the relevant conclusions of Corollaries 1 and 3.

Figure 2d plots the impact of government subsidies and anti-piracy efforts on the profit of the knowledge provider. It can be seen from Figure 2d that, the knowledge provider's profit always increases with government subsidies and anti-piracy efforts, which can be explained from the following two aspects. Firstly, the knowledge provider does not have to bear the cost of anti-piracy efforts, which leads it to enjoy the additional economic and reputation benefits of anti-piracy efforts through the "free-riding" effect. Secondly, from the analysis results of Figure 2b, we can find that both government subsidies and anti-piracy efforts will increase the unit quality signing bonus, that is, the knowledge provider can obtain more profits from the platform. This result is consistent with the relevant conclusions of Corollaries 2 and 4.

Figure 2e plots the impact of government subsidies and anti-piracy efforts on the profit of the platform. It can be seen from Figure 2e that, when government subsidies are not considered (i.e., $s = 0$), the platform's optimal profit shows an inverted U-shaped relationship with the anti-piracy effort level, and when the anti-piracy effort level reaches a certain value, it reaches the maximum. This result is consistent with the relevant conclusions of Corollary 2. Moreover, the main reason for the rapid decline in the platform's profit after reaching the maximum is related to the cost of anti-piracy efforts. Excessive anti-piracy efforts lead to a lower increase in profit than cost expenditure. Thus, in practice, it can be considered that the government, knowledge provider and platform jointly bear the cost of anti-piracy efforts, or redistribute the additional profits brought by anti-piracy efforts to relieve the pressure of the platform. On the other hand, whether the level of anti-piracy efforts changes or not, the platform's profit always increases with government subsidies. However, compared to no government subsidies and no anti-piracy efforts (i.e., $e = 0$ and $s = 0$), the platform's profit is higher only when the subsidies exceed a certain value. This result is consistent with the relevant conclusions of Corollary 4.

In addition, comparing Figure 2d,e, we can find that although the knowledge provider's and the platform's profits will increase with government subsidies, the trend of variation in their profits is different. More specifically, when government subsidies are lower (higher) than a certain value, the profit of the knowledge provider is higher (lower) than that of the platform. For example, when $s = 0.1$, the platform's profit is less than 1, while the knowledge provider's profit exceeds 2; when $s = 1$, the knowledge provider's profit is less than 5, while the platform's profit exceeds 6. This result indicates that with the increase in subsidies, the platform, as the leader in the knowledge payment product supply chain, and its profit are more sensitive to subsidies. In the long run, the platform will become the largest beneficiary of government subsidies, while the knowledge provider will obtain relatively less profit. Therefore, when implementing the subsidy policy, the government should consider the primary–secondary relationship of supply chain members.

## 7. Conclusions, Managerial Implications and Limitations

### 7.1. Main Conclusions

This paper develops a knowledge payment product supply chain system with a knowledge provider and a platform, and sheds light on how government subsidies and anti-piracy efforts affect the knowledge provider's and platform's optimal strategies using a game theoretic model. In the model, the knowledge provider sets the quality level of the knowledge product, the platform sets the retail price and unit quality signing bonus, and then the government subsidizes the platform according to the sales volume of the authorized knowledge product. We constructed and compared game models under three modes, that is, no government subsidies and no anti-piracy efforts (NN mode), only anti-piracy efforts (NA mode) and both government subsidies and anti-piracy efforts (SA mode). Our research shows that government subsidies and anti-piracy efforts have important effects on the knowledge provider's and platform's optimal decisions and profits. Mainly, the following conclusions are obtained:

(1)　Compared with no anti-piracy efforts, the anti-piracy effort behavior can always improve the quality level and unit quality signing bonus of a knowledge payment product. When government subsidies are not considered, the retail price of the knowledge product increases with the platform's anti-piracy efforts but decreases when the government subsidies are higher than a certain threshold. In the practice of knowledge payments, price is often an important factor affecting consumers' purchase decisions. The price of an authorized knowledge product is generally high, which makes many consumers search for pirated products. This phenomenon will lead to difficulties in selling authorized products. However, a reasonable government

subsidy strategy can reduce prices and expand the size of the authorized product market. Government subsidies can become an application strategy for the future knowledge payment industry.

(2)  In terms of the impact of anti-piracy efforts on profits, for the knowledge payment platform, both the increases and decreases of its profit and the anti-piracy effort level are restricted by the anti-piracy effort cost. Furthermore, the platform's profit increases first and then decreases with the level of anti-piracy efforts, that is, there is an optimal anti-piracy effort level to maximize its profit. However, the knowledge provider's profit always increases with the anti-piracy effort level, and it will become the largest beneficiary of the platform's anti-piracy effort behavior through the "free-riding" effect. In the knowledge payment market, the existence of the "free-riding" effect is beneficial for the knowledge provider, but the platform may lose its anti-piracy enthusiasm due to the pressure of the cost of anti-piracy efforts. Therefore, the knowledge provider can appropriately bear part of the cost and establish a good cooperative relationship with the platform.

(3)  Compared with the case of no government subsidies and no anti-piracy efforts, government subsidy behaviors can significantly increase the profit of the knowledge provider, but may not necessarily increase the profit of the platform. In fact, the platform's profit only increases when government subsidies are higher than a certain threshold. This also shows that the platform is the direct object of government subsidies, and its profit will be more sensitive to the amount of subsidies. Therefore, the government should fully consider the situation of the knowledge payment platform itself when formulating the subsidy strategy, thereby optimizing the matching degree between the subsidy strategy and the platform. Moreover, there exists a certain threshold, and when government subsidies are lower than this threshold, the knowledge provider will obtain more profits. In contrast, if subsidies are higher than this threshold, the profit of the platform is higher than that of the knowledge provider. Interestingly, when the government provides high subsidies and the platform makes low anti-piracy efforts, it not only helps to improve the anti-piracy enthusiasm and profit of the platform, but also enables the knowledge provider to obtain additional economic and reputation benefits.

## 7.2. Managerial Implications

The managerial implications section of this paper aims to pass on the transparent and applicable information found by researchers to managers and help them to better manage their work. Given the insights gained through the game models conducted, and the research conclusions analyzed, this paper provides the following management implications for the decision-making activities of participants in the knowledge payment product supply chain:

(1)  The anti-piracy efforts of a platform not only help improve the quality level of knowledge payment products, but also increase the profits of a knowledge provider and a platform to a certain extent. Therefore, the anti-piracy effort behaviors of a platform should be encouraged to be actively implemented. In addition, since the platform needs to bear the high anti-piracy effort costs when taking some anti-piracy measures, this may reduce its enthusiasm for anti-piracy. Therefore, the knowledge provider should also participate in anti-piracy activities, share the costs of anti-piracy efforts and share the additional benefits brought by anti-piracy efforts.

(2)  Government subsidies improve the quality level of a knowledge product and reduce the retail price of a product in a certain subsidy range. This is conducive to guiding different consumers' purchase decisions on authorized and pirated knowledge products, and improving the profits of supply chain members. Therefore, a government's subsidy strategy should be implemented in the long term and intensified. Moreover, in the knowledge payment product supply chain, both the knowledge provider and platform will make decisions to maximize their own profit based on the government subsidies, and the party directly subsidized by the government will be more sensitive. Therefore, it is necessary for the government to consider the difference in policy effects when implementing the subsidy strategy.

(3)  Government subsidies combined with anti-piracy efforts are conducive to combating piracy and promoting the sales of authorized knowledge products. Therefore, governments should coordinate with knowledge payment platforms to jointly maintain the healthy and orderly development of the knowledge payment industry. In this regard, firstly, the government can select more influential knowledge payment platforms (such as Zhihu Live, Himalaya FM, Dedao, etc.) as objects for subsidies and appeal to the platforms to carry out anti-piracy activities (such as the legal publicity of piracy). Then, the government needs to adjust the subsidy amount according to the sales of the authorized knowledge product in a timely manner,

and eventually implement and promote subsidy policies on a large scale for platforms that carry out anti-piracy efforts. In addition, in order to increase consumers' willingness to pay for authorized knowledge products, the government can provide a certain subsidy to consumers who purchase authorized knowledge products.

### 7.3. Limitations and Future Research

There are several limitations to our work. Firstly, we assumed that the knowledge provider and platform are completely rational. However, due to that their energy and time are often limited in reality, they are often bounded rational when making decisions. Therefore, the impact of government subsidies and anti-piracy efforts on the knowledge payment product supply chain should be studied when all supply chain members are bounded rational in the future. Secondly, in this paper, the supply chain is composed of a knowledge provider and a platform, which is obviously a simplified version of the actual situation. In knowledge payment practice, the supply chain may be composed of multiple knowledge providers and platforms, which is more complex than the model in this paper. Therefore, more market subjects can be included into the model in future research, such as competing knowledge providers or competing platforms, which may lead to some more interesting and unexpected conclusions. Thirdly, in order to facilitate the processing, we may have ignored some relevant factors when constructing the model, such as the uncertainty of the quality of the knowledge product, the network effect of pirated knowledge, etc. If these factors are integrated into the model, the model will be further expanded upon and optimized.

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### Appendix A

**Proof of Proposition 1**. The Stackelberg game model is solved by the reverse induction method. From Equation (5), we can obtain the first and second derivatives of $q$, $\partial \pi_K^{NN}/\partial q = c - kq$ and $\partial^2 \pi_K^{NN}/\partial q^2 = -k$. Obviously, $\partial^2 \pi_K^{NN}/\partial q^2$ is smaller than zero, which means that $\pi_K^{NN}$ is a strictly concave function with $q$. Let $\partial \pi_K^{NN}/\partial q = 0$, and we can obtain the reaction function of the knowledge provider, $q^{NN} = c^{NN}/k$. And then, substituting the reaction function into Equation (6), we can obtain $\frac{\partial \pi_P^{NN}}{\partial c} = \frac{p-2c}{k}$, $\frac{\partial^2 \pi_P^{NN}}{\partial p^2} = -2\theta - \frac{2(1-\theta)}{1-\alpha}$ and $\frac{\partial^2 \pi_P^{NN}}{\partial c^2} = -\frac{2}{k}$. Hence, the Hessian matrix is $H = \begin{pmatrix} \frac{\partial^2 \pi_P^{NN}}{\partial p^2} & \frac{\partial^2 \pi_P^{NN}}{\partial p \partial c} \\ \frac{\partial^2 \pi_P^{NN}}{\partial c \partial p} & \frac{\partial^2 \pi_P^{NN}}{\partial c^2} \end{pmatrix} = \begin{pmatrix} -2\theta - \frac{2(1-\theta)}{1-\alpha} & \frac{1}{k} \\ \frac{1}{k} & -\frac{2}{k} \end{pmatrix}$. After simple calculation, we know that the Hessian matrix is a negative definite matrix if $(4\theta k - 1)\alpha < 4k - 1$, and thus $\pi_P^{NN}$ is a strictly jointly concave function with $p$ and $c$. Let the first derivative of the platform's profit with respect to $p$ and $c$ be zero, and we can obtain Equations (7) and (8). And then, substituting Equation (8) into the reaction function, Equation (9) can be obtained. Finally, substituting the obtained Equations (7)–(9) into Equations (5) and (6), Equations (10) and (11) can be obtained. □

**Proof of Proposition 2**. The reverse induction method is still used for the solution, and the proof process is similar to Proposition 1. □

**Proof of Proposition 3**. The reverse induction method is still used for the solution, and the proof process is similar to Proposition 1. □

**Proof of Corollary 1**. From Equations (7) and (14), we can obtain that

$$p^{NA*} - p^{NN*} = \frac{2\alpha^2 ek(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{A1}$$

From Equations (8) and (15), we can obtain that

$$c^{NA*} - c^{NN*} = \frac{\alpha^2 ek(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{A2}$$

From Equations (9) and (16), we can obtain that

$$q^{NA*} - q^{NN*} = \frac{\alpha^2 e(\alpha\theta - 1)}{4\theta k\alpha - \alpha - 4k + 1} \tag{A3}$$

According to the conditions $(4\theta k - 1)\alpha < 4k - 1$, $\alpha\theta < 1$, Equations (A1)–(A3) can easily be judged as positive numbers. □

**Proof of Corollary 2**. The proof process is similar to Corollary 1. □

**Proof of Corollary 3**. The proof process is similar to Corollary 1. □

**Proof of Corollary 4**. The proof process is similar to Corollary 1. □

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