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Governmental enforcement against piracy on media platforms

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ABSTRACT

The rapid growth of illegal websites hosting pirated content has significantly reduced demand for legitimate media platforms, causing substantial economic losses to the media industry. Governmental departments must take measures to combat these illegal websites and restrict access to pirated content. This paper examines governmental enforcement against piracy on media platforms that offer consumer services under three revenue models: subscription, ad-based, and mixed. Our analysis yields the following key findings with critical managerial insights. First, under the subscription and mixed models, the optimal governmental enforcement levels lie within the piracy threat region where piracy exists in the market, but there is no demand for it, whereas under the ad-based model, the optimal governmental enforcement can allow the piracy to have a demand and even if no enforcement occurs. Second, optimal governmental enforcement exhibits a non-monotonic effect with respect to the quality of pirated content under each revenue model, which implies that the government does not necessarily strengthen its enforcement facing a higher quality of pirated content. Finally, the optimal governmental enforcement decreases as the consumer nuisance cost for advertisement increases under the ad-based model, whereas it presents a non-monotonic change under the mixed model. We further extend our main model to a duopoly platform setting and a situation of decreasing marginal efficiency of enforcement. The results demonstrate that the insights derived from our main model remain hold. These findings suggest that social planners should consider media platforms' revenue models and market conditions when formulating enforcement policies against piracy.

1. Introduction

The rapid development and popularization of the Internet make digital content more readily available to the public, thus bringing significant benefits to media platforms. At the same time, piracy of digital content is becoming pervasive with increasingly sophisticated file-sharing and stream-ripping technologies. According to data released by MUSO (a data company[1]), pirated video content was accessed 141 billion times in 2023, an increase of nearly 10 % from 2022 [1]. Rampant piracy erodes the demand for legitimate content and causes significant economic losses to the media industry. The rapidly increasing rate of illegal streaming and downloading resulted in a loss of US$6.7 billion for the entertainment industry as of July 2022 [2]. Facing the threat of piracy, media platforms are adopting extensive efforts to fight against it. For example, Netflix uses digital rights management to fight video piracy and protect the copyrights of its premium content. YouTube invests in manual inspection and algorithmic technology to improve Content ID for creators.

However, the platforms' efforts are mainly limited to their sites or tracking media content and identifying if, when, and by whom it has been plagiarized. Removing pirated content outside their sites is usually beyond their reach. In this case, governments play a leading role in combating piracy and curbing its spread. For example, Brazil has implemented "Operation 404" since 2019, successfully shutting down nearly 1000 pirate websites and at least 720 illegal music apps [3]. Similarly, Indonesia has been blocking pirate sites since mid-2019, and traffic to those sites dropped by 75 % as of January 2022 [4]. In China, the copyright authorities have removed over 250,000 links to copyright infringement websites and penalized more than 40,000 illegal online accounts [5]. In addition, the High Court of the United Kingdom blocked the Pirate Bay and 93 pirated websites [6], and the Canadian government blocked access to infringing Internet services [7]. These successful cases show that governments are crucial in combating illegal websites. The governments' anti-piracy strategies increase the costs of consuming

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[1] See https://www.muso.com/

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piracy, thus reducing the amount of piracy. This paper mainly focuses on governmental enforcement against piracy on media platforms.

Platforms provide services to consumers based on different revenue models. For instance, HBO Now and Tidal adopt a subscription model where consumers can enjoy all the content directly by subscribing to their services. Pluto TV and Jango use an ad-based model, where consumers can enjoy the content freely but have to tolerate advertisements and incur nuisance costs. Spotify and Hulu employ a mixed model, combining subscription and ad-based models. Consumers have different experiences in terms of content quality and cost under different revenue models, which is why they have incentives to search for pirated content. Hence, whether governments should formulate policies to combat piracy based on the platforms' revenue models is of interest. To the best of our knowledge, limited research has been conducted on governmental enforcement against piracy on media platforms. Our study aims to fill this gap by answering the following research questions:

(1) How should the government implement enforcement under different revenue models?
(2) How does the quality of pirated content affect the optimal enforcement level?
(3) How does consumer nuisance cost for advertisements affect the optimal enforcement level?

To this end, we develop a game-theoretical model where a platform offers services to consumers through one of three revenue models—subscription model, ad-based model, or mixed model—in which the government sets the enforcement level for piracy when it occurs. Under the subscription model, the platform offers consumers a subscription service only by setting a subscription fee; under the ad-based model, the platform only offers consumers an ad-based service by setting advertising times; under the mixed model, the platform offers consumers a subscription service and an ad-based service by setting a subscription fee and advertising times. Consumers who subscribe to the platform's service can enjoy all the content directly; consumers who use the ad-based service can enjoy the content freely but must tolerate advertisements and incur nuisance costs; and consumers who want to enjoy pirated content experience some search costs due to governmental enforcement. Under each model, we derive the optimal enforcement level for the government and pricing and/or advertising strategies for the platform. Through analysis, we obtain the following results with important managerial insights.

First, under each revenue model, the market can be divided into three distinct regions with increases in the government's enforcement levels: the piracy existence region, the piracy threat region, and the piracy disappearance region. The piracy existence region refers to the region where demand for pirated content exists; the piracy threat region is the region where piracy exists in the market, but there is no demand for it; the piracy disappearance region is the region where pirated content has disappeared from the market, and the platform acts as a monopolist. When there is no cost for enforcement, under the subscription and mixed models, the optimal enforcement level lies within the piracy threat region, whereas under the ad-based model, the optimal enforcement level can be achieved in the piracy existence region, and no enforcement occurs. When enforcement incurs costs, the optimal enforcement level may be located in the piracy existence or piracy threat regions.

Second, the optimal enforcement level may decrease with the quality of pirated content, which is in sharp contrast with conventional wisdom. Intuitively, as the quality of pirated content increases, the government should strengthen its enforcement to increase consumer search costs, thus promoting the platform demand and improving social welfare. However, our analysis reveals that when the quality of pirated content is relatively high, the government may lower its enforcement level. The rationale behind this result is as follows. High-quality piracy poses a great threat to the platform. In this case, the platform profit is secondary, and consumer surplus is dominant in social welfare. Expecting that the platform will set a relatively low price, the government softens its enforcement as the quality of pirated content increases, such that the platform further decreases its price. The decreased price greatly increases consumer demand, thereby improving consumer surplus and, thus, social welfare.

Third, the optimal enforcement level decreases with nuisance cost under the ad-based model, whereas it may increase with nuisance cost under the mixed model. This situation arises when the nuisance cost is relatively high, the subscription model starts to come into play. As the nuisance cost increases, the platform has to reduce the subscription fee to attract more consumers to choose the subscription service and shorten the advertising time to retain some consumers who use the ad-based service. According to this expectation, the government sets a higher enforcement level to ensure the platform obtains enough profits, thus improving social welfare.

The paper is organized as follows: In Section 2, we review the relevant literature. In Section 3, we develop a game-theoretical model involving the government, the platform, piracy, and consumers. In Section 4, we derive the optimal strategies for the government and the platform under three platform revenue models. In Section 5, we consider the model with enforcement costs. Subsequently, we extend the base model in Section 6. The final section concludes the paper.

2. Literature review

Our study is mainly related to two streams of research: different revenue models and piracy.

The first related stream involves one [8–11] or several [12–15] revenue models. Chen et al. [16] compared two revenue models for online trading platforms: the advertising and brokerage models. Fan et al. [17] considered the selling or advertising strategies for online digital media. Zhang et al. [18] compared two pricing strategies for information products: free product and bundling. Bhargava [19] considered multiple bundling strategies for digital goods. Cheng et al. [20] considered three software free trial strategies: limited version, time-locked, or hybrid. Recently, Li et al. [21] explored three pricing strategies for digital music and discussed their connections. Amaldoss et al. [22] identified the circumstances under which media platforms adopt the free-content, paid-content-with-ads, or paid-content-with-ads strategy depending on the allocation between content and advertising. Li et al. [23] considered two models for the platform, with the option of a resale model or an agency model. Devalve and Pekeč [24] analyzed the optimal subscription prices and advertising quantities for two-sided media platforms. Jeong et al. [25] examined two contract types and divided piracy risk costs into linear piracy costs and fixed piracy costs.

Our study differs significantly from existing research on digital products. Previous studies on revenue models neglected the impact of piracy. In contrast, we argue that piracy has become a key factor that cannot be ignored when influencing digital product pricing strategies. We contribute to this stream of research by considering different revenue models in the presence of piracy.

The second related stream involves piracy. One branch of this stream explores the optimal pricing or quality of the product when piracy exists [26–31]. Lahiri and Dey [9] studied the quality of information goods that maximize monopolists' profits in the presence of piracy. Chellappa and Shivendu [32] examined the pricing of digital experience goods in vertically segmented markets. Jin et al. [33] considered the pricing problem in the information goods bundling decision in the presence of piracy. Nan et al. [34] considered platform pricing under platform regulation and government direct or indirect regulatory decisions.

Our research differs from previous literature in that it comprehensively examines the pricing strategies of the platform under three revenue models in the presence of piracy by offering a more comprehensive and in-depth analytical perspective.

The second branch of this stream focuses on strategies to reduce piracy. Some studies examined possible ways to combat piracy through price discrimination [35], digital rights management [36], piracy control [37], or versions [38]. Apart from the above anti-piracy methods, Danaher et al. [39] stated that competing with piracy through digital distribution is beneficial for media companies in the face of their inability to prevent the penetration of digital channels. Danaher et al. [40] summarized what businesses can do to compete with piracy. Koh et al. [41] investigated the advent of digital music, which weakens the effect of piracy.

While most previous literature has explored various strategies to reduce piracy from the perspective of platforms, the government-oriented perspective is equally crucial. Governmental regulatory measures, characterized by their enforceability and rigorous legal safeguards, provide more solid support for combating piracy. Therefore, our study focuses on strategies and measures to reduce piracy from the governmental perspective, which complements previous literature.

Other branches of this stream involve piracy regulation. Several studies found that stricter enforcement against piracy may reduce product innovation and social welfare [42–45]. Tsai and Chiou [46] found that strict enforcement does not necessarily result in greater welfare than without enforcement, but sufficiently strict enforcement can increase welfare. Waters [47] found that piracy increases welfare in fixed-size markets, while the opposite is true in growing markets. Nan et al. [48] suggested that higher levels of piracy enforcement can be harmful to firms if the incremental consumer perception of premium quality is higher than the incremental perception of pirated quality. Jain et al. [49] analyzed social welfare in three illegal content monitoring scenarios. Nan et al. [50] investigated the optimal level of protection for monopoly platforms under two revenue models. Sun et al. [51] studied two effects that can arise from piracy regulation by software firms and explored the impact of these two effects on the regulation and profits.

Unlike previous studies, we not only analyze in-depth the government's enforcement efforts in combating piracy, but also explore the impact of piracy quality on regulation efforts. In addition, we consider the enforcement level as an endogenous variable, and specifically consider the complex situation of a duopoly market, which greatly enriches the existing research content in this field and provides novel insights.

3. Model

Consider a media platform that provides services to consumers in a market where piracy exists. The media platform may use one of three revenue models: the subscription model, the ad-based model, or the mixed model. Under the subscription model, the platform only offers consumers a subscription service; under the ad-based model, the platform only offers consumers an ad-based free service; under the mixed model, the platform offers consumers both a subscription service and an ad-based free service. Subscribers can access all content directly, whereas users of the ad-based service can access content for free but must tolerate advertisements. We assume that the content quality in the subscription service is higher than that in the ad-based service. Formally, the content quality in the subscription service is denoted by q and that in the ad-based service is denoted by αq, where $0 < \alpha < 1$. This assumption is based on the fact that subscription services provided by most media platforms (such as Pandora, Spotify, Youku, and Tencent Video) offer higher content quality than those provided by free services. In particular, Spotify claims a music quality of 160 Kbps for ad-based consumers and 320 Kbps for subscribers.[2] Also, it is common knowledge that one can obtain the best quality service by paying for it.

Pirated media content is illegal media copied from the legitimate versions of the subscription or ad-based services using stream-ripping software or mobile apps. Therefore, the quality of piracy largely depends on the state of the software or mobile apps used for replication, and its quality usually does not exceed that of the legitimate version of the replicated product. Formally, we assume that the quality of the pirated content is βq, where $0 < \beta < 1$. Notably, the quality of the pirated content can be lower or higher than the quality of the ad-based service. If the pirated content is copied from the ad-based service, then the quality of the pirated content is undoubtedly lower than that of the ad-based service, i.e., $\alpha > \beta$. However, the quality of the pirated content can be higher than that of the ad-based service if the pirated content is copied from the subscription service, i.e., $\alpha < \beta$.

The consumer type distribution is common knowledge, but the type of each consumer is known only to herself. Each consumer demands, at most, one unit of the service. Consumers are heterogeneous in their preferences for quality v, which is uniformly distributed over [0,1].

We first explore the utility function of consumers under the subscription service. Consumers who use the subscription service need to pay a subscription fee to access unlimited media content on the platform. Following previous literature [17,21], the net utility that the consumer of type v obtains from the subscription service is given by

$$U_s = vq - P, \tag{1}$$

where P represents the subscription fee for the entire lifecycle of the media service.

We then derive the utility function of consumers under the ad-based service. Consumers who utilize the ad-based service incur no fee but must tolerate the advertisements. The presence of advertisements hinders their experience, thus triggering user dissatisfaction, which is termed nuisance cost. Following the previous literature [52], the net utility that the consumer of type v obtains from the ad-based service is given by

$$U_a = v\alpha q - \theta A, \tag{2}$$

where A represents the advertising time and $\theta > 0$ denotes the nuisance cost per unit of advertising time that the consumer incurs.

Finally, we investigate the utility function of consumers under the piracy service. The utility of consumers who utilize pirated content is related to the enforcement level E. Higher enforcement levels imply greater difficulty for consumers in accessing pirated content. Consequently, the utility for consumers who use pirated content is given by

$$U_p = v\beta q - E. \tag{3}$$

Following the literature of information goods [21,53], the marginal production cost of media content is designated as zero.

Generally, the government's policymaking is a long-term decision and difficult to change, while the platform's marketing strategies are more flexible. In addition, ex-post enforcement may be too slow to maintain market competitiveness [54] successfully. In line with previous literature [34], we construct the game where the government acts as the leader and the platform acts as the follower. Specifically, the sequence of events is as follows for each revenue model (subscription, ad-based, or mixed models). First, social planners decide the optimal enforcement level. Second, the platform sets the subscription fee and/or advertising time. Third, consumers decide whether to consume the platform's service(s), the pirated content, or nothing. Table 1 provides the notations used throughout the paper.

4. Equilibrium analysis

In this section, we analyze the equilibrium solutions under the subscription, ad-based, and mixed models. We solve the game under each revenue model by backward induction. We use superscripts S, A, and M to represent the subscription, ad-based, and mixed models, respectively. Within the mixed model, we use superscripts ML and MH to denote scenarios where the quality of pirated content is lower and higher than

[2] See https://support.spotify.com/us/article/audio-quality/ (accessed on May 12, 2024).

Table 1
Summary of notations.

Notation	Definition
i	Revenue model, $i \in \{S, A, M\}$ represents subscription, ad-based, mixed models, respectively
v	The consumer's valuation of the quality
q	The quality of the content in the subscription service
α	The quality discount coefficient of the content in the ad-based service
β	The quality discount coefficient of the pirated content
P	Price of the subscription service
θ	The nuisance cost of advertising to consumers
A	Advertising time for ad-based service
E	Intensity of enforcement
ξ	Advertisement revenue rate
k	Enforcement costs
π^i	Profit under model i
CS^i	Consumer surplus under model i
SW^i	Social welfare under model i

that of ad-based service, respectively.

4.1. Subscription model

Under the subscription model, we denote the marginal consumer who is indifferent between subscribing to the platform's service and using pirated content by v_1^S, and the marginal consumer who is indifferent between using pirated content and forgoing the use of media services by v_2^S. The consumers' choices are illustrated in Fig. 1. Solving $U_s = U_p$ and $U_p = 0$ simultaneously yields $v_1^S = \frac{P-E}{(1-\beta)q}$ and $v_2^S = \frac{E}{\beta q}$. Consumers with valuations in the interval $[v_1^S, 1]$ subscribe to the platform service; those with valuations in the interval $[v_2^S, v_1^S]$ choose pirated content; and those with valuations in the interval $[0, v_2^S]$ forgo the use of a media service. Correspondingly, the subscription demand and pirated content demand are given by $Q_s^S = 1 - v_1^S$ and $Q_p^S = v_1^S - v_2^S$, respectively. When $v_1^S \le v_2^S$, the demand for pirated content is zero. Correspondingly, the subscription demand is given by $Q_s^S = 1 - \frac{P}{q}$.

In sum, the subscription demand and pirated content demand are given by

$$\{Q_s^S, Q_p^S\} = \begin{cases} \left\{1 - \dfrac{P}{q}, 0\right\}, & \text{if } v_1^S \le v_2^S, \\ \left\{1 - \dfrac{P-E}{(1-\beta)q}, \dfrac{P-E}{(1-\beta)q} - \dfrac{E}{\beta q}\right\}, & \text{otherwise.} \end{cases} \tag{4}$$

Correspondingly, the platform's profit under the subscription model is given by

$$\pi^S = \begin{cases} P\left(1 - \dfrac{P}{q}\right), & \text{if } v_1^S \le v_2^S, \\ P\left(1 - \dfrac{P-E}{(1-\beta)q}\right), & \text{otherwise.} \end{cases} \tag{5}$$

Social planners, who are often affiliated with governmental agencies, are individuals tasked with formulating anti-piracy strategies. The main metric considered by social planners to implement anti-piracy strategy selection is social welfare (SW), which is the sum of consumer surplus and profit. Consumer surplus (CS) refers to the difference between the price consumers are willing to pay and the actual price they pay. Therefore, social welfare can be expressed as follows:

$$SW^S = \pi^S + CS^S. \tag{6}$$

Fig. 1. Consumers' choices under the subscription model.

Here,

$$CS^S = \begin{cases} \displaystyle\int_{\frac{P}{q}}^{1} (vq - P)\mathrm{d}v, & \text{if } v_1^S \le v_2^S, \\ \displaystyle\int_{\frac{P-E}{(1-\beta)q}}^{1} (vq - P)\mathrm{d}v, & \text{otherwise.} \end{cases} \tag{7}$$

In line with previous literature [9], we exclude the surpluses of illegal users because it is improbable that social planners would be interested in promoting the well-being of such individuals. Given enforcement level E, maximizing the platform's profit yields the optimal pricing strategy in Lemma 1.

Lemma 1. *Under the subscription model, given the enforcement level E, the platform's optimal pricing strategy is summarized in Table 2.*

Lemma 1 shows that when the enforcement level is relatively low, i.e., $0 \le E < \frac{(1-\beta)\beta q}{2-\beta}$, some consumers choose pirated content. We refer to this region as the *piracy existence region*. The substitutability between the platform's service and pirated content drives the platform to set a lower price to stimulate consumers to subscribe to the platform's service. As the enforcement level increases, both the subscription fee and the number of subscribers increase. The increases in subscription fees and the number of subscribers increase the platform's profit.

When the enforcement level is moderate, i.e., $\frac{(1-\beta)\beta q}{2-\beta} \le E < \frac{\beta q}{2}$, no consumers choose pirated content, but the subscription fee is still related to the quality of pirated content. This condition occurs because the media platform regards pirated content as a threat and sets a sufficiently low price such that no demand exists for pirated content. From another point of view, piracy acts as a competitor, ensuring that the platform cannot overprice its subscription fee. We refer to this region as the *piracy threat region*. As the enforcement level increases, the threat of piracy gradually weakens. Therefore, the subscription fee gradually increases, which prevents some consumers from signing up for the platform. Although the number of consumers decreases, the decreased profit due to the decrease in the number of consumers is sufficiently compensated by the increased profit due to the increase in subscription fees, thereby increasing the platform's profit.

When the enforcement level is relatively high, i.e., $\frac{\beta q}{2} \le E \le \beta q$, no one opts for pirated content and the platform acts as a monopolist. We refer to this region as the *piracy disappearance region*. In this region, the platform's profit and subscription fee ultimately are independent of E. The following Proposition 1 characterizes the optimal enforcement level.

Proposition 1. *Under the subscription model, the optimal enforcement level is given by* $E^{S*} = \frac{(1-\beta)\beta q}{2-\beta}$. *It increases in* β *when* $\beta \in (0, 2-\sqrt{2}]$ *and decreases when* $\beta \in (2-\sqrt{2}, 1)$.

Proposition 1 shows that under the subscription model, the optimal enforcement level is achieved at the boundary line between the piracy existence region and the piracy threat region. The reason for this condition is as follows. In the piracy existence region, as the enforcement level increases, the subscription fee and the number of subscribers increase simultaneously. This greatly improves the platform's profit, thus increasing the total social welfare. In contrast, in the piracy threat region, the increased subscription fee due to stricter enforcement lowers consumer demand while increasing profit. The decrease in consumer demand combined with the decrease in the average surplus leads to a rapid decline in total consumer surplus. The increase in platform profit cannot offset the decrease in consumer surplus, ultimately leading to a decrease in social welfare. Therefore, social welfare decreases in the piracy threat region.

Proposition 1 also shows an interesting result: The optimal enforcement level can decrease with the quality of pirated content, which contrasts with the intuition that social planners should strengthen their

Table 2
Optimal responses of the platform under the subscription model.

Regions	p^{S^*}	$Q_s^{S^*}$	$Q_p^{S^*}$	π^{S^*}
$0 \leq E < \frac{(1-\beta)\beta q}{2-\beta}$	$\frac{E+(1-\beta)q}{2}$	$\frac{E+(1-\beta)q}{2q(1-\beta)}$	$\frac{E\beta-2E+\beta q-\beta^2 q}{2q(1-\beta)\beta}$	$\frac{(E+(1-\beta)q)^2}{4q(1-\beta)}$
$\frac{(1-\beta)\beta q}{2-\beta} \leq E < \frac{\beta q}{2}$	$\frac{E}{\beta}$	$\frac{\beta q - E}{\beta q}$	0	$\frac{E(\beta q - E)}{\beta^2 q}$
$\frac{\beta q}{2} \leq E \leq \beta q$	$\frac{q}{2}$	$\frac{1}{2}$	0	$\frac{q}{4}$

enforcement as the quality of the pirated content increases. This reason is that when the quality of the pirated content is sufficiently high, piracy poses a great threat to the platform. In this case, the platform profit plays a secondary role, and consumer surplus plays a dominant role in social welfare. Expecting that the platform will set a sufficiently low price, the government softens its enforcement as the quality of the pirated content increases, such that the platform further decreases its price. The decreased price greatly increases consumer demand, thereby improving consumer surplus and thus social welfare.

4.2. Ad-based model

Under the ad-based model, we denote the marginal consumer who is indifferent between the platform ad-based service and using pirated content by v_1^A, and the marginal consumer who is indifferent between using pirated content and forgoing the use of media services by v_2^A. Consumers' choices are illustrated in Fig. 2. Specifically, consumers with valuations in the interval $[v_1^A, 1]$ use the ad-based service; those with valuations in the interval $[v_2^A, v_1^A]$ choose pirated content and those with valuations in the interval $[0, v_2^A]$ forgo the use of media service. By using $U_a = U_p$ and $U_p = 0$, we obtain $v_1^A = \frac{\theta A - E}{(\alpha-\beta)q}$ and $v_2^A = \frac{E}{\beta q}$. Therefore, the ad-based demand and piracy demand are given by $Q_a^A = 1 - v_1^A$ and $Q_p^A = v_1^A - v_2^A$, respectively. When $v_1^A \leq v_2^A$, the demand for piracy is zero. Correspondingly, the ad-based demand is given by $Q_a^A = 1 - \frac{\theta A}{\alpha q}$.

In sum, the ad-based demand and pirated demand are given by

$$\{Q_a^A, Q_p^A\} = \begin{cases} \left\{1 - \dfrac{\theta A}{\alpha q}, 0\right\}, & \text{if } v_1^A \leq v_2^A, \\ \left\{1 - \dfrac{\theta A - E}{(\alpha-\beta)q}, \dfrac{\theta A - E}{(\alpha-\beta)q} - \dfrac{E}{\beta q}\right\}, & \text{otherwise.} \end{cases} \tag{8}$$

The profit of the platform under the ad-based model is given by

$$\pi^A = \begin{cases} \xi A\left(1 - \dfrac{\theta A}{\alpha q}\right), & \text{if } v_1^A \leq v_2^A, \\ \xi A\left(1 - \dfrac{\theta A - E}{(\alpha-\beta)q}\right), & \text{otherwise.} \end{cases} \tag{9}$$

Here, $\xi > 0$ is the advertisement revenue rate.

Then, the social welfare under the ad-based model is given by

$$SW^A = \pi^A + CS^A, \tag{10}$$

where

$$CS^A = \begin{cases} \displaystyle\int_{\frac{\theta A}{\alpha q}}^{1} (v\alpha q - \theta A)\mathrm{d}v, & \text{if } v_1^A \leq v_2^A, \\ \displaystyle\int_{\frac{\theta A - E}{(\alpha-\beta)q}}^{1} (v\alpha q - \theta A)\mathrm{d}v, & \text{otherwise.} \end{cases} \tag{11}$$

Fig. 2. Consumers' choices under the ad-based model.

Given enforcement level E, maximizing the platform's profit yields the optimal advertising strategy in Lemma 2.

Lemma 2. *Under the ad-based model, given the enforcement level E, the platform's optimal advertising strategy is summarized in Table 3.*

The outcomes in Lemma 2 are similar to those in Lemma 1. When the enforcement level is relatively low, i.e., $0 \leq E < \frac{(\alpha-\beta)\beta q}{2\alpha-\beta}$, the platform shares the market with piracy and some consumers choose to obtain the pirated content. This region is referred to as the *piracy existence region*. As the enforcement level increases, the length of the advertising time and the demand for ad-based services increase, making the platform more profitable. When the enforcement level is moderate, i.e., $\frac{(\alpha-\beta)\beta q}{2\alpha-\beta} \leq E < \frac{\beta q}{2}$, piracy poses threats to the platform's service, but there is no demand for it. This region is the *piracy threat region*. As the enforcement level increases, the platform has a motivation to increase its advertising time, and the demand for ad-based services decreases. However, the rise in profit from additional advertising compensates for the loss in profit resulting from the decrease in demand, leading to an overall increase in profit. When the enforcement level is relatively high, i.e., $\frac{\beta q}{2} \leq E \leq \beta q$, a strong enforcement level has driven piracy out of the market. This region is the *piracy disappearance region*. Neither the advertising time nor the platform profit depends on the enforcement level. The following Proposition 2 characterizes the optimal enforcement level under the ad-based model.

Proposition 2. *Under the ad-based model, the optimal enforcement level is as follows:*

(1) When $0 < \theta < \xi$, the optimal enforcement level is given by

$$E^{A^*} = \begin{cases} \dfrac{(\alpha-\beta)\beta q}{2\alpha-\beta}, & \text{if } 0 < \beta \leq \dfrac{\alpha\theta}{\xi}, \\ \dfrac{(\theta-\xi)\beta q}{\theta-2\xi}, & \text{if } \dfrac{\alpha\theta}{\xi} < \beta < \alpha. \end{cases}$$

It increases in β when $0 < \theta \leq (2-\sqrt{2})\xi$. When $(2-\sqrt{2})\xi < \theta < \xi$, it increases first in β when $\beta \in (0, (2-\sqrt{2})\alpha]$, then decreases when $\beta \in \left((2-\sqrt{2})\alpha, \frac{\alpha\theta}{\xi}\right]$, and finally increases in β when $\beta \in \left(\frac{\alpha\theta}{\xi}, \alpha\right)$.

(2) When $\xi \leq \theta \leq 2\xi$, the optimal enforcement level is given by $E^{A^*} = \frac{(\alpha-\beta)\beta q}{2\alpha-\beta}$. It increases in β when $\beta \in (0, (2-\sqrt{2})\alpha]$ and decreases when $\beta \in ((2-\sqrt{2})\alpha, \alpha)$.

(3) When $\theta > 2\xi$, the optimal enforcement level is given by

$$E^{A^*} = \begin{cases} 0, & \text{if } 0 < \beta \leq \dfrac{\alpha(\theta-2\xi)}{2(\theta-\xi)}, \\ \dfrac{q(\alpha-\beta)(2\beta\theta+2\alpha\xi-\alpha\theta-2\beta\xi)}{3\alpha\theta-2\beta\theta-2\alpha\xi+2\beta\xi}, & \text{if } \dfrac{\alpha(\theta-2\xi)}{2(\theta-\xi)} < \beta < \alpha. \end{cases}$$

It first remains unchanged in β when $\beta \in \left(0, \frac{\alpha(\theta-2\xi)}{2(\theta-\xi)}\right]$, then increases when $\beta \in \left(\frac{\alpha(\theta-2\xi)}{2(\theta-\xi)}, \frac{3\alpha\theta-\sqrt{2}\alpha\theta-2\alpha\xi}{2\theta-2\xi}\right]$, and finally decreases in β when $\beta \in \left(\frac{3\alpha\theta-\sqrt{2}\alpha\theta-2\alpha\xi}{2\theta-2\xi}, \alpha\right)$.

Table 3
Optimal responses of the platform under the ad-based model.

Regions	A^{A^*}	$Q_a^{A^*}$	$Q_p^{A^*}$	π^{A^*}
$0 \le E < \frac{(\alpha-\beta)\beta q}{2\alpha-\beta}$	$\frac{E+(\alpha-\beta)q}{2\theta}$	$\frac{E+\alpha q-\beta q}{2q(\alpha-\beta)}$	$\frac{E\beta-2\alpha E+\alpha q\beta-q\beta^2}{2(\alpha-\beta)\beta q}$	$\frac{(E+(\alpha-\beta)q)^2\xi}{4\theta q(\alpha-\beta)}$
$\frac{(\alpha-\beta)\beta q}{2\alpha-\beta} \le E < \frac{\beta q}{2}$	$\frac{\alpha E}{\theta\beta}$	$\frac{\beta q-E}{\beta q}$	0	$\frac{E\alpha(\beta q-E)\xi}{q\beta^2\theta}$
$\frac{\beta q}{2} \le E \le \beta q$	$\frac{\alpha q}{2\theta}$	$\frac{1}{2}$	0	$\frac{\alpha q\xi}{4\theta}$

Proposition 2 shows that the optimal enforcement level depends on the nuisance cost θ. Specifically, when the nuisance cost is relatively small, i.e., $0 < \theta \le 2\xi$, the optimal enforcement level is located in the piracy threat region. In contrast, when the nuisance cost is relatively great, i.e., $\theta > 2\xi$, the optimal enforcement level is located in the piracy existence region. In particular, when the quality of the pirated content is not too high, i.e., $0 < \beta \le \frac{\alpha(\theta-2\xi)}{2(\theta-\xi)}$, the government even chooses to give up enforcement. The intuition is as follows. A great nuisance cost prevents the platform from setting a long advertising time. If the government increases its enforcement efforts, the strengthened enforcement allows the platform to implement longer advertising times, greatly lowering consumer demand and surplus. Thus, the government sets a low enforcement level so that a demand for piracy exists.

Fig. 3 illustrates how the quality of pirated content affects the optimal enforcement level under the ad-based model.

When β is relatively low, the optimal enforcement level usually increases with β, except when θ is large. This condition occurs because when the quality of pirated content is low, consumers generally accept pirated content less, and piracy poses a relatively small threat to the platform. In such cases, the government increases enforcement efforts to combat piracy, which increases consumer demand and platform profit. Thus, social welfare also increases. However, when θ is large, consumers have a strong nuisance to advertising, and altering their choice of platform service would be difficult even with increased enforcement efforts. In addition, the quality of pirated content is very low, thus posing no substantial threat to the platform. Consequently, the government will not implement enforcement against piracy.

When β is large, the optimal enforcement level increases with β if θ is small and decreases with β if θ is large, because a larger β has a negative impact on platform profit and a positive impact on consumer surplus. When θ is small, the platform is more attractive to consumers, which is why platform profit plays a dominant role in social welfare. As the quality of pirated content increases, the government raises the enforcement level to increase the platform demand and allow the platform to increase the advertising time, thus improving the platform's profit and social welfare. In contrast, when θ is large, consumer surplus plays a dominant role in social welfare. As the quality of pirated content increases, the government lowers the enforcement level such that the platform has to shorten the advertising time, which increases consumer surplus and thus improves social welfare.

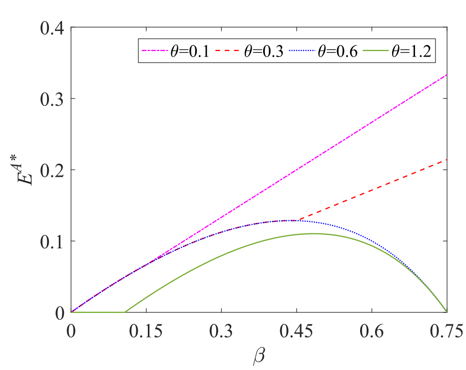


Fig. 3. Optimal enforcement level E^{A^*} varies with β ($\alpha = 0.75, q = 1, \xi = 0.5$).

Corollary 1 states how the nuisance cost θ affects the optimal enforcement level.

Corollary 1. *Under the ad-based model, the optimal enforcement level (weakly) decreases with θ.*

Corollary 1 shows that the optimal enforcement level (weakly) decreases as the nuisance cost increases. This result occurs because a higher nuisance cost can prevent the platform from setting a longer advertising time. Therefore, the government lowers its enforcement level to force the platform to further shorten its advertising time and promote platform demand, thus improving consumer surplus and social welfare.

4.3. *Mixed model*

Under the mixed model, the platform provides consumers with both a subscription service and an ad-based service. Consumers have four options: subscribing to the platform's service, adopting the platform's ad-based service, using pirated content, or forgoing all of the above. It is noted that the quality of pirated content can be lower or higher than that of the content provided by the ad-based service. Therefore, we conduct equilibrium analysis in two cases: $\beta < \alpha$ and $\beta > \alpha$.

4.3.1. *Case $\beta < \alpha$*

In this case, the quality of the pirated content is lower than that of the content provided by the ad-based service. Fig. 4 illustrates consumers' choices with $v_3^{ML} < v_2^{ML} \le v_1^{ML} \le 1$, where v_1^{ML} denotes the marginal consumer who is indifferent between opting for the subscription service and adopting the ad-based service, v_2^{ML} denotes the marginal consumer who is indifferent between adopting the ad-based service and acquiring pirated content, and v_3^{ML} denotes the marginal consumer who is indifferent between using pirated content and forgoing the use of media service. Solving $U_s = U_a$, $U_a = U_p$, and $U_p = 0$ simultaneously, yields $v_1^{ML} = \frac{P-\theta A}{(1-\alpha)q}$, $v_2^{ML} = \frac{\theta A-E}{(\alpha-\beta)q}$, and $v_3^{ML} = \frac{E}{\beta q}$. Correspondingly, consumers with valuations in the interval $[v_1^{ML}, 1]$ subscribe to the platform service; those with valuations in the interval $[v_2^{ML}, v_1^{ML}]$ adopt the ad-based service; those with valuations in the interval $[v_3^{ML}, v_2^{ML}]$ choose pirated content; and those with valuations in the interval $[0, v_3^{ML}]$ forgo the use of media service. Therefore, the demands for the subscription service, the ad-based service, and the pirated content are given by $Q_s^{ML} = 1 - v_1^{ML}$, $Q_a^{ML} = v_1^{ML} - v_2^{ML}$, and $Q_p^{ML} = v_2^{ML} - v_3^{ML}$, respectively.

If $v_2^{ML} \le v_3^{ML} \le v_1^{ML} \le 1$, then the demand for the pirated content is zero. Correspondingly, the demands for the subscription service and the ad-based service are given by $Q_s^{ML} = 1 - \frac{P-\theta A}{(1-\alpha)q}$ and $Q_a^{ML} = \frac{P-\theta A}{(1-\alpha)q} - \frac{\theta A}{\alpha q}$. If $v_1^{ML} < v_2^{ML}$, then the mixed model reduces to the subscription model; if $v_1^{ML} > 1$, then the mixed model reduces to the ad-based model.

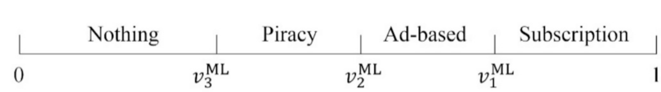


Fig. 4. Consumers' choices under the mixed model with $\beta < \alpha$.

In sum, the demands for the subscription service, the ad-based service, and the pirated content under the mixed model with $\beta < \alpha$ are as follows:

$$\left\{Q_s^{\mathrm{ML}}, Q_a^{\mathrm{ML}}, Q_p^{\mathrm{ML}}\right\} = \begin{cases} \left\{1 - \dfrac{P-\theta A}{(1-\alpha)q}, \dfrac{P-\theta A}{(1-\alpha)q} - \dfrac{\theta A - E}{(\alpha-\beta)q}, \dfrac{\theta A - E}{(\alpha-\beta)q} - \dfrac{E}{\beta q}\right\}, & \text{if } v_3^{\mathrm{ML}} < v_2^{\mathrm{ML}} \le v_1^{\mathrm{ML}} \le 1, \\ \left\{1 - \dfrac{P-\theta A}{(1-\alpha)q}, \dfrac{P-\theta A}{(1-\alpha)q} - \dfrac{\theta A}{\alpha q}, 0\right\}, & \text{if } v_2^{\mathrm{ML}} \le v_3^{\mathrm{ML}} \le v_1^{\mathrm{ML}} \le 1. \end{cases} \tag{12}$$

Therefore, the platform's profit is given by

$$\pi^{\mathrm{ML}} = \begin{cases} P\left(1 - \dfrac{P-\theta A}{(1-\alpha)q}\right) + \xi A\left(\dfrac{P-\theta A}{(1-\alpha)q} - \dfrac{\theta A - E}{(\alpha-\beta)q}\right), & \text{if } v_3^{\mathrm{ML}} < v_2^{\mathrm{ML}} \le v_1^{\mathrm{ML}} \le 1, \\ P\left(1 - \dfrac{P-\theta A}{(1-\alpha)q}\right) + \xi A\left(\dfrac{P-\theta A}{(1-\alpha)q} - \dfrac{\theta A}{\alpha q}\right), & \text{if } v_2^{\mathrm{ML}} \le v_3^{\mathrm{ML}} \le v_1^{\mathrm{ML}} \le 1. \end{cases} \tag{13}$$

The social welfare is as follows:

$$SW^{\mathrm{ML}} = \pi^{\mathrm{ML}} + CS^{\mathrm{ML}}, \tag{14}$$

where

$$CS^{\mathrm{ML}} = \begin{cases} \displaystyle\int_{\frac{P-\theta A}{(1-\alpha)q}}^{1} (vq - P)\mathrm{d}v + \int_{\frac{\theta A - E}{(\alpha-\beta)q}}^{\frac{P-\theta A}{(1-\alpha)q}} (v\alpha q - \theta A)\mathrm{d}v, & \text{if } v_3^{\mathrm{ML}} < v_2^{\mathrm{ML}} \le v_1^{\mathrm{ML}} \le 1, \\ \displaystyle\int_{\frac{P-\theta A}{(1-\alpha)q}}^{1} (vq - P)\mathrm{d}v + \int_{\frac{\theta A}{\alpha q}}^{\frac{P-\theta A}{(1-\alpha)q}} (v\alpha q - \theta A)\mathrm{d}v, & \text{if } v_2^{\mathrm{ML}} \le v_3^{\mathrm{ML}} \le v_1^{\mathrm{ML}} \le 1. \end{cases} \tag{15}$$

Given enforcement level E, maximizing the platform's profit yields the optimal joint pricing and advertising strategy in Lemma 3.

Lemma 3. *Under the mixed model with $\beta < \alpha$, given enforcement level E, the platform's optimal joint pricing and advertising strategy is summarized in Table 4.*

The results in Lemma 3 can be best presented graphically in Fig. 5, which illustrates the results as a function of the enforcement level E and nuisance cost θ. As under the subscription and ad-based models, under the mixed model with $\beta < \alpha$, the figure is similarly partitioned into three

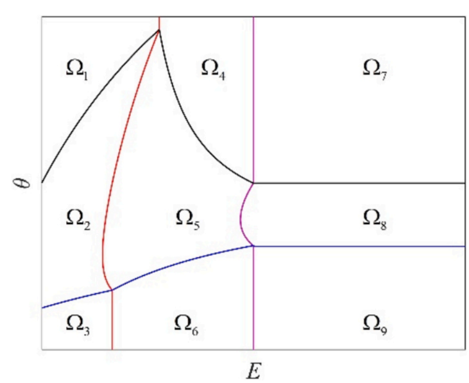


Fig. 5. Best responses of the platform under the mixed model with $\beta < \alpha$.

Table 4
Optimal responses of the platform under the mixed model with $\beta < \alpha$.

Regions	$P^{\mathrm{ML}*}$	$A^{\mathrm{ML}*}$
Ω_1	$\dfrac{E + (1-\beta)q}{2}$	$\dfrac{E(2-\alpha-\beta) + q(\alpha-\beta)(1-\beta)}{2(1-\beta)\theta}$
Ω_2	$\dfrac{\xi(\alpha-1)((E+(1-\beta)2q)\theta + E\xi)}{(\alpha-\beta)\theta^2 + 2\xi(\alpha+\beta-2)\theta + \xi^2(\alpha-\beta)}$	$\dfrac{(\alpha-1)((\alpha-\beta)q\theta + (2E+(\alpha-\beta)q)\xi)}{(\alpha-\beta)\theta^2 + 2\xi(\alpha+\beta-2)\theta + \xi^2(\alpha-\beta)}$
Ω_3	$\dfrac{E + (2-\alpha-\beta)q}{2}$	$\dfrac{E + (\alpha-\beta)q}{2\theta}$
Ω_4	$\dfrac{E}{\beta}$	$\dfrac{E\alpha}{\beta\theta}$
Ω_5	$\dfrac{E\alpha(\theta+\xi) + (1-\alpha)\beta\theta q}{2\beta\theta}$	$\dfrac{E\alpha}{\beta\theta}$
Ω_6	$\dfrac{E\alpha + (1-\alpha)\beta q}{\beta}$	$\dfrac{E\alpha}{\beta\theta}$
Ω_7	$\dfrac{q}{2}$	$\dfrac{\alpha q}{2\theta}$
Ω_8	$\dfrac{2q(1-\alpha)\theta\xi}{4\theta\xi - \alpha(\theta+\xi)^2}$	$\dfrac{\alpha q(1-\alpha)(\theta+\xi)}{4\theta\xi - \alpha(\theta+\xi)^2}$
Ω_9	$\dfrac{(2-\alpha)q}{2}$	$\dfrac{\alpha q}{2\theta}$

regions according to the magnitude of E: the *piracy existence region* (regions Ω_1–Ω_3), the *piracy threat region* (regions Ω_4–Ω_6), and the *piracy disappearance region* (regions Ω_7–Ω_9).

When θ is relatively small (regions Ω_3, Ω_6, Ω_9), a lower nuisance cost drives consumers to prefer the ad-based service with numerous advertisements over the subscription service with a high subscription fee, which leads to no consumer choosing to subscribe. In these regions, the platform makes a profit only from the ad-based service. When θ is moderate (regions Ω_2, Ω_5, Ω_8), the increase in nuisance cost leads to a decrease in demand for the ad-based service, reducing the space available for advertisements on the platform and limiting the revenue generated from advertisements. In terms of the platform, the best way to address the issue of declining profit caused by a decrease in ad-based consumers is to generate profit from a subscription service by reducing subscription fees. In these regions, the platform earns profit from both the subscription service and the ad-based service. When θ is high (regions Ω_1, Ω_4, Ω_7), although advertising time decreases with θ, the nuisance cost is large enough to drive consumers away from the ad-based service, thereby leading to only the demand for the subscription service. In these regions, the platform makes a profit only from the subscription service.

From Lemma 3, we can straightforwardly conclude the profit source of the platform under the mixed model with $\beta < \alpha$ in Corollary 2.

Corollary 2. *Under the mixed model with* $\beta < \alpha$, *there exist two thresholds of* θ, θ_1^{ML} *and* θ_2^{ML}, *such that the platform makes a profit only from the ad-based service if* $0 < \theta \leq \theta_1^{ML}$; *the platform makes a profit from both the subscription service and the ad-based service if* $\theta_1^{ML} < \theta \leq \theta_2^{ML}$; *the platform makes a profit only from the subscription service, otherwise. Here,* θ_1^{ML} *and* θ_2^{ML} *are given in the Online Appendix Part A.*

Proposition 3 characterizes the optimal enforcement level under the mixed model with $\beta < \alpha$.

Proposition 3. *Under the mixed model with* $\beta < \alpha$, *the optimal enforcement level is located in the piracy threat region. It can be non-monotonic with respect to* β *and* θ.

Proposition 3 indicates that under the mixed model with $\beta < \alpha$, the optimal enforcement level lies in the piracy threat region where piracy exists in the market, but there is no demand for it. Specifically, when the quality of pirated content is low, the optimal enforcement level is usually taken at the boundary line between the piracy existence and piracy threat regions; when the quality of pirated content is high, enforcement efforts are correspondingly intensified, falling within the piracy threat region. However, there exists a special scenario where, when $\frac{1}{2}(3\xi - \alpha\xi) + \frac{1}{2}\xi\sqrt{9 - 10\alpha + \alpha^2} < \theta < \frac{2\xi - \alpha\xi}{\alpha} + \frac{2\xi}{\alpha}\sqrt{1-\alpha}$ (see the proof of Proposition 3 in the Online Appendix Part A), in cases of high-quality pirated content, enforcement efforts will decrease from within the piracy threat region to the boundary line. Fig. 6(a) illustrates how the optimal enforcement level varies with β for different values of θ.

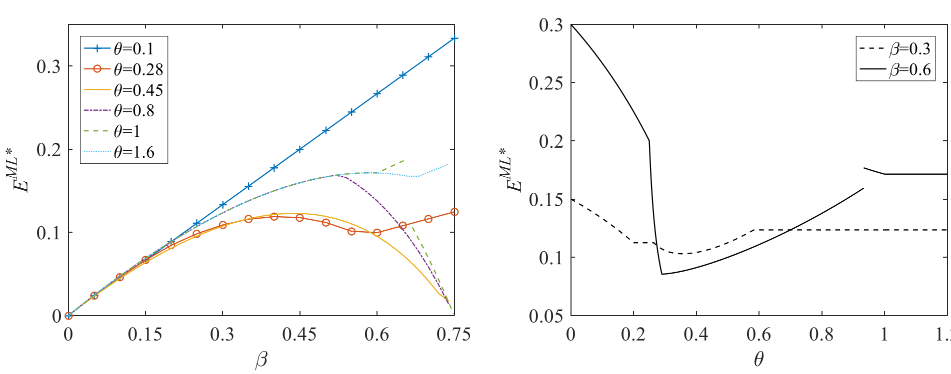
The reason behind this may be that when the quality of pirated content is low, the threat it poses to the media platform is relatively small. Consequently, social planners adopt a relatively lenient strategy, with the optimal enforcement level falling on the boundary line between the piracy existence and threat regions. However, as the quality of pirated content gradually improves, the threat posed by pirated content to the media platform increases significantly. Consequently, social planners will correspondingly intensify enforcement efforts in response to the rise in piracy quality. Therefore, the optimal enforcement level is achieved within the piracy threat region.

However, in an exceptional case, when $\frac{1}{2}(3\xi - \alpha\xi) + \frac{1}{2}\xi\sqrt{9 - 10\alpha + \alpha^2} < \theta < \frac{2\xi - \alpha\xi}{\alpha} + \frac{2\xi}{\alpha}\sqrt{1-\alpha}$, the optimal enforcement strategy exhibits different trends. This phenomenon primarily arises because, when θ is relatively high, the media platform confronts the transition between subscription and mixed models. When the quality of pirated content is high, the platform's optimal strategy shifts towards the mixed model, attracting consumers who use pirated content to switch to the legitimate platform by offering an ad-based service. Since the platform can effectively direct consumers from pirated websites to the legitimate platform through an ad-based service, it alleviates the issue of piracy to a certain extent. In this scenario, social planners appropriately reduce enforcement efforts, causing the optimal enforcement level to shift from the piracy threat region to the boundary line between the piracy existence region and the piracy threat region.

The optimal enforcement level under the mixed model can also be non-monotonic with respect to θ, as shown in Fig. 6(b). When θ is low, the mixed model degenerates into the ad-based model where the optimal enforcement level decreases with θ, which is consistent with Corollary 1. As θ increases, the platform's optimal revenue strategy shifts towards a mixed model. When θ is relatively low, advertisements hold appeal for consumers. Consequently, the intensity of enforcement exerted by social planners on piracy tends to diminish slightly. However, as θ increases, more and more consumers are turning to the subscription service. Accordingly, the platform's revenue model gradually transitions towards the subscription model. The attractiveness of ad-based service diminishes due to rising nuisance cost, and pirated content begins to exert a certain degree of temptation on consumers. Consequently, social planners need to enhance their enforcement. When θ reaches a high level, the subscription model starts to come into play. Since the subscription model is unrelated to the nuisance cost, the optimal enforcement level is independent of θ.

4.3.2. Case $\beta > \alpha$

In this case, the quality of the pirated content is higher than that of the content provided by the ad-based service. Consumers who prefer high quality tend to favor piracy over ad-based services. Fig. 7 illustrates



(a) with respect to β (b) with respect to θ

Fig. 6. Optimal enforcement level E^{ML^*} ($\alpha = 0.75, q = 1, \xi = 0.5$).

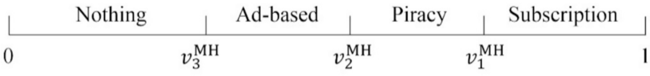


Fig. 7. Consumers' choice under the mixed model with $\beta > \alpha$.

consumers' choices with $v_3^{MH} \leq v_2^{MH} < v_1^{MH} \leq 1$, where v_1^{MH} denotes the marginal consumer who is indifferent between subscribing to a service and using pirated content, v_2^{MH} denotes the marginal consumer who is indifferent between adopting the ad-based service and using pirated content, and v_3^{MH} denotes the marginal consumer who is indifferent between adopting the ad-based service and giving up the use of media service.

Similar to Case $\beta < \alpha$, we can obtain the equilibrium enforcement level and pricing and advertising strategies, which are given in the Online Appendix Part B. Fig. 8 shows the platform's best responses under the mixed model with $\beta > \alpha$, and Corollary 3 summarizes the results.

Corollary 3. *Under the mixed model with $\beta > \alpha$, there exist two thresholds of θ, θ_1^{MH} and θ_2^{MH}, such that the platform makes a profit only from the ad-based service if $0 < \theta \leq \theta_1^{MH}$; the platform makes a profit from both the subscription service and the ad-based service if $\theta_1^{MH} < \theta \leq \theta_2^{MH}$; the platform makes a profit only from the subscription service, otherwise. Here, θ_1^{MH} and θ_2^{MH} are given in the Online Appendix Part B.*

Proposition 4 explores the optimal enforcement level under the mixed model with $\beta > \alpha$.

Proposition 4. *Under the mixed model with $\beta > \alpha$, the optimal enforcement level is located in the piracy threat region. It can be non-monotonic with respect to β and θ.*

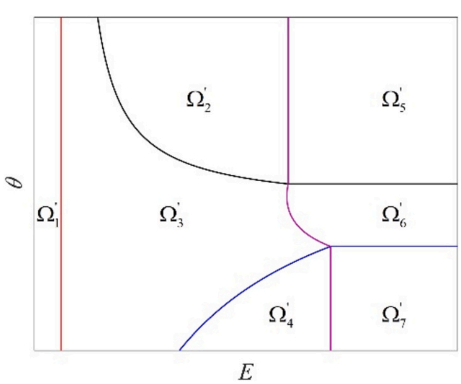


Fig. 8. Best responses of the platform under the mixed model with $\beta > \alpha$.

Proposition 4 is similar to Proposition 3: both show that the social planner and the platform can cut off the demand for piracy under the mixed model. When the quality of the pirated content is higher than the quality in the ad-based service, the optimal enforcement level can also be non-monotonic with respect to β and θ, as shown in Figs. 9(a) and 9 (b).

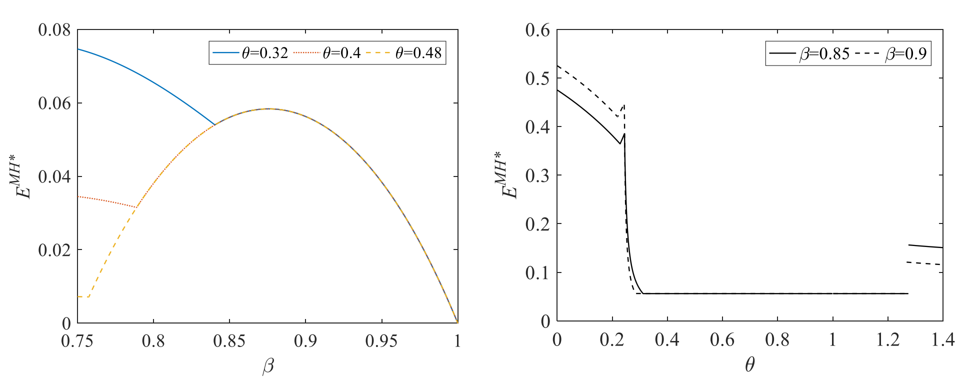
Unlike Case $\beta < \alpha$, when θ is low, the optimal enforcement level does not consistently decrease with increasing θ; rather, it exhibits a slight increase (approximately 0.215 to 0.245 in Fig. 9(b)). This increment occurs precisely at the boundary line between the mixed threat region and the ad-based threat region (i.e., the boundary line between regions Ω_3' and Ω_4' in Fig. 8). As θ increases, in the threat region, the optimal revenue model for the media platform gradually shifts towards the mixed model. Although the demand for pirated content is zero, the potential threat posed by piracy is greater than that in the scenario where $\beta < \alpha$. This is because the quality of pirated content surpasses that of ad-based content, leading consumers to exhibit a greater preference for utilizing pirated content. In light of this, social planners will cautiously intensify enforcement efforts, aiming to effectively curb pirated content while ensuring that the platform's ad-based service is adequately protected.

When θ is moderate, the attractiveness of ad-based service gradually diminishes, while subscription service becomes more appealing to consumers. The social planner will gradually reduce the enforcement level, with the optimal enforcement level taken at the boundary line between the piracy existence region and piracy threat region (i.e., the boundary line between regions Ω_1' and Ω_3' in Fig. 8). Due to the decreased attractiveness of ad-based service caused by higher nuisance cost, and considering that the quality of subscription service surpasses that of pirated content, it is unnecessary for the social planner to increase enforcement to protect ad-based service. The boundary line between the piracy existence region and the piracy threat region is independent of θ. Hence, the optimal enforcement level does not vary with θ.

When θ is large, the optimal enforcement level is taken at the boundary line between the mixed threat region and the subscription threat region (i.e., the boundary line between regions Ω_2' and Ω_3' in Fig. 8). This is because when the nuisance cost is high, consumers will not choose an ad-based service. Additionally, the subscription service has the advantage of higher quality compared to pirated content. As θ increases, the optimal enforcement level decreases.

5. Enforcement costs

Government enforcement may require substantial investments, such as finding and shutting down illegal websites and prosecuting violators. For example, Hadopi, a government agency established in France, has



(a) with respect to β (b) with respect to θ

Fig. 9. Optimal enforcement level E^{MH*} ($\alpha = 0.75, q = 1, \xi = 0.5$).

spent 82 million euros in the 10 years since its founding to keep the anti-piracy agency running [55]. The UK government has provided £3 million in new funding to the City of London Police Intellectual Property Crime Unit to step up action against digital piracy and counterfeit goods [56]. We incorporate the governmental enforcement costs and find some new conclusions. The government's optimization problem is given by $\max_{E}\{SW - kE^2\}$, where kE^2 is the governmental enforcement cost. Proposition 5 shows the optimal enforcement levels under the subscription and ad-based models.

Proposition 5. (1) *Under the subscription model, the optimal enforcement level is given by*

$$E^{S^*} = \begin{cases} \dfrac{(1-\beta)\beta q}{2-\beta}, & \text{if } 0 < k \le \dfrac{1}{4\beta q(1-\beta)}, \\ \dfrac{q(1-\beta)}{1+8kq(1-\beta)^2}, & \text{if } k > \dfrac{1}{4\beta q(1-\beta)}. \end{cases}$$

(2) *Under the ad-based model, the optimal enforcement level is given by*

$$E^{A^*} = \begin{cases} \dfrac{q\alpha\beta(\theta-\xi)}{\alpha\theta - 2kq\beta^2\theta - 2\alpha\xi}, & \text{if } 0 < \theta \le \dfrac{\alpha\beta\xi}{\alpha^2 + 2kq\alpha\beta^2 - 2kq\beta^3}, \\ \dfrac{(\alpha-\beta)\beta q}{2\alpha-\beta}, & \text{if } \dfrac{\alpha\beta\xi}{\alpha^2 + 2kq\alpha\beta^2 - 2kq\beta^3} < \theta \le \dfrac{2\alpha\xi}{\alpha + 4kq\alpha\beta - 4kq\beta^2}, \\ 0, & \text{if } 0 < \beta < \dfrac{\alpha}{2} \text{ and } \theta \ge \dfrac{2(\alpha-\beta)\xi}{\alpha - 2\beta}, \\ \dfrac{-q(\alpha-\beta)(\alpha\theta - 2\beta\theta - 2\alpha\xi + 2\beta\xi)}{3\alpha\theta - 2\beta\theta - 2\alpha\xi + 2\beta\xi + 8kq(\alpha-\beta)^2\theta}, & \text{otherwise.} \end{cases}$$

Proposition 5(1) states that, under the subscription model, the optimal enforcement level may be adopted within the piracy existence region or on the boundary line between the piracy existence region and the piracy threat region. When the enforcement costs are relatively low, the social planners possess the capability and inclination to enhance enforcement efforts, aiming to curb pirated content at minimal expense effectively. Thus, when the enforcement costs are low, the optimal enforcement level lies exactly on the boundary line between the piracy existence region and the piracy threat region. However, the situation is quite different when the enforcement costs are high. The high cost of enforcement poses greater regulatory challenges for social planners. Social planners are thus more inclined to adopt a more conservative strategy: that is, to ensure that a certain level of crackdown on pirated content is maintained while at the same time strictly controlling the cost of enforcement. Therefore, when the enforcement costs are high, the optimal enforcement level is taken within the piracy existence region.

Proposition 5(2) indicates that, under the ad-based model, the situation with enforcement costs is similar to that in the main model without enforcement costs. The optimal enforcement level can be achieved in both the piracy existence region and the piracy threat region. Specifically, the optimal enforcement level occurs in the piracy threat region when the nuisance cost is low, and in the piracy existence region when the nuisance cost is high. For the sake of intuition, we employ numerical analysis to characterize the changes in social welfare and the optimal enforcement level for different values of θ, both with and without enforcement costs, as shown in Fig. 10. The symbol '*' in Fig. 10 represents the maximum social welfare, i.e., the optimal enforcement level.

Under the mixed model, due to the complexity of the problem, we characterize the change in social welfare with enforcement costs in the Online Appendix Part A with numerical analysis. Through numerical examples, we can obtain that the optimal enforcement level can fall within either the piracy existence region or the piracy threat region, which is the same conclusion as the subscription model and the ad-based model. This result arises because the high cost of enforcement places significant economic pressure on the social planner when combating piracy, making it less likely to adopt overly strict enforcement measures.

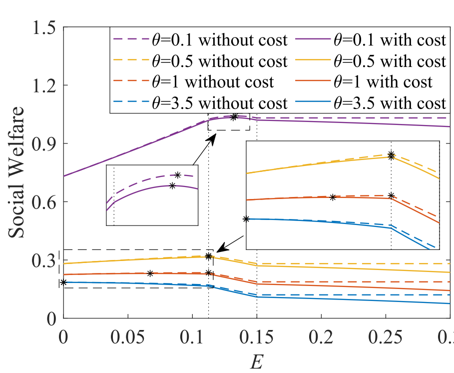


Fig. 10. Social welfare with and without enforcement costs under the ad-based model ($\alpha = 0.75, \beta = 0.3, q = 1, \xi = 0.5, k = 0.5$).

6. Model extensions

In this section, we relax some assumptions to check the robustness of our main results and gain some new implications.

6.1. Decreasing marginal efficiency of enforcement

In the base model, we assume that the efficiency of pirated content enforcement increases linearly with enforcement effort. Here, we consider the decreasing marginal efficiency of piracy enforcement efforts, so that the utility for consumers who use pirated content is $v\beta q - \sqrt{E}$. All other assumptions, including the sequence of events, remain unchanged. Equilibrium pricing and advertising strategies can be found in the Online Appendix Part C.

Our analysis shows that according to the magnitude of enforcement effort E, it can be divided into three regions: the *piracy existence region*, the *piracy threat region*, and the *piracy disappearance region*. Under the subscription and mixed models, the optimal enforcement level can be taken in the piracy threat region, while under the ad-based model, the optimal enforcement level can be taken in the piracy existence region in addition to the piracy threat region. When the marginal efficiency of enforcement decreases, social planners need to implement higher enforcement to achieve maximum social welfare. The reason behind this is that as enforcement effort increases, for every additional unit of the enforcement effort, the utility of consumers using pirated content decreases. As a result, social planners must adopt stricter enforcement strategies to curb piracy more effectively. In addition, the optimal enforcement level is non-monotonic with respect to β. Hence, the insights derived from the base model still hold.

6.2. Duopoly

In real life, consumers frequently make choices among several legal alternatives (e.g., Netflix, YouTube) in addition to piracy. In this section, we consider a duopoly market where the heterogeneity of users is analyzed from two dimensions: the heterogeneity of user preferences (horizontal differences) and the heterogeneity of consumers' quality preferences (vertical differences) between the two competing platforms. On the one hand, horizontal differences suggest that consumers demonstrate different preferences towards the two platforms. Consumers are uniformly distributed along a line between platforms, with platform 1 located at 0 and platform 2 at 1, which has been adopted by most of the existing research [57,58]. Vertical differences, on the other hand, refer to the heterogeneity in consumers' preferences for quality. We derive the equilibrium pricing and advertising strategy, as well as the optimal enforcement level under the mixed model in the Online Appendix Part C.

Our results indicate that according to the increase in enforcement level, it can still be divided into three regions: the *piracy existence region*, the *piracy threat region*, and the *piracy disappearance region*. However, unlike the monopoly scenario, in the duopoly scenario, the optimal enforcement level may be achieved within the piracy existence region. The reason behind this is that in a duopoly market, consumers can choose between two platforms offering legal media services in addition to piracy. In response to the challenges posed by pirated content as well as competing platforms, both platform 1 and platform 2 may choose to reduce subscription fees and adjust advertising strategies to attract a larger consumer base. In this scenario, social planners may tend to adopt a lower enforcement level because both platforms have spontaneously lowered their subscription fees and advertising time, effectively reducing consumer demand for pirated content. Furthermore, the optimal enforcement level is non-monotonic with respect to β. The insights drawn from the base model still hold.

7. Conclusion

Piracy has become an urgent issue that needs to be addressed by digital media platforms and governments. In this study, we delve into the government's optimal enforcement strategies under different revenue models on media platforms. This study not only further enriches the existing literature on piracy regulation but also provides important insights for the government to seek effective ways to combat piracy efficiently.

First, we observe significant differences in government enforcement strategies across various revenue models. However, one commonality can be found—as enforcement efforts increase, the market is gradually divided into three regions: the piracy existence region, the piracy threat region, and the piracy disappearance region. When there is no cost to enforcement, the optimal enforcement strategy of social planners tends to focus on the piracy threat region. This finding holds for both subscription and mixed models, except for the ad-based model. Under the ad-based model, when the nuisance cost is high, even increased government enforcement will not be able to divert consumers from pirated content to using the platform's ad-based service. As a result, the optimal enforcement strategy of the social planner falls within the piracy existence region. When enforcement costs are considered, the optimal enforcement strategies under the three revenue models may all be achieved within the piracy existence region or the piracy threat region. This is because, in the context of enforcement with cost, social planners need to weigh the cost and effectiveness of enforcement, and therefore their enforcement efforts are usually more prudent and relatively lower in intensity compared to enforcement without cost.

Second, we emphasize that higher piracy quality does not necessarily lead to stricter government regulation. In fact, under different revenue models, enforcement efforts vary with the quality of pirated content. Under the subscription model, the optimal enforcement level first increases and then decreases with the quality of pirated content. Under the ad-based model, when the nuisance cost is low, the optimal enforcement level increases with the quality of pirated content; when the nuisance cost is high, the optimal enforcement level first increases and then decreases with the quality of the pirated content. Under the mixed model, the trends are a combination of the former two yet slightly different. The impact of the quality of pirated content on the optimal enforcement level exhibits different trends under different models, which is caused by the unique characteristics of each model.

Third, we highlight how nuisance cost affects the optimal enforcement level. Under the ad-based model, the optimal enforcement level decreases with nuisance cost. Under the mixed model, when the nuisance cost is high, the mixed model degenerates into a subscription model, where the nuisance cost does not affect government enforcement; when the nuisance cost is low, the mixed model degenerates into an ad-based model so that the optimal enforcement level decreases with the nuisance cost, which is the same as in the ad-based model. When the nuisance cost is moderate, the optimal enforcement level appears to increase or decrease.

According to empirical research, after the UK courts blocked 53 piracy websites in November 2014, visits to the blocked websites dropped dramatically by 90 % and were not transferred to other unblocked websites, reducing overall piracy by 16 %–22 %. This suggests that effective government regulatory measures in the fight against piracy can significantly reduce the number of visits to pirate websites, indicating the practical significance of our research on government regulatory measures to combat piracy. At the same time, the initiative prompted a 6 % rise in visits to paid legal streams such as Netflix and a 10 % increase in views of legal ad-supported streams such as the BBC [59]. The empirical result not only profoundly reveals the differentiated impacts of governmental regulatory measures against piracy on media platforms across different revenue models but also indirectly validates the conclusions of our theoretical model, which suggests that the implementation of governmental regulatory strategies differs based on the distinct revenue models of media platforms. In addition, if increased enforcement is ineffective in deterring piracy, new models (such as indirectly supported distribution and advertising supported distribution) to accommodate effective distribution remain the most effective approach [60], which further proves the rationality of our research on government regulatory strategies for pirated content under different revenue models.

Our research has several implications. First, from a theoretical perspective, our study integrates research on digital platform pricing and piracy regulation. The model considers the government's regulatory strategies under different revenue models, which is more aligned with the government's role in regulating piracy in reality. This study not only produces some interesting findings but also enriches the theoretical research on piracy regulation. Second, from the perspective of media platforms, digital products refer to goods with a negligible marginal production cost and high susceptibility to piracy. This feature poses significant challenges to the pricing decisions of media platforms. Through modeling and analysis in this study, we can draw managerial conclusions that are crucial for media platforms about pricing strategies when dealing with piracy. Finally, from the social planner's perspective, our research suggests that the enforcement level does not necessarily increase with the quality of pirated content and nuisance cost. Crucially, social planners must balance platform profitability and consumer surplus in developing effective anti-piracy strategies.

This research has several limitations and can be addressed for future research. First, there are other pricing models for media platforms, such as the bundling of digital media platforms with internet providers or cellular providers. Second, the subscription service is shared among family members. Finally, we assume the media quality is exogenously given, which can be used as a decision variable for future studies.

CRediT authorship contribution statement

Meiqian Li: Writing – original draft, Methodology. **Guowei Liu:** Writing – review & editing, Methodology. **Guofang Nan:** Writing – review & editing. **Yinliang (Ricky) Tan:** Writing – review & editing.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dss.2025.114458.

Data availability

No data was used for the research described in the article.

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