

Composite Pricing and Quality Differentiation of Internet Platform

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Abstract

This research considers the incentive of Internet service providers (ISPs) to upgrade the delivery quality of high- and low-quality content providers (CPs). Building a Hotelling model where a monopolistic ISP interacts with two mobile service providers and consumers through an ISP, we demonstrate that discriminatory or regulated (uniform) quality upgrades as the platform critically affects composite pricing, CP surplus, consumer surplus, and social welfare. Findings show that a low-quality CP and a high-quality CP are always better off with uniform research and development (R&D) in a covered market. However, the ISP, consumer surplus, and social welfare are always better off with discriminatory R&D versus uniform R&D. Our analysis

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extends to an uncovered market, showing that a low-quality CP, consumer surplus, and social welfare are always better off with discriminatory R&D, but the profits of the ISP and high-quality CP are ambiguous. We also examine how the bargaining power between the ISP and CPs influences quality packages, pricing strategies, and social welfare. Our main results remain valid even when incorporating the bargaining power between the ISP and CPs.

Keywords: Platforms, Inter-group Externality, Discriminatory R&D, Uniform R&D, Quality Improving R&D

JEL Classification: D4, L1, L4, L5

1. Introduction

With the increasing consumption in technology and media industries, such as internet services and online content and media services, competition over price and service quality is becoming increasingly fierce. In composite services encompassing internet and content services like the digital distribution of telecommunications and television content over the internet, internet service providers (ISPs) like Xfinity, Spectrum, and Optimum primarily offer internet and cable TV services. They consist of two components and players: content providers (CPs) and ISPs.

This composite service encompassing internet and content services utilizes the ISP's internet infrastructure to allow customers to receive programming. There is a cost associated with accessing basic channels, with an additional charge applying for more premium channels along with internet service.¹ In other scenarios, ISPs also provide a composite service combining internet service with mobile service, often referred to as mobile virtual network operators (MVNOs). This specific service offers discounts and cell phone plans alongside the usual Wi-Fi packages. Its advantage is the convenience and lower cost of billing for consumers along with basic and simple cellular data coverage for browsing, hotspots, and other deals. However, priority features or services might be limited compared to those provided directly by mobile service providers (or cellular carriers) such as Verizon, AT&T, and T-Mobile. Benefiting from being both internet providers and cellular carriers, ISPs also give discounts for combining phone plans with internet plans, providing consumers with more options and features.²

Both theoretical and empirical studies show that the internet market is encouraged to provide corresponding composite services and prices in quality to match the preferences of a target group of consumers in order to

¹ <https://www.lexology.com/commentary/tech-data-telecoms-media/taiwan/shay-partners/mod-formally-serves-as-telecommunications-service>.

² <https://www.highspeedinternet.com/resources/best-internet-and-mobile-bundles>.

achieve higher profits and increased consumer satisfaction with services. In this sense, the research and development (R&D) component is crucial to improving the infrastructure of broadband service quality and conditions (see Kalvit et al., 2019). Academic scholars and government bodies are increasingly targeting how complementarity and pricing strategies affect consumer preferences, reflecting real-world buying scenarios. Liu et al. (2010) explore these dynamics using digital subscriber line (DSL) services as their examples. They investigate how complementarities and substitution effects influence pricing strategies and mention that complementarities between internet and cellular services through a single provider bring more benefits to consumers than providing these services separately.³

In the context above, one key issue from a government perspective is network neutrality, especially composite pricing in the telecommunications industry. Network neutrality presents a significant challenge for governments regarding whether or not it should be imposed as a law. Network neutrality regulation is also an issue between governments and ISPs, with regard to the provision of a non-discriminatory and open network environment for CPs (Hahn and Wallsten, 2006; Schuett, 2010).

Wu (2003) defines that network neutrality typically advocates for equal and non-discriminatory treatment from ISPs toward all data from all CPs over their internet networks. He argues that network neutrality promotes fairness for both consumers and CPs and is also profitable for ISPs. In terms of classification, Schuett (2010) states that network neutrality covers two aspects: zero rating and non-discrimination. Garrett et al. (2022) further classify network neutrality into three main types: prohibiting network traffic differentiation, establishing specific conditions for specialized services, and zero rating. Many arguments suggest that network neutrality has negative effects, such as reducing network innovation, increasing illegal contents and online piracy, and potentially harmful consumers (Marsden, 2010; Hahn and

³ The model proposed by Liu et al. (2010) builds on other research covering bundling and complementarity, such as Manchanda et al. (1999), Seetharaman et al. (1999), Russell and Petersen (2000), Chung and Rao (2003), Wedel and Zhang (2004), Seetharaman et al. (2005), Song and Chintagunta (2006), and Gentzkow (2007).

Wallsten, 2006).

The literature mainly looks at price mechanisms and strategies in two-sided markets, given their significance throughout platform media. The competition effect and correlation among agents are generally used to determine prices and are often highlighted and mostly described through intra- and inter-group externality effects, as many pioneering studies note like Caillaud and Jullien (2001, 2003), Rochet and Tirole (2003, 2004, 2006), Armstrong (2006), and Eisenmann et al. (2006). The concept of two-sided markets is widely known for demonstrating a variety of online and offline business behaviors in real-world applications. Examples include streaming service providers like Airbnb, American Express, Ebay, and Facebook. Banerjee et al. (2017) mention that a two-sided market structure demonstrates direct interaction between consumers and suppliers, creating benefits and utilities through an intermediary platform.⁴

By considering a composite strategy of two products, Sun (2018) and Baranes and Vuong (2022) analyze outcomes of price strategies in competition. Sun (2018) explores vertical differentiation between complementary products in horizontally-differentiated platform competition. She concludes that bundling enhances welfare, particularly when differentiation between platforms is low and quality differentiation between complementary products is high. Our paper differs from Sun (2018), because Sun (2018) targets bundling strategies and bundling impact on platform competition and welfare, while we evaluate ISP investment decisions and

⁴ This paper connects to the literature on two-sided markets and R&D incentives. Musacchio et al. (2009) show that two-sided pricing with network neutrality regulation benefits social welfare under extreme advertising and sensitivity rates. Economides and Tag (2012) and Caves (2012) find that zero-rating practices under network neutrality regulation reduce monopolistic platform power, improving total surplus. Choi and Kim (2010) demonstrate that network neutrality weakens content providers' investment incentives in a discriminatory regime. Li et al. (2020) highlight the significant role of electronic payment system market power in asymmetric price changes, suggesting varying welfare impacts of regulations based on R&D levels. Wang et al. (2023) focus on innovation investment and subsidy strategies in e-commerce competition, but overlook endogenous quality upgrades in composite price structures.

regulatory impacts on quality upgrades for CPs.

Baranes and Vuong (2022) influentially extend Singh and Vives (1984) by including a quadratic utility function to determine consumer demand in their model, wherein a monopolistic ISP makes an investment decision on two vertically-differentiated content providers. Similar to Baranes and Vuong (2022), we also examine the regulatory impacts on quality upgrades of a monopolistic ISP and two types of CPs. We consider an ISP that provides composite services of both internet service and a content package through its internet infrastructure to consumers. In Baranes and Vuong (2022)'s model with elastic demand, each consumer is able to access both high- and low-quality services at double internet prices.

We offer an alternative perspective by using an inelastic model within the Hotelling model to demonstrate implications behind composite services. As internet services become increasingly essential in real-world consumption, we consider that demand for them is price inelastic - a notion supported by studies on OECD countries (Goel et al., 2006). This suggests that inelastic demand is more prevalent and applicable in this real-world setting versus elastic demand. This utility through the Hotelling model represents a common concept in uniform distribution of market demand, which aims to ensure that each user will only purchase one type of internet service - a situation we consider to be closer to real-world applications. We believe that the Hotelling model described here is an appropriate framework to study composite pricing and quality upgrading in the industry for internet and content services.

By applying the same idea of price mechanism in two-sided markets, we now ignore the parameter of network externality. This is done in order to focus on the role of composite prices to simply represent price interaction in this model.⁵ Different from the literature and with the concept of network

⁵ Rysman (2009) says the idea's popularity lies in the simplicity of two-sided markets. This concept illustrates the interaction between customers and content providers in a convenient manner, where cross-group network externality is a crucial property of two-sided markets, as the participation by one group makes goods or services more valuable for another group. This indicates that the number of joining agents on each side also depends on the prices charged to both sides by platforms.

neutrality, we investigate the impact of discriminatory and regulated (uniform) quality research and development (R&D) regimes under composite pricing on social welfare. Based on the above, we formulate the following research issues to investigate.

1. Examine the incentives for a platform to invest in quality R&D through composite pricing mechanisms.
2. Explore the effects of discriminatory and regulated (uniform) quality R&D regimes under composite pricing on consumer surplus and social welfare.

By building a Hotelling model, we analyze a scenario where a monopolistic ISP interacts with CPs and consumers through an internet service platform.⁶ In this setup, the ISP's service and the CPs' content are complementary. This configuration allows us to explore how an ISP's quality differentiation affects pricing for both CPs and consumers. Our motivation stems from the ISP's incentive to invest in quality upgrades to facilitate better content delivery to CPs. This paper demonstrates that the choice of quality upgrades by the platform critically affects pricing, CP surplus, consumer surplus, and social welfare.

The model additionally connects many commonly used practices in technology industries where two-sided market structures are prevalent in composite services. We also provide interesting results in welfare analysis, suggesting that discriminatory R&D may be more socially desirable than uniform R&D. This context closely resembles real situations in the mobile service and ISP industries. The coordinated effect of composite services could lead to the possibility that ISPs see different incentives for their offers due to the intensity of competition between content providers. Our analysis

⁶ Kim (2020) utilizes a Hotelling model, assuming that an ISP with a vertical affiliation directly interconnects the affiliated CP's traffic to its network for free, while imposing a direct interconnection fee on the unaffiliated CP. That study finds that the affiliated CP invests more in content quality when the rival CP indirectly interconnects, resulting in a higher overall level of content investment. In contrast, our paper primarily focuses on the ISP's quality upgrading and the regulatory impacts on quality upgrades for CPs.

reveals that low-quality and high-quality content providers benefit from uniform R&D. Irrespective of content provider quality, discriminatory R&D consistently leads to superior outcomes for the ISP platform, consumer surplus, and overall social welfare. This also implies that neutrality (uniform quality upgrade) is not always beneficial to social welfare. We further extend the analysis to an uncovered market and find that low-quality CP, consumer surplus, and social welfare still benefit from discriminatory R&D. However, the profits of the ISP and high-quality CP remain ambiguous, differing the results in the covered market case.

The rest of the paper runs as follows. Section 2 describes the model. Section 3 analyzes quality upgrading investment. Section 4 compares welfare. Section 5 discusses extensions. Section 6 concludes.

2. Model

This study considers a monopolistic ISP that facilitates interaction between internet users and mobile CPs through composite services. This implies that the ISP offers two components of internet service and two different qualities of content to consumers as a complementary product. Our model corresponds to the standard Hotelling (1929) model in composite prices for a two-sided market setting.

We discuss two distinct CPs, labelled CP_H and CP_L and located at the two ends of a Hotelling segment, $x = 0$ and $x = 1$, respectively. They compete for consumers on the other side. We assume that each content provider offers an asymmetric intrinsic value, denoted as α_H and α_L for high and low preferences of consumption by consumers, respectively. For simplicity, we normalize $\alpha_H = \alpha \geq 1 = \alpha_L$ as an intrinsic value that a consumer gains from subscribing to the internet service for high-quality content. Parameter α captures the original degree of vertical product differentiation without quality upgrading. A larger α indicates a larger quality difference before quality upgrading.

We assume that the respective intrinsic value is sufficiently large so

that the market is fully covered in Section 3 and Section 4.⁷ This implies that consumers decide to subscribe to composite services from either one of the two CPs that is the closest to their ideal. A mass group of consumers is thus normalized to 1 with a uniform distribution along an interval between 0 and 1.

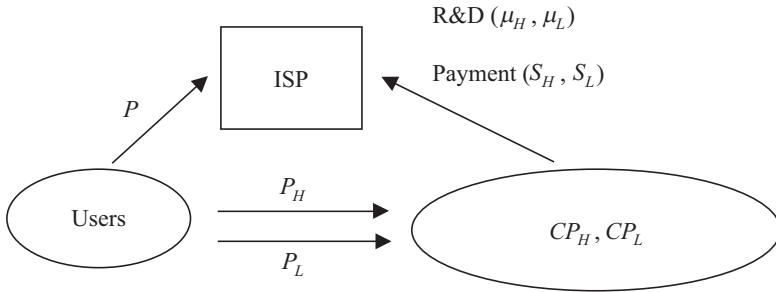


Figure 1 Model Structure

Let z denote each consumer’s location on the interval. We will use n_H and n_L to represent the number of consumers who purchase high- or low-quality content, respectively. These consumers pay composite prices: $P_H + P$ or $P_L + P$, where P_H (P_L) for high- (low-) quality content, and P is internet price. Let t represent the horizontal differentiation between content providers. For simplicity, we assume that the marginal cost is normalized to zero for both the internet and contents.

The unregulated ISP chooses to provide the quality upgrade to only one CP (either CP_H or CP_L), or both CPs. The game’s stages under an unregulated regime run as follows. In the first stage, the ISP offers quality packages to CPs, which include an internet quality level and a lump-sum fee; i.e., $\{\mu_i, S_i\}$, $i \in \{H, L\}$. We denote μ_i , $i = H, L$, as the level of quality upgrade and S_i , $i = H, L$, as a lump-sum fee. In practice, an ISP has the technical capability to regulate the quality of internet service, including the average speed at which content is delivered to end users. Therefore, we assume that the ISP can make separate investments to enhance service quality and provide different levels

⁷ Section 5 extends the analysis to the case where the market is uncovered.

of upgrades to CPs.

Following Baranes and Vuong (2022), we assume that the unit cost associated with μ_i is given by $c(\mu_i) = \mu_i^2 / 2$, $i = H, L$. This key assumption significantly simplifies the complexities arising from interactions between investment costs at different levels of quality upgrades provided to both CPs, allowing us to focus on the roles of content substitution and differentiation. This assumption is appropriate as our primary objective is to examine the ISP's investment in upgrading network infrastructure within this model. Without R&D in quality upgrades, the ISP provides the same basic speed and charges zero fees to CPs, which is $\{\mu_i = 0, S_i = 0\}$. In the second stage, CP_i decides whether or not to accept the ISP's offer. In the third stage, the ISP and both content providers set their prices to consumers. They cover internet price and content prices, P and P_i , respectively. We use Figure 1 to illustrate the model structure and examine the ISP's investment decisions, both with and without regulatory restrictions, while analyzing their impacts on social welfare.

Employing backward induction from the third stage, the utilities of consumers buying high- or low- quality content in the market are:

$$U_H = (\alpha + \mu_H) - (P_H + P) - t(1 - z), \quad (1a)$$

$$U_L = (1 + \mu_L) - (P_L + P) - tz. \quad (1b)$$

By setting $U_H = U_L$, we derive a marginal consumer who has indifferent utility between the two types of contents, \hat{z} . Hence, the numbers of consumers for the high- and low-quality content are:

$$n_L(P_H, P_L) = \hat{z} = \frac{1}{2} - \frac{(\alpha - 1) + (\mu_H - \mu_L) + (P_L - P_H)}{2t}, \quad (2a)$$

$$n_H(P_H, P_L) = \frac{1}{2} + \frac{(\alpha - 1) + (\mu_H - \mu_L) + (P_L - P_H)}{2t}. \quad (2b)$$

3. Analysis

This section derives equilibrium outcomes in each subgame. To ensure that the maximization problems yield admissible solutions, we impose the following assumption throughout this paper.

Assumption. $t > \frac{4\alpha}{9}$, and $\alpha \leq 3t - \frac{1}{3}$.

The first one requires that t , the horizontal differentiation between content providers, is sufficiently high to ensure that under discriminatory quality upgrades, the quality improvement level of low-quality products is positive. The second one ensures that all prices are non-negative.

When a quality upgrade is available, the ISP can choose to provide an exclusive offer to CPs. The superscript D corresponds to the ISP's decision for a discriminatory quality upgrade for CPs. Applying $\mu_L > 0$ and $\mu_H > 0$ into equation (1a) and equation (1b), we can determine the consumer utility associated with buying high- or low-quality content. The profit functions of the ISP and the upgraded CPs are:

$$\max_P \Omega = P(n_H + n_L) - \frac{\mu_H^2}{2} - \frac{\mu_L^2}{2} + S_H + S_L, \quad (3a)$$

$$\max_{P_i} \pi_i = P_i n_i - S_i, \quad i = H, L. \quad (3b)$$

The ISP can charge a lump-sum payment, S_i , which is the difference in the CP's profit with the upgrading and the outside option (without the offer):

$$S_i = P_i n_i - \pi_i^j. \quad (3c)$$

Here, equilibrium profit from the outside option is superscripted with π_i^j . This outside option, π_i^j , represents the reservation profit of CP_i , that is, the profit of CP_i earns when its competitor receives a quality upgrade while CP_i does not. In our setup, a CP is assessed a fee equivalent to the difference in

its profits when receiving a quality upgrade versus not receiving one. This contractual arrangement effectively functions as a first-price auction. The superscript j denotes either the Case H or Case L, indicating that only CP_H or CP_L receives a quality upgrade. This outside option is commonly used in the literature, including Baranes and Vuong (2022).

Our analysis distinguishes between four distinct scenarios concerning the provision of quality upgrades by an ISP to CPs. First, we examine two cases where only a single CP receives an upgrade: Case H, representing an upgrade exclusively to the high-quality content provider (CP_H), and Case L, where the upgrade is extended solely to the low-quality content provider (CP_L). Subsequently, we consider scenarios where both CP_H and CP_L are eligible for quality enhancements. Case D (denoted by superscript “D”) signifies a regime where the ISP implements discriminatory quality upgrades, allowing for differentiated levels of service improvement between CPs. Conversely, Case U (denoted by superscript “U”) represents a regulatory environment where the ISP is prohibited from engaging in quality upgrade discrimination, necessitating uniform treatment for all upgraded CPs.

In Case H, only the CP_H receives a quality upgrade ($\mu_H > 0$), while the CP_L remains unchanged ($\mu_L = S_L = 0$). When $\mu_L = 0$, equation (1a) and equation (1b) determine consumer utility for high- and low-quality content. The profit functions of the ISP and the upgraded CPs from equation (3a) to equation (3c) lead first-order conditions of the ISP and CPs in the second stage to be:

$$\frac{\partial \Omega}{\partial P} = 1 > 0, \quad (4a)$$

$$\frac{\partial \pi_H}{\partial P_H} = \frac{1}{2} + \frac{(\alpha - 1) + \mu_H + (p_L - 2p_H)}{2t} = 0, \quad (4b)$$

$$\frac{\partial \pi_L}{\partial P_L} = \frac{1}{2} - \frac{(\alpha - 1) + \mu_H + (2p_L - p_H)}{2t} = 0.^8 \quad (4c)$$

⁸ The second-order conditions (i.e., $\partial^2 \pi_i / \partial P_i^2 = \partial^2 \pi_j / \partial P_j^2 = -1 / t < 0$) are satisfied. The stability condition (i.e., $(\partial^2 \pi_i / \partial P_i^2)(\partial^2 \pi_j / \partial P_j^2) - (\partial^2 \pi_i / \partial P_i \partial P_j)(\partial^2 \pi_j / \partial P_j \partial P_i) = 3 / 4t^2 > 0$) is satisfied.

By solving (4b) and (4c) simultaneously, we obtain:

$$P_H = t + \frac{(\alpha - 1) + \mu_H}{3}, \quad (5a)$$

$$P_L = t - \frac{(\alpha - 1) + \mu_H}{3}. \quad (5b)$$

From (4a), we know that a higher ISP price is better for the ISP. The maximum ISP price is the willingness to pay by the marginal consumer who is indifferent from consuming any CPs through the internet. Therefore, after substituting equation (5a) and equation (5b) to equation (1a) and equation (1b) and making them equal to zero, we derive:

$$\bar{P} = \frac{(\alpha + 1) + \mu_H - 3t}{2}. \quad (5c)$$

In the first stage, the ISP's objective function to choose the level of high-quality upgrade is:

$$\max_{\mu_H} \Omega = P(n_H + n_L) - \frac{\mu_H^2}{2} + S_H = P(n_H + n_L) - \frac{\mu_H^2}{2} + P_H n_H - \pi_H^L. \quad (6)$$

The corresponding first-order condition is:

$$\frac{d\Omega}{d\mu_H} = \frac{1}{2} - \mu_H + \frac{(\alpha - 1) + \mu_H + 3t}{9t} = 0. \quad (7)$$

Equation (7) yields the optimum level of quality upgrade for CP_H , which leads to the outside option profit of CP_L as:

⁹ The second-order condition (i.e., $d^2\Omega / d\mu_H^2 = (1 - 9t) / 9t < 0$) is satisfied by Assumption.

$$\mu_H^H = \frac{15t + 2(\alpha - 1)}{2(9t - 1)}, \quad (8a)$$

$$\mu_L^H = \frac{t[(6\alpha + 1) - 18t]^2}{8(9t - 1)^2}. \quad (8b)$$

The superscript H denotes Case H.

In Case L, only the CP_L receives a quality upgrade ($\mu_L > 0$), while the CP_H remains unchanged ($\mu_H = S_H = 0$). When $\mu_H = 0$, the first-order conditions of the ISP and CPs in the second stage are:

$$\frac{\partial \Omega}{\partial P} = 1 > 0, \quad (9a)$$

$$\frac{\partial \pi_H}{\partial P_H} = \frac{1}{2} + \frac{(\alpha - 1) - \mu_L + (p_L - 2p_H)}{2t} = 0, \quad (9b)$$

$$\frac{\partial \pi_L}{\partial P_L} = \frac{1}{2} - \frac{(\alpha - 1) - \mu_L + (2p_L - p_H)}{2t} = 0.^{10} \quad (9c)$$

With the same routine calculation as in the previous section, we obtain:

$$P_H = t + \frac{(\alpha - 1) - \mu_L}{3}, \quad (10a)$$

$$P_L = t - \frac{(\alpha - 1) - \mu_L}{3}, \quad (10b)$$

$$\bar{P} = \frac{(\alpha + 1) + \mu_L - 3t}{2}. \quad (10c)$$

In the first stage, the ISP's objective function to choose the level of low-quality upgrade is:

$$\max_{\mu_L} \Omega = P(n_H + n_L) - \frac{\mu_L^2}{2} + S_L = P(n_H + n_L) - \frac{\mu_L^2}{2} + P_L n_L - \pi_L^H. \quad (11)$$

¹⁰ The second-order conditions and the stability condition are satisfied, and they are the same as those in Case H.

The corresponding first-order condition is:

$$\frac{d\Omega}{d\mu_L} = \frac{1}{2} - \mu_L - \frac{(\alpha-1) - \mu_L + 3t}{9t} = 0. \quad (12)$$

Equation (12) yields the optimum level of quality upgrade for CP_L , which leads to the outside option profit of CP_H as follows:

$$\mu_L^L = \frac{15t - 2(\alpha - 1)}{2(9t - 1)}, \quad (13a)$$

$$\pi_H^L = \frac{t[(6\alpha - 13) + 18t]^2}{8(9t - 1)^2}. \quad (13b)$$

The superscript L denotes Case L.

In Case D, the ISP implements discriminatory quality upgrades, allowing for differentiated levels of service improvement between CPs. Under quality upgrade discrimination, equations (13b) and (8b) represent the outside option to determine S_H and S_L , respectively. Therefore, from equation (3c), we know that $S_H = P_H n_H - \pi_H^L$ and $S_L = P_L n_L - \pi_L^H$.

From equations (3a) and (3b) with the same routine calculation as in the previous section, the corresponding first-order conditions are:

$$\frac{\partial \Omega}{\partial P} = 1 > 0, \quad (14a)$$

$$\frac{\partial \pi_H}{\partial P_H} = \frac{1}{2} + \frac{(\alpha - 1) + (\mu_H - \mu_L) + (p_L - 2p_H)}{2t} = 0, \quad (14b)$$

$$\frac{\partial \pi_L}{\partial P_L} = \frac{1}{2} - \frac{(\alpha - 1) + (\mu_H - \mu_L) + (2p_L - p_H)}{2t} = 0. \quad (14c)$$

¹¹ The second-order condition (i.e., $\partial^2 \Omega / \partial \mu_L^2 = (1 - 9t) / 9t < 0$) is satisfied by Assumption.

¹² The second-order conditions (i.e., $\partial^2 \pi_i / \partial P_i^2 = \partial^2 \pi_j / \partial P_j^2 = -1 / t < 0$) are satisfied.

We obtain internet price and content prices for given levels of quality upgrades in the second stage (i.e., $\bar{P}(\mu_H, \mu_L)$, $P_H(\mu_H, \mu_L)$, $P_L(\mu_H, \mu_L)$).¹³ In the first stage, the ISP now determines the level of quality upgrade by maximizing:

$$\max_{\mu_H, \mu_L} \Omega = P(n_H + n_L) - \frac{\mu_H^2}{2} - \frac{\mu_L^2}{2} + S_H + S_L. \quad (15)$$

The corresponding first-order conditions are:

$$\frac{d\Omega}{d\mu_H} = \frac{1}{2} - \mu_H + \frac{2(\alpha - 1 + \mu_H - \mu_L)}{9t} = 0, \quad (16a)$$

$$\frac{d\Omega}{d\mu_L} = \frac{1}{2} - \mu_L - \frac{2(\alpha - 1 + \mu_H - \mu_L)}{9t} = 0,^{14} \quad (16b)$$

where we obtain the equilibrium level of quality upgrades as follows:

$$\mu_H^D = \frac{9t + 4\alpha - 8}{2(9t - 4)}, \quad (17a)$$

$$\mu_L^D = \frac{9t - 4\alpha}{2(9t - 4)}, \quad (17b)$$

where superscript D denotes both CPs receive quality upgrade discrimination.

Based on the above result, we have Lemma 1.

Lemma 1.

For the discriminatory quality upgrade, the ISP provides asymmetric quality upgrades to both CPs, whereas the ISP tends to provide higher quality upgrades to the high-quality CP when the quality difference between two CPs without quality upgrading, α , is greater.

¹³ $\bar{P} = 1/2 + [\alpha + (\mu_H + \mu_L) - 3t]/2$, $p_H = t + [(\alpha - 1) + (\mu_H - \mu_L)]/3$, and $p_L = t - [(\alpha - 1) + (\mu_H - \mu_L)]/3$.

¹⁴ The second order conditions (i.e., $\partial^2 \Omega / \partial \mu_H^2 = \partial^2 \Omega / \partial \mu_L^2 = (2 - 9t)/9t < 0$) and the stability condition $(9t - 4)/9t > 0$ are satisfied by Assumption.

From comparative statics, we observe that the ISP may prefer to asymmetrically raise the higher quality upgrade. This result is in-line with research like Baranes and Vuong (2022) who discuss the incentive of asymmetric quality or efficient production concepts. This intuitively suggests that the asymmetry allows the ISP to extract more rents from the higher quality of CP.

In Case U, the ISP is prohibited from engaging in quality upgrade discrimination, necessitating uniform treatment for all upgraded CPs. The timing of the game under nondiscrimination regulation is as follows: In the first stage, the ISP determines the quality upgrades. Subsequently, in the second stage, both the ISP and the CPs simultaneously set their respective prices. Then end-users decide the quantity of each content to purchase.

When discriminatory quality upgrade is not allowed, CPs must receive the same quality upgrade (i.e., $\mu_H = \mu_L = \mu$). In this situation, we know that the difference between CPs' profits and the outside option profits is equal to zero. This implies that the ISP receives zero lump-sum payment from CPs ($S_H = S_L = 0$). With uniform quality upgrades, the ISP is obliged to provide equal quality enhancements to both CPs. This prevents the emergence of an "outside option" or "reservation profit" scenario for either CP, as both are treated identically. Consequently, the ISP is limited to charging a zero lump-sum payment.

From equation (3a) and equation (3b) with routine calculation as in the previous section, the corresponding first-order conditions are:

$$\frac{\partial \Omega}{\partial P} = 1 > 0, \quad (18a)$$

$$\frac{\partial \pi_H}{\partial P_H} = \frac{1}{2} + \frac{(\alpha - 1) + (p_L - 2p_H)}{2t} = 0, \quad (18b)$$

$$\frac{\partial \pi_H}{\partial P_L} = \frac{1}{2} - \frac{(\alpha - 1) + (2p_L - p_H)}{2t} = 0. \quad (18c)$$

We obtain internet price and content prices for given levels of quality

upgrades (i.e., $P_H, P_L, \bar{P}(\mu)$) in the second stage.¹⁵ Similarly, we substitute them into equation (3a) for maximization.

Based on our previous analysis, we straightforwardly compute the equilibrium level of quality upgrades in the first stage as:¹⁶

$$\mu^U = \frac{1}{2}. \quad (19)$$

Subscript U corresponds to the ISP's decision for a uniform quality upgrade. By comparing (19) to (17a) and (17b), we have Lemma 2.

Lemma 2.

For uniform quality upgrade, the ISP provides symmetric quality upgrades to both CPs. The size of the optimal quality upgrade parameter is now independent of the differentiation in quality in both CPs, which contrasts from Lemma 1.

This is because we consider a model with a covered market and price inelasticity. Subsequently, Section 5 shall relax this assumption and further discuss equilibrium of the uncovered market. From Lemma 1 and Lemma 2, we have the following proposition.

Proposition 1.

Comparing the results of the discriminatory quality upgrade with those of the uniform quality upgrade, we find that:

- i) *The high-quality CP receives the higher quality upgrade under discrimination than that under uniform quality upgrade (i.e., $\mu_H^D > \mu^U$);*
- ii) *The low-quality CP always benefits from the higher quality upgrade under the uniform quality upgrade (i.e., $\mu_L^D > \mu^U$); and*

¹⁵ $\bar{P} = 1/2 + (\alpha - 3t + 2\mu)/2$, $p_H = t + [(\alpha - 1)/3]$, and $p_L = t - [(\alpha - 1)/3]$.

¹⁶ $d\Omega/d\mu = 1 - 2\mu = 0$ and $d^2\Omega/d\mu^2 = -2 < 0$.

iii) The high- and low-quality CPs achieve higher profits under the uniform quality upgrade.

Proof. See Appendix 1.

□

When the ISP employs the discriminatory quality upgrade, it enhances the quality improvement level for the high-quality product while reducing it for the low-quality product. In a covered market, the magnitude of quality change for both products remains the same. For the CP_H , this differentiated quality upgrade strategy leads to an increase in its product's quality level. While its price and output experience a slight uptick, the resulting profit increase is less than the additional lump-sum payment required for differentiated quality upgrades. Therefore, the discriminatory quality upgrade reduces the profit of the CP_H . Furthermore, for the CP_L , the differentiated quality upgrade strategy means a decrease in the quality improvement of its low-quality product. Both its price and volume experience slight declines. With this profit reduction, compounded by the additional lump-sum payment required for differentiated quality upgrades, the profit of CP_L will necessarily decrease. This result aligns with the literature, such as Baranes and Vuong (2022). However, their conclusion is based on a flexible demand model, whereas our analysis is based on an inelastic demand model within a covered market. Section 5 shall extend our discussion to examine the model under an uncovered market, assessing the robustness of the result.

4. Consumer Surplus and Social Welfare Comparison

We now analyze the effect of price mechanisms on social welfare. The social welfare function comprises total consumer surplus and industrial profits. First, let SW and CS denote social welfare and consumer surplus, respectively, given by:

$$SW = \Omega + \pi_H + \pi_L + CS. \quad (20)$$

$$CS = \int_0^{\frac{z}{2}} [1 + \mu_L - (P_L + P) - tz] dz + \int_{\frac{z}{2}}^1 [\alpha + \mu_H - (P_H + P) - t(1 - z)] dz. \quad (21)$$

Proposition 2.

Proposition 2 The ISP platform, consumer surplus, and social welfare are always better off with discriminatory R&D.

Proof. See Appendix 2. □

Under the uniform case (Case U), the ISP intuitively loses its ability to maximize the optimal level and extract profits from CPs. This implies that the ISP would earn less when competition between the two CPs is higher. Consumer surplus is enhanced by discriminatory R&D because the benefits for consumers purchasing high-quality content are relatively higher than those for consumers purchasing low-quality content. Our comparisons indicate regulatory trade-offs between competition in the content market and social welfare, where the social planner might agree to let the ISP dampen market competition to increase consumer surplus and social welfare.

To analyze the ISP's profit difference under discriminatory versus uniform quality improvements, we divide the profit difference into three components: 1) revenue difference ΔTR , 2) lump-sum payment difference $\Delta(S_H + S_L)$, and 3) quality enhancing cost difference $\Delta\mu c$. Among these, the revenue difference function is defined as $\Delta TR = [P^D(n_H^D + n_L^D)] - [P^U(n_H^U + n_L^U)]$. However, under uniform quality improvement, the lump-sum payment is zero, or $S_i = 0$, meaning that the lump-sum payment difference corresponds to the total lump-sum payments received by the ISP from two CPs under discriminatory quality improvement: $\Delta(S_H + S_L) = S_H^D + S_L^D$. Additionally, the quality improvement cost difference function is defined as $\Delta\mu c = (1/2)\{[(\mu_H^D)^2 + (\mu_L^D)^2] - 2(\mu^U)^2\}$. Relative to uniform quality improvement, the product prices and total market output remain unchanged under discriminatory R&D, resulting in $\Delta TR = 0$. Furthermore, the total lump-sum payments received by the ISP from CPs exceed the total quality

improvement costs, meaning $\Delta(S_H + S_L) > \Delta\mu c$. Summarizing the analysis, discriminatory R&D enhances the ISP's profit.

Since the increase in ISP's profits surpasses the decline in profits of the two CPs, the total industry profit difference is positive. Considering the resulting rise in consumer surplus, an ISP's discriminatory R&D is guaranteed to enhance overall social welfare.¹⁷ Our findings also align with Bourreau et al. (2015) regarding the negative impact of non-discrimination on ISP's investment. However, we diverge on the implications for content market competition. While Bourreau et al. (2015) analyze effects within a competitive ISP market, our research indicates that unregulated ISP investment promotes greater content differentiation. This theoretical insight is supported by empirical evidence from Briglauer et al. (2023), which demonstrates that non-discrimination regulations negatively impacted fiber investments by ISPs in OECD countries from 2003 to 2019.

5. Discussions

5.1 The Case of An Uncovered Market

This section extends the analysis to the case where the market is uncovered. Under an uncovered market, we keep the location of the two CPs fixed at the two end points of the market line. We assume that the respective intrinsic value is not sufficiently large, and so the market is uncovered. This implies that consumers decide whether to subscribe to composite services from the CP that is closest to their ideal.

The game stage and the utilities of consumers in the market are the same as those under a covered market. By setting $U_i = 0$, \hat{z}_i represents a marginal

¹⁷ When CPs are symmetric, that is $\alpha = 1$, an ISP has no reason to offer differentiated quality upgrades. In a covered market, this symmetry and fixed total quantity lead the ISP's optimal strategy to naturally equalize quality upgrades for both CPs. Consequently, all equilibrium outcomes including total profit, consumer surplus, and social welfare are the same, regardless of whether the ISP can differentiate quality or must provide uniform quality.

consumer who has indifferent utility between buying product i or not buying it, $i = H, L$. Hence, the numbers of consumers purchasing the two quality content types are derived as:

$$n_L(P_H, P_L) = \hat{z}_L = \frac{1 + \mu_L - P - P_L}{t},$$

$$n_H(P_H, P_L) = 1 - \hat{z}_H = \frac{\alpha + \mu_H - P - P_H}{t}.$$

Appendix 3 provides a detailed proof. Given $t = 20$, in order to ensure the positive quantity of low-quality products under the uniform quality improvement case, we can determine that the initial product quality level must be less than 5.1379.¹⁸ We summarize the comparison of profits, consumer surplus, and social welfare with an uncovered market in Table 1.

Table 1 Comparison of Profits, Consumer Surplus, and Social Welfare in An Uncovered Market.

α	$\Delta\Omega$	$\Delta\pi_H$	$\Delta\pi_L$	ΔCS	ΔSW
2	-0.001178	0.003452	0.004733	0.016966	0.023972
3	0.003261	0.003068	0.006483	0.030522	0.043334
4	0.011724	0.001166	0.007570	0.048137	0.068597
5	0.024209	-0.002253	0.007994	0.069810	0.099760

Proposition 1 and Proposition 2 may not hold for the profit of ISP as well as the profits of high-quality CP under an uncovered market. We denote $\Delta\Omega$ as the ISP's profit differences under discrimination and uniform. Specifically, when α is small, we find $\Delta\Omega$ is negative. The reason are as follows: By comparing the results under a covered market (C) and the uncovered market (UC), we observe the following profit differences for the ISP: $\Delta TR^{UC} < \Delta TR^C = 0$, and quality enhancement gains

¹⁸ Under an uncovered market and the uniform quality improvement case, the quantity of low-quality products is $n_L^U = [2(\alpha - 1) - 3t(\alpha - 5)]/4t(9t - 2)$. Given $t = 20$, we can derive $\alpha|_{n_L^U=0} = 5.1379$.

$[(S_H^D + S_L^D)^{UC} - \Delta\mu c^{UC}] < [(S_H^D + S_L^D)^C - \Delta\mu c^C]$. When α is small and the market is uncovered, the ISP's net surplus from quality enhancement is lower than those under covered market. This means the total lump-sum revenue doesn't significantly exceed the total cost of quality upgrades. Therefore, Proposition 2 may not hold in the uncovered market case. This result differs from Baranes and Vuong (2022). Their conclusion is based on a flexible demand model, whereas our analysis uses an inelastic demand model within an uncovered market. Our findings yield more interesting results because the quantity isn't fixed in an uncovered market. However, consumer surplus and social welfare remains higher under discriminatory R&D than that under uniform R&D. This conclusion holds in both covered and uncovered market cases.

By comparing the profits of two types of CPs under the uncovered market to the covered market, we find that $\Delta\pi_H$ moves from positive to negative as α increases. In contrast, $\Delta\pi_L$ increase with α and remains positive. The reason is as follows. For high-quality CP, compared to the case of a covered market, when the market is uncovered and discriminatory quality upgrade is allowed, product prices, quantities, and the level of quality upgrade rise more significantly, while the lump-sum payments are relatively lower. This suggests that high-quality CP may benefit from ISP employing a differentiated quality upgrade. For low-quality CP, compared to a covered market, in an uncovered market where discriminatory quality upgrade is allowed, the prices and quantities of low-quality products rise, with a relatively higher degree of quality upgrade, while the lump-sum payments remain lower. Consequently, this enhances the profit of low-quality CP. From Table 2, we derive the above economic intuition.

Table 2 shows the differences in various variables when the differentiated quality upgrades compared to a uniform quality upgrade. $\Delta\mu_i$, ΔP_i and ΔS_i represent the differences of the CP $_i$ in product quality improvement level, product price, and lump-sum payment, respectively. ΔP denotes the change in the ISP's product price, ΔN is the change in total output, and $\Delta S - \Delta\mu c$ is the difference in the ISP's net surplus from quality upgrades. Among these, $\Delta\mu_i = \mu_i^D - \mu_i^U$, $\Delta P_i = P_i^D - P_i^U$, $\Delta n_i = n_i^D - n_i^U$, $\Delta S_i = S_i^D - S_i^U$ and $\Delta P = P^D - P^U$.

Table 2 Results of $\Delta\mu_i$, ΔP , ΔP_i , Δn_i , ΔN , ΔS_i and $\Delta S - \Delta\mu c$ in An Uncovered Market.

α	$\Delta\mu_H$	$\Delta\mu_L$	ΔP	ΔP_H $= t\Delta n_H$	ΔP_L $= t\Delta n_L$	ΔN	ΔS_H	ΔS_L	$\Delta S - \Delta\mu c$
2	0.03443	0.00879	-0.50562	0.27002	0.25720	0.02636	0.02060	0.00515	0.02439
3	0.05445	0.00317	-0.67416	0.36430	0.33866	0.03515	0.04634	0.00515	0.04871
4	0.07447	-0.00245	-0.84270	0.45859	0.42012	0.04394	0.08239	0.00515	0.08274
5	0.09450	-0.00807	-1.01124	0.55287	0.50135	0.05272	0.12873	0.00515	0.12647

5.2 Bargaining Power

This subsection adopts the method of bargaining power, β , to describe how profits are shared among the ISP and CPs. Under this case, we investigate how the bargaining power between the ISP and CPs affects the quality packages, the pricing strategies, and the social welfare. We assume that a larger β indicates greater ISP bargaining power. When $\beta = 1$, our model's results in this subsection revert to those presented in Proposition 1 and Proposition 2. Conversely, a smaller β implies greater CP bargaining power.

To analyze the importance of bargaining power, we differentiate all difference functions related to the quality discrimination compared to the uniform quality with respect to β , leading to the following conclusions. First, R&D levels: Given any bargaining power, compared to the uniform-quality improvement by ISP, the differentiated quality improvement will enhance the quality improvement level of high-quality CP while reducing the quality improvement level of low-quality CP; i.e., $\Delta\mu_H = [2\beta(\alpha - 1)] / [(9t - 4\beta)] = -\Delta\mu_L > 0$. This result aligns with Proposition 1. As bargaining power increases, the quality improvement gap between high-quality and low-quality CPs widens, meaning high-quality CP receives greater improvements, while low-quality CP receives smaller increases with β : $d\Delta\mu_H / d\beta = [18t(\alpha - 1)] / [(9t - 4\beta)^2] = -(d\Delta\mu_L) / d\beta > 0$.

Second, regarding price and quantity effects: ISP's price remains unchanged. High-quality CP's price and quantity increase, but low-quality

CP's price and quantity decrease. Overall output remains constant due to a covered market: $\Delta P = 0$, $\Delta p_H = 2\Delta n_H = -\Delta p_L = -2\Delta n_L = [4\beta(\alpha - 1)] / [3(9t - 4\beta)] > 0$. It shows that $d\Delta p_H / d\beta = 2(d\Delta n_H) / d\beta = -(d\Delta p_L) / d\beta = -2(d\Delta n_L) / d\beta = [12t(\alpha - 1)] / [(9t - 4\beta)^2] > 0$. As bargaining power increases, price and quantity changes become more pronounced, meaning the price and quantity of high-quality products rise further, while those of low-quality products decline.

We also find that increased bargaining power leads the ISP to charge higher lump-sum payments from CPs. The rise in payments is more significant for CP_H , while for CP_L the change depends on their initial quality level. When the initial quality level is high (low), greater bargaining power reduces (expands) the rate of increase in lump-sum payment for CP_L .

In the presence of bargaining power, the ISP's profit difference is positive, and it is larger as bargaining power grows: $\Delta\Omega > 0$, $d\Delta\Omega / d\beta > 0$. However, the change in high-quality CP's profit isn't always negative. Specifically, if β is small, the high-quality CP's profit will be higher under the differentiated quality improvement. This result differs from Proposition 1. If the ISP's bargaining power is low and the initial quality level is high, then the profit increases; otherwise, it decreases. However, CP_L always experiences a decline in profit. As ISP bargaining power increases, the profit gap between high- and low-quality CPs expands, until ultimately reversing and becoming negative: $\Delta\pi_H \gtrless 0$, if $\beta \lesseqgtr \beta|_{\Delta\pi_H=0}$, $\Delta\pi_L < 0$, $d\Delta\pi_H / d\beta \gtrless 0$, if $\alpha \gtrless \alpha|_{\frac{d\Delta\pi_H}{d\beta}=0}$, $d\Delta\pi_L / d\beta < 0$.

Regarding the consumer surplus and social welfare, we find that higher bargaining power increases consumer surplus for buyers of high-quality products while reducing surplus for buyers of low-quality products. But overall consumer surplus increases because the gain in high-quality product consumer surplus outweighs the loss in low-quality product consumer surplus. As bargaining power grows, the disparity between high- and low-quality product consumer surpluses widens: $\Delta CS_H > 0$, $\Delta CS_L < 0$, $\Delta CS > 0$, $d\Delta CS_H / d\beta > 0$, $d\Delta CS_L / d\beta < 0$, and $d\Delta CS / d\beta < 0$. Overall, in the presence of bargaining power, the ISP platform, consumer surplus, and social welfare are always better off with discriminatory R&D, and the welfare difference

expands as bargaining power increases: $\Delta SW > 0$, $d\Delta SW / d\beta > 0$. The ISP platform, consumer surplus, and social welfare are always better off with discriminatory R&D. Thus, the results of Proposition 2 remain valid in the presence of bargaining power.

6. Conclusions

This research investigates an ISP platform's incentives for quality upgrades in the presence of endogenous quality upgrades between high- and low-quality CPs. Traditional ideas from the literature suggest that discriminatory treatment has an anticompetitive effect that decreases social welfare. However, using the Hotelling model and quality differentiation, we find that discrimination that reduces social welfare does not always hold.

This paper presents the ISP's motivation to enhance the delivery quality for both high- and low-quality CPs. Using a Hotelling model, we explore the interactions between a monopolistic ISP, two CPs, and consumers on an internet service platform. The findings reveal that quality upgrades, whether discriminatory or regulated (uniform), have significant implications for pricing structures, CP benefits, consumer surplus, and overall social well-being. The results indicate that the low-quality CP and high-quality CP always benefit more from uniform R&D in a covered market. However, the ISP, consumer surplus, and social welfare consistently gain more from discriminatory R&D than uniform R&D. In uncovered markets, the findings suggest that the low-quality CP, consumer surplus, and social welfare consistently improve with discriminatory R&D, although the impacts on ISP profits and the high-quality CP remain uncertain. Our study offers policy implications, suggesting that welfare-improving uniform treatment may not be attainable when considering quality upgrades.

There are several ways in which this paper could be extended for future studies. First, we could relax the assumption of a monopolistic ISP to see how sensitive our results are to the platforms' market structure. Second, we can ignore the parameter of network externality and focus on price mechanism. It

would be interesting to discuss the role of network externality and its effect on composite prices and quality upgrades. These extensions are reserved for future research.

Appendix 1 Proposition 1

Proof. Given Assumptions 1 and 2, we let Δ denote the differences in equilibria under discrimination and uniform. Below, $\Delta\mu_i$, ΔP_i , Δn_i and $\Delta\pi_i$ respectively denote the differences in product quality improvement level, product price, quantity, and profit for CP_i . ΔP represents the change in the ISP's product price. Thus, the differences in equilibria are:

$$\Delta P_H = -\Delta P_L = 2t\Delta n_H = -2t\Delta n_L = \frac{4(\alpha - 1)}{3(9t - 4)} > 0,$$

$$\Delta P = P^D - P^U = 0,$$

$$\Delta\mu_H = -\Delta\mu_L = \frac{2(\alpha - 1)}{9t - 4} > 0,$$

$\Delta\pi_H = \pi_H^D - \pi_H^U = -[15t - 2(\alpha - 1)] / [72t(9t - 1)^2] \phi < 0$, where $\phi = 9t(4\alpha + 12t - 7) - 2(\alpha - 1) > 0$, and $\alpha \leq 3t - 1/3$ by assumption.

$\Delta\pi_L = \pi_L^D - \pi_L^U = [15t + 2(\alpha - 1)] / [72t(9t - 1)^2] \theta < 0$, where $\theta = 9t(4\alpha - 12t - 1) - 2(\alpha - 1) < 0$, and $\alpha \leq 3t - 1/3$ by assumption.

□

Appendix 2 Proposition 2

Proof. $\Delta\Omega = \Omega^D - \Omega^U = \varphi / [4(9t - 4)(9t - 1)^2] > 0$, where $\varphi = 4(\alpha - 1)^2 + 9t[8\alpha(\alpha - 2) + 5t(36t - 25) + 28] > 0$, and $\alpha \leq 3t - 1/3$ by assumption.

$\Delta CS = CS^D - CS^U = [2(\alpha - 1)^2(9t - 2)] / [9t(9t - 4)^2] > 0$, $CS^D = [t[9\alpha(\alpha - 2) + 9t(9t - 8) + 25]] / [4(9t - 4)^2]$, and $CS^U = [[\alpha(\alpha - 2 + 9t^2 + 1)]] / 36t$.

$\Delta SW = SW^D - SW^U = [2(\alpha - 1)^2(27t - 10)] / [9t(9t - 4)^2] > 0$, $SW^D = [9t[\alpha(5\alpha + 18t) - t(9t - 35)] - 16\alpha(\alpha - 4) - t(234\alpha + 187) + 32] / [4(9t - 4)^2]$, and $SW^U = [5\alpha(\alpha - 2) + 9t(2\alpha - t + 3) + 5] / 36t$.

□

Appendix 3 The Case of An Uncovered Market

Proof. The game stage and the utilities of buying the high-quality or low-quality content in an uncovered market are the same as in a covered market. By setting $U_i = 0$, \hat{z}_i represents a marginal consumer who has indifferent utility between buying product i or not buying it. Hence, the numbers of consumers buying the two quality products are:

$$n_L(P_H, P_L) = \hat{z}_L = \frac{1 + \mu_L - P - P_L}{t}, \quad (\text{A1a})$$

$$n_H(P_H, P_L) = 1 - \hat{z}_H = \frac{\alpha + \mu_H - P - P_H}{t}. \quad (\text{A1b})$$

□

Quality Upgrade Discrimination ($\mu_L > 0$ and $\mu_H > 0$)

Case H ($\mu_H > 0$, $\mu_L = S_L = 0$)

When $\mu_L = 0$, equation (A1a) and equation (A1b) determine the consumer utility associated with buying high- or low-quality content. The profit functions of the ISP and the upgraded CPs (CPs) from equation (3a) to equation (3c) lead to first-order conditions of the ISP and CPs in the second stage to be:

$$\frac{\partial \Omega}{\partial P} = \frac{(1 + \alpha) + \mu_H - (4P + P_L + 2P_H)}{t} = 0, \quad (\text{A2a})$$

$$\frac{\partial \pi_H}{\partial P_H} = \frac{\alpha + \mu_H - (P + 2P_H)}{t} = 0, \quad (\text{A2b})$$

$$\frac{\partial \pi_L}{\partial P_L} = \frac{1 - (P + 2P_L)}{t} = 0. \quad (\text{A2c})$$

By solving the three FOCs simultaneously, we derive equilibrium prices of ISP and CPs as:

$$P_H = \frac{5(\alpha + \mu_H) - 1}{10}, \quad (\text{A3a})$$

$$P_L = \frac{2}{5}, \quad (\text{A3b})$$

$$\bar{P} = \frac{1}{5}. \quad (\text{A3c})$$

In the first stage, the ISP chooses the level of high-quality upgrade. The corresponding first-order condition is:

$$\frac{d\Omega}{d\mu_H} = \frac{\alpha + (1-2t)\mu_H}{2t} = 0. \quad (\text{A4})$$

The second-order condition (i.e., $d^2\Omega / d\mu_H^2 = (1-2t) / 2t < 0$) is satisfied if $t > 1/2$. Equation (A4) yields the optimum level of quality upgrade for CP_H , which leads to the outside option profit of CP_L as:

$$\mu_H^H = \frac{\alpha}{2t-1}, \quad (\text{A5a})$$

$$\pi_L^H = \frac{4}{25t}. \quad (\text{A5b})$$

Case L ($\mu_H = S_H = 0, \mu_L > 0$)

Similar to *Case H*, when $\mu_H = 0$, the first-order conditions of the ISP and CPs in the second stage are:

$$\frac{d\Omega}{\partial P} = \frac{(1+\alpha) + \mu_L - (4P + 2P_L + P_H)}{t} = 0, \quad (\text{A6a})$$

$$\frac{d\Omega}{\partial P_H} = \frac{\alpha - (P + 2P_H)}{t} = 0, \quad (\text{A6b})$$

$$\frac{d\Omega}{\partial P_L} = \frac{1 + \mu_L - (P + 2P_L)}{t} = 0. \quad (\text{A6c})$$

We solve for the equilibrium internet price and content prices as:

$$P_H = \frac{5(1 + \mu_L) - \alpha}{10}, \quad (\text{A7a})$$

$$P_L = \frac{2}{5}, \quad (\text{A7b})$$

$$\bar{P} = \frac{\alpha}{5}. \quad (\text{A7c})$$

In the first stage, the ISP chooses the level of high-quality upgrade. The corresponding first-order condition is:

$$\frac{d\Omega}{d\mu_L} = \frac{1+(1-2t)\mu_L}{2t} = 0. \quad (\text{A8})$$

The second-order condition (i.e., $d^2\Omega / d\mu_L^2 = (1-2t) / 2t < 0$) is satisfied if $t > 1/2$. Equation (A8) yields the optimum level of quality upgrade for CP_L , which leads to the outside option profit of CP_H as:

$$\mu_L^L = \frac{1}{2t-1}, \quad (\text{A9a})$$

$$\mu_H^L = \frac{4\alpha^2}{25t}. \quad (\text{A9b})$$

Case D: Both CPs Receive Quality Upgrade Discrimination

In a later section under quality upgrade discrimination, equation (A5b) and equation (A9b) represent the outside option to determine S_H and S_L , respectively.

This study uses equations (A5b) and (A9b) as the outside options in equation (3c) to determine the lump-sum payment (S_i) in this regime. From equation (3a) and equation (3b) with the same routine calculation as in the previous section, the corresponding first-order conditions are:

$$\frac{\partial\Omega}{\partial P} = \frac{(1+\alpha)+(\mu_H+\mu_L)-2(2P+P_L+P_H)}{t} = 0, \quad (\text{A10a})$$

$$\frac{\partial\pi_H}{\partial P_H} = \frac{\alpha+\mu_H-(P+2P_H)}{t} = 0, \quad (\text{A10b})$$

$$\frac{\partial\pi_L}{\partial P_L} = \frac{1+\mu_L-(P+2P_L)}{t} = 0. \quad (\text{A10c})$$

We obtain internet price and content prices for given levels of quality upgrades in the second stage (i.e., \bar{P} , $P_H(\mu_H)$, $P_L(\mu_L)$). In the first stage, the ISP determines the level of quality upgrade by maximizing (15). The corresponding first-order conditions are:

$$\frac{d\Omega}{d\mu_H} = \frac{\alpha - \mu_H(2t-1)}{2t} = 0, \quad (\text{A11a})$$

$$\frac{d\Omega}{d\mu_L} = \frac{1 - \mu_L(2t-1)}{2t} = 0, \quad (\text{A11b})$$

where we obtain the equilibrium level of quality upgrades as:

$$\mu_H^D = \frac{\alpha}{2t-1}, \quad (\text{A12a})$$

$$\mu_L^D = \frac{1}{2t-1}. \quad (\text{A12b})$$

Case U: Banning Quality Upgrade Discrimination ($\mu_H = \mu_L = \mu$ and $S_H = S_L = 0$)

When discriminatory quality upgrade is not allowed, CPs must receive the same quality upgrade (i.e., $\mu_H = \mu_L = \mu$). In this situation, we know that the difference in CPs' profits with the outside option profits is equal to zero. This implies that the ISP receives zero lump-sum payment from CPs ($S_H = S_L = 0$). From equation (3a) and equation (3b) with routine calculation as in the previous section, the corresponding first-order conditions are:

$$\frac{\partial \Omega}{\partial P} = \frac{(1+\alpha) + 2\mu - (4P + P_L + P_H)}{t} = 0, \quad (\text{A13a})$$

$$\frac{\partial \pi_H}{\partial P_H} = \frac{\alpha + \mu - (P + 2P_H)}{t} = 0, \quad (\text{A13b})$$

$$\frac{\partial \pi_L}{\partial P_L} = \frac{1 + \mu - (P + 2P_L)}{t} = 0, \quad (\text{A13c})$$

We obtain internet price and content prices for given levels of quality

upgrades (i.e., $P_H(\mu)$, $P_L(\mu)$, $\bar{P}(\mu)$) in the second stage. Similarly, we substitute them into equation (3a) for maximization.

Based on our previous analysis, we straightforwardly compute the equilibrium level of quality upgrades in the first stage as:

$$\mu^U = \frac{1 + \alpha}{9t - 2}.$$

By comparing μ_H^D to μ^U , we derive $\mu_H^D - \mu^U = [\alpha(7t - 1) - (2t - 1)] / [(9t - 2)(2t - 1)] > 0$.

By comparing $\mu_L^D = 1 / (2t - 1)$ to μ^U , we derive $\mu_L^D - \mu^U = [(7t - 1) - \alpha(2t - 1)] / [(9t - 2)(2t - 1)] \gtrless 0$ if $\alpha \gtrless [(7t - 1)] / [(2t - 1)]$.

Appendix 4 Bargaining Power

Proof. Considering bargaining power, we revise the ISP's objective function (3) as:

$$\max_P \Omega = P(n_H + n_L) - \frac{\mu_H^2}{2} - \frac{\mu_L^2}{2} + \beta \sum_{i=H,L} S_i, \quad (\text{A14a})$$

$$\max_{P_i} \pi_i = P_i n_i - \beta S_i, \quad i = H, L \quad (\text{A14b})$$

In the above equation, β represents the bargaining power of ISP, $\beta \in [0, 1]$. A higher β indicates greater bargaining power for ISP, meaning ISP can extract higher lump-sum payments from CPs. Under this model setting, we find that considering β does not affect the first-order conditions in the pricing stage, and so the analysis of the pricing stage under different scenarios will be omitted.

□

Quality Upgrade Discrimination ($\mu_L > 0$ and $\mu_H > 0$)

Case H ($\mu_H > 0$, $\mu_L = S_L = 0$)

In the first stage, the ISP chooses the level of high-quality upgrade. The

corresponding first-order condition is:

$$\frac{d\Omega}{d\mu_H} = \frac{1}{2} - \mu_H + \frac{\beta[(\alpha - 1) + \mu_H + 3t]}{9t} = 0. \quad (\text{A15})$$

The second-order condition (i.e., $d^2\Omega / d\mu_H^2 = -[(9t - \beta)] / 9t < 0$) is satisfied if $t > \beta / 9$. Equation (A15) yields the optimum level of quality upgrade for CP_H , which leads to the outside option profit of CP_L as:

$$\mu_H^H = \frac{3t(3 + 2\beta) + 2\beta(\alpha - 1)}{2(9t - \beta)}, \quad (\text{A16a})$$

$$\mu_L^H = \frac{t[6\alpha + (4\beta - 3) - 18t]^2}{8(9t - \beta)^2}. \quad (\text{A16b})$$

Case L ($\mu_H = S_H = 0, \mu_L > 0$)

Similar to *Case H*, when $\mu_H = 0$, the first-order condition of the ISP and CPs in the first stage is:

$$\frac{d\Omega}{d\mu_L} = \frac{1}{2} - \mu_L - \frac{\beta[(\alpha - 1) + \mu_H + 3t]}{9t} = 0. \quad (\text{A17})$$

The second-order condition (i.e., $d^2\Omega / d\mu_L^2 = d^2\Omega / d\mu_H^2 t < 0$) is satisfied if $t > \beta / 9$. Equation (A17) yields the optimum level of quality upgrade for CP_L , which leads to the outside option profit of CP_H as:

$$\mu_L^L = \frac{3t(3 + 2\beta) - 2\beta(\alpha - 1)}{2(9t - \beta)}, \quad (\text{A18a})$$

$$\mu_H^L = \frac{t(6\alpha - 4\beta + 18t - 9)^2}{8(9t - \beta)^2}. \quad (\text{A18b})$$

Case D: Both CPs Receive Quality Upgrade Discrimination

In the first stage, the ISP now determines the level of quality upgrade. The corresponding first-order conditions are:

$$\frac{d\Omega}{d\mu_H} = \frac{2\mu_H(2\beta - 9t) + 4\beta[(\alpha - 1) - \mu_L] + 9t}{18t} = 0, \quad (\text{A19a})$$

$$\frac{d\Omega}{d\mu_L} = \frac{2\mu_L(2\beta - 9t) - 4\beta[(\alpha - 1) + \mu_H] + 9t}{18t} = 0, \quad (\text{A19b})$$

where we obtain the equilibrium level of quality upgrades as:

$$\mu_H^D = \frac{9t + 4\beta(\alpha - 2)}{2(9t - 4\beta)}, \quad (\text{A20a})$$

$$\mu_L^D = \frac{9t - 4\alpha\beta}{2(9t - 4\beta)}. \quad (\text{A20b})$$

Based on the above result, we find when the lump-sum payment between ISP and CPs is negotiated that the quality improvement strategy adopted by the ISP for the two CPs remains the same as in Proposition 1. Additionally, the higher the ISP's bargaining power is, the greater is the level of quality improvement for the high-quality CP, while the level of quality improvement for the low-quality CP decreases; i.e., $d\mu_H^D/d\beta = -d\mu_L^D/d\beta = 18t(\alpha - 1)/(9t - 4\beta)^2 > 0$.

Case U: Banning Quality Upgrade Discrimination ($\mu_H = \mu_L = \mu$ and $S_H = S_L = 0$)

When the ISP is prohibited from adopting a differentiated quality enhancement and receives zero lump-sum payments from CPs ($S_H = S_L = 0$), it can be inferred that negotiating lump-sum payments between ISP and CPs does not impact the outcomes. Therefore, the results in this section can be referenced from the results in Section 3, equation (4).

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網路平台的組合定價與品質差異

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摘 要

本研究旨在探討網路服務平台廠商 (ISP) 提升高品質和低品質內容提供者 (CP) 的品質研發。我們建立一個 Hotelling 模型，其中獨占 ISP 廠商提供網路服務平台於兩家分別為高品質以及低品質的內容服務供應商和消費者。我們證明平台的差異或受監管（單一）品質研發對組合定價、兩 CP 廠商利潤、消費者剩餘和社會福利至關重要。研究結果顯示，在覆蓋市場中，低品質 CP 和高品質 CP 在透過單一品質提升的研發 (R&D) 下利潤較高。然而，與單一品質研發相比，差異性研發對 ISP 廠商利潤、消費者剩餘和社會福利更有利。我們也將分析擴展到未覆蓋市場，結果顯示消費者剩餘和社會福利仍然在差異性研發下較高，但低品質 CP 廠商利潤轉而提高，而 ISP 廠商和高品質 CP 廠商的利潤並不明確。我們也延伸探討 ISP 和 CP 之間的議價力如何影響品質研發、定價策略和社會福利，並證明我們的主要結果在存在議價力下仍然成立。

關鍵詞：平台、群體間外部性、差異研發、單一研發、品質提升研發
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