Revenue Sharing of ISP and CP in a Competitive Environment

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Abstract. We considered a revenue sharing problem between a content provider (CP) and a Internet service provider (ISP) when two ISPs competes with each other. ISPs can provide a piracy monitoring service, which may increase the profit of CP, to incentivize CP to collaborate with one of them. We modeled the problem as a multi-stage game and characterized an equilbrium content price, piracy monitoring level, and revenue sharing ratio. We found a condition in which ISP and CP may collaborate even under competition. We also provide numerical results.

Keywords: Revenue sharing · Content piracy · ISP competition

1 Introduction

The importance of Internet for contents delivery is getting more and more important as more people consume them with Internet. The number of subscribers of Netflix, the largest online streaming service provider, has reached 69 Million (Q3, 2015) according to statista.com [1]. The number of youtube user is more than 1 Billion and 4 Billion video views are consumed every day [2]. According to Cisco, global IP traffic has increased more than five-fold in the past five years, and the wireless traffic growth rate is expected to be 61% per year from 2013 to 2018 [3].

Such a high traffic growth put a burden on Internet infrastructure, network upgrades in both backbone and access are needed. Internet service providers all over the world have invested in 3G and LTE wireless access network for last several years. For example, three Korean service providers (SKT, KT, and LGU+) spent between \$6B and \$8B per year during 2011–2013 [4]. To reflect such a burden on investment, the major US ISPs including AT&T, Comcast, TWC, and Verizon claimed that extra regulation would threaten new investment and innovation on network upgrades [5].

The debate between ISPs and CPs have been on-going under the name of *network neutrality*. One of the main issues is about how to share the investment costs for network upgrade in a reasonable manner. CP side argues that it is necessary for the new innovation and fair competition. The other side argues that network neutrality can hinder the proper development of network infrastructure and deployment of high-quality services.

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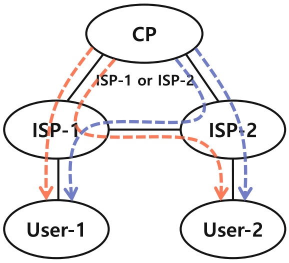


Fig. 1. Internet ecosystem

Researchers have considered possibility of content charge by ISPs for recovering investment cost [6–9]. Kamiyama (2014a, 2014b) considered a content charge system that ISPs charge a fee for each content delivery using a 3 stage Stackelberg model. In [8,9], authors explored a possibility of revenue sharing with a means of piracy monitoring. The ISPs provide a piracy monitoring service to CPs to increase the demand for legitimate contents. According to [10], the traffic of illegal contents represents about 23.8 % of total Internet traffic. For example, the popular Netflix show "House of Cards" season three was downloaded illegally approximately 682,000 times within the first 24h of being available [11]. If such service of ISP can help increasing the profit of CPs, CPs can be more willing to collaborate with ISPs in revenue sharing.

In this work, we extend the results of [8,9] to a competitive situation in which there are two ISPs. When one ISP asks for profit sharing, CPs can switch to another ISP who does not require the sharing. Therefore, introduction of profit sharing may not always be a good solution to the ISP. In our model, we assume that only one of the ISPs provides the piracy monitoring service, while the other does not, to understand the impacts of competition on the profit sharing behavior.

The rest of the paper is organized as follows: In Sect. 2, we explain the details of our game models including players, payoff functions, and sequence of games. Section 3 derives the best responses of users, CP, and ISP-1, and finds each player's strategy. In Sect. 4, we show the simulation results of model. Finally, we conclude the paper in Sect. 5.

2 System Model

We consider an Internet ecosystem that consists of a CP, two ISPs, and a set of N users as shown in Fig. 1. CP provides its contents to the users using networks of the ISPs. It contracts with one of ISPs, say ISP-i, for the network access and pays a_i per unit traffic for delivery of contents for $i = 1, 2$. We assume that two ISPs are in a peering relationship and do not need to settle for the exchange.

The two ISPs are different in that ISP 1 requests revenue sharing to CP while ISP 2 does not. If CP contracts with ISP 1, it shares γ fraction of its revenue with the ISP on top of the access fee. In return for the revenue sharing, ISP 1 provides a strengthened piracy monitoring service to protect copyrighted contents to be spread over the Internet. For example, a technique such as DPI (deep packet inspection) can be used to implement such a protection service. As the ISP deliberately involves in contents protection, it is more difficult for users to infringe copyrighted content over ISP-1's network.

Users pay a content price p to CP for getting the contents. The price could be different depending on which ISP is chosen by CP. On the other hand, they can get the contents in an illegal way without paying the price[1].

User Utility: A user of type v has the following utility function:

$$u_v = \begin{cases} v - p, & \text{if a type } v \text{ user buys a legal content;} \\ (1-\alpha)v - \beta, & \text{if a type } v \text{ user acquires an illegal content;} \\ 0, & \text{otherwise,} \end{cases} \tag{1}$$

where v is the willingness to pay for the contents, p is the content price, α is quality degradation factor between 0 and 1, and β is the cost for copyright infringement. If a type v user purchases a contents, its net-utility is $v - p$. If he acquires it in an illegal way, the value of illegal copy is smaller than a legitimate one by αv. The second term β models efforts or costs for acquiring an illegal copy. When ISP 1 provides strengthen piracy protection, the value of β increases.

CP Profit: The profit of CP depends on contents price p, profit sharing ratio γ, access fee a per unit content, and protection level β. Let ϕ_i be the profit function of CP when it contracts with ISP i, for $i = 1, 2$. Then, it is given by:

$$\phi_i(p; \gamma, \beta, a) = D(p, \beta)((1-\gamma)p - a), i = 1, 2, \tag{2}$$

where $D(p, \beta)$ is a demand function for legitimate contents.

Profit of the ISPs: Let π_i be the profit function of ISP i, then it is given by:

$$\pi_i(\beta; p, \gamma, a) = (a + \gamma p)D(p, \beta) - c(\beta), i = 1, 2, \tag{3}$$

where β is the piracy protection level, p is the content price, γ is the revenue sharing ratio, and a is the access fee. Here, $aD(p\beta)$ is the revenue from the access charge, $\gamma p D(p, \beta)$ is the revenue from the profit sharing and $c(\beta)$ is the cost for maintaining piracy protection level β. We assume that $c(\beta)$ is nondecreasing function of β. As ISP 2 does not request profit sharing, γ of ISP-2 is 0, and we assume that β of ISP-2 is constant to be $\underline{\beta}$. Hence,

$$\pi_2(\underline{\beta}; p, 0, a) = aD(p, \underline{\beta}) - c(\underline{\beta}).$$

We further assume that the access fee a is the same for two ISPs as the access network market is competitive.

[1] For example, P2P service such as bitTorrent provides a way to getting a contents without proper payment.

Sequence of Game: We consider a game between ISP-1 and CP. Even though ISP-2 is in the model, ISP-2 does not have any strategies to control unlike ISP-1. ISP-1's controls profit sharing ratio γ, piracy protection level β. CP's needs to determine which ISP to choose and the price p for the content. We model the game as multi-stage sequential game as follows:

1. ISP-1 and CP negotiate profit sharing ratio γ_1.
2. Given profit sharing ratio γ_1, ISP-1 determines the monitoring level β_1.
3. Given (γ_i, β_i) of ISP-i, $i = 1, 2$, CP selects one of the ISPs to maximize its profit and determines its content price p.
4. Let $\beta = \beta_1$ if ISP-1 is chosen; or $\beta = \beta_2$, otherwise. Given (p, β), users determines its behavior among three possibilities: buying level content, acquiring illegal content, or doing nothing.

3 Analysis of Best Responses and Equilibrium

3.1 User Behaviors

To maximize their utilities of (1), users select one of three options: (a) buying a legitimate contents, (b) downloading an illegal content, and (c) doing nothing. A user of type v makes a legal purchase if $v - p \geq (1-\alpha)v - \beta$ and $v - p \geq 0$ or if $v \geq v_0 := \max(\frac{p-\beta}{\alpha}, p)$. Similarly, he downloads an illegal content if $(1-\alpha)v - \beta \geq v - p$ and $(1-\alpha)v - \beta \geq 0$ or $\frac{\beta}{1-\alpha} \leq v \leq \frac{p-\beta}{\alpha}$.

If the distribution function of user type is $F(\cdot)$, then the demand $D(p, \beta)$ for legal contents can be expressed as

$$D(p, \beta) = 1 - F(v_0) = 1 - F\left(\max(\frac{p-\beta}{\alpha}, p)\right). \tag{4}$$

Here, we normalized the maximum demand to be 1 without loss of generality.

If $\frac{p-\beta}{\alpha} \leq p$, only legal purchase can happen; otherwise, legal or illegal contents downloads coexist. To see this, note that the first condition implies $\beta \geq (1-\alpha)p$. The cost β of piracy is so high it is better off for users to buy legal contents. On the other hand, if $\frac{p-\beta}{\alpha} \geq p$ or $\max(\frac{p-\beta}{\alpha}, p) = \frac{p-\beta}{\alpha}$, both legal and illegal contents coexist.

We can limit our attention to $\beta \leq p(1-\alpha)$ or $\max(\frac{p-\beta}{\alpha}, p) = \frac{p-\beta}{\alpha}$ because an equilibrium always exists in the low β regime. When there is no piracy users, increasing β no longer helps the ISP but costs more. Hence, the ISP does not increase β more than $p(1-\alpha)$. Hence, the above demand function can be rewritten into:

$$D(p, \beta) = 1 - F\left(\frac{p-\beta}{\alpha}\right).$$

If the consumer type v is uniformly distributed on the continuum of $[0, \bar{v}]$, where $\bar{v}$ is the maximum willingness to pay, the demand becomes a linear function:

$$D(p, \beta) = 1 - \left(\frac{p-\beta}{\bar{v}\alpha}\right). \tag{5}$$

3.2 Strategy of CP

CP determines the optimal content price p^* and chooses one of the ISPs to contract with. Let p_i^* be the optimal price on the condition that CP contracts with ISP-i. Then, we have the following proposition on optimal p_i^*.

Proposition 1. *Assume that CP contracts with ISP-i. Given monitoring level β_i and profit sharing rate γ_i, the optimal content price p_i^* of CP is:*

$$p_i^* = \begin{cases} p_i^{1*} := \frac{\alpha\bar{v}+\beta_i}{2} + \frac{a}{2(1-\gamma_i)}, & \text{if } \beta \leq \beta_c; \\ p_i^{M*} := \frac{\beta_i}{1-\alpha}, & \text{oherwise.} \end{cases} \quad (6)$$

where $\beta_c = \frac{1-\alpha}{1+\alpha}(\alpha\bar{v} + \frac{a}{1-\gamma_1})$.

Sketch of proof: As the profit function (2) of CP is concave in p_i, applying the first order condition gives the desired results. ∎

With the optimal content price p_i^*, CP determines which ISP network to use for a larger profit. Note that for any monitoring level β_i and profit sharing rate γ_i, $\phi_i(p_i^*;\gamma_i,\beta_i,a) \geq 0$. Then, we compare the profit from contracting each ISP. In case of contracting with ISP-1, the profit function of CP is given as:

$$\phi(p_1^*;\gamma_1,\beta_1,a) = \begin{cases} \frac{-(1-\gamma_i)}{\bar{v}(1-\alpha)^2}(\beta_i - \bar{v}(1-\alpha))(\beta_i - \frac{a(1-\alpha)}{1-\gamma_i}), & \text{if } \beta \leq \beta_c; \\ \frac{(1-\gamma_i)^2}{4\alpha\bar{v}(1-\gamma_i)}(\beta_i - (\frac{a}{1-\gamma_i} - \alpha\bar{v}))^2, & \text{otherwise,} \end{cases} \quad (7)$$

where $\beta_c = \frac{1-\alpha}{1+\alpha}(\alpha\bar{v} + \frac{a}{1-\gamma_1})$. We can also derive the profit function of CP contracting with ISP-2 by plugging $\gamma_2 = 0$ and $\beta_2 = \beta_L$[2] as:

$$\phi(p_2^*;\gamma_2,\beta_2,a) = \frac{(\alpha\bar{v} - a)^2}{4\alpha\bar{v}}, \quad (8)$$

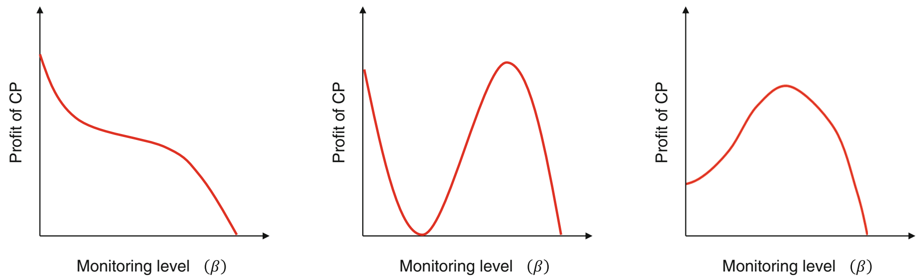
where $p_2^* = \frac{\alpha\bar{v}+a}{2}$.

Shape of $\phi(p_1^*;\gamma_1,\beta_1,a)$: First, we characterize the shape of $\phi(p_1^*;\gamma_1,\beta_1,a)$. There are three different increasing/decreasing patterns of $\phi(p_1^*)$[3] as a function of β in terms of γ_1 as shown in Fig. 2. The three plots correspond to the three cases, (A) $\gamma \leq 1 - \frac{a}{\alpha\bar{v}}$; (B) $1 - \frac{a}{\alpha\bar{v}} < \gamma \leq 1 - \frac{a}{\bar{v}}$; and (C) $\gamma > 1 - \frac{a}{\bar{v}}$, respectively. Due to space limitaition, we omit the detailed derivations.

ISP Selection: CP selects ISP-1 if $\phi(p_1^*) \geq \phi(p_2^*)$. Otherwise, it chooses ISP-2. After thorough analysis, we have following proposition and observations. It turns out that the access fee plays an important role in ISP selection. We skip the analysis due to space limitation.

Proposition 2. *If $a < \alpha^2\bar{v}$ and $1 - \alpha \leq \gamma_1 \leq 1 - \frac{a^2}{\alpha^2\bar{v}^2}$, contracting with ISP-2 always provides a higher profit to CP than doing with ISP-1.*

[2] For the simplicity of analysis, we assume that $\beta_L = 0$.
[3] We will use $\phi(p_1^*)$ and $\phi(p_1^*;\gamma_1,\beta_1,a)$, interchangeably, for the sake of readability.



(a) $\gamma \leq 1 - \frac{a}{\alpha \bar{v}}$ (b) $1 - \frac{a}{\alpha \bar{v}} < \gamma \leq 1 - \frac{a}{\bar{v}}$ (c) $\gamma > 1 - \frac{a}{\bar{v}}$

Fig. 2. Three different shapes of $\phi(p_1^*)$

Proposition 2 says that selecting ISP-2 is always better off than selecting ISP-1 with a small access fee a and a large profit sharing rate γ_1, regardless of monitoring level β_1. Otherwise, we can always find some monitoring level with which contracting with ISP-1 is more beneficial.

Let $\mathcal{B} := \{\beta_1 | \phi(p_1^*) \geq \phi(p_2^*), \phi(p_1^*) \geq 0\}$.

Observation

1. CP tends to be better off with ISP-1 as an access fee a increases.
2. *When* γ_1 *is small, there exists* $\tilde{\beta}$ *such that* $\mathcal{B} = \{0 \leq \beta_1 \leq \tilde{\beta}\}$.
3. *When* γ_1 *is large, there exist* $\check{\beta}$ and $\hat{\beta}$ *such that* $\mathcal{B} = \{\beta | 0 < \check{\beta} \leq \beta_1 \leq \hat{\beta}\}$

Observation 1 describes the influences of the access fee changes. With a small access fee, contracting with ISP-1 is less likely to be more beneficial to CP. In other words, given a profit sharing level γ_1, the higher access fee, the larger domain of β_1 that provides a higher profit. In addition, we observe some counter-intuitive findings.

In general, it is easy to think that a monitoring level and a profit sharing rate increases or decreases together. However, the above two observations shows a different views. To the former, though the profit sharing rate is small, the monitoring level is bounded below by $\check{\beta}$ in order for ISP-1 to be chosen. Similarly, to the latter, the monitoring level is supposed to be bounded above by $\hat{\beta}$. These mean that there can be a minimum and a maximum levels of a monitoring level for ISP-1 to be chosen by CP. For more details, refer the technical report.

3.3 Strategy of ISP

In this section, we find the optimal monitoring level β_1^* of ISP-1 that maximizes its profit $\pi_1(\beta_1; p_1^*, \gamma_1)$. We assumed that $c(\beta) := \kappa\beta^2$ where κ is a positive constant. Plugging (5) and (6) into the profit function (3) of ISP-1, we have

$$\pi_1(\beta_1; p_1^*, \gamma_1) = \begin{cases} -\frac{\gamma_1 + \kappa\bar{v}(1-\alpha)^2}{\bar{v}(1-\alpha)^2}\beta_1^2 + \frac{(\bar{v}\gamma_1 - \alpha)}{\bar{v}(1-\alpha)}\beta_1 + a, & \text{if } \beta_1 \leq \beta_c; \\ \frac{\gamma_1 - 4\kappa\alpha\bar{v}}{4\alpha\bar{v}}\beta_1^2 + \frac{\alpha\bar{v}\gamma_1 + a}{2\alpha\bar{v}}\beta_1 + \frac{(a(2-\gamma_1) + \alpha\bar{v}\gamma_1(1-\gamma_1))(\alpha\bar{v}(1-\gamma_1) - a)}{4\alpha\bar{v}(1-\gamma_1)^2}, & \text{otherwise.} \end{cases}$$

Table 1. Increase/decrease of ISP profit function and the potential optimal monitoring levels without competition*

Cases				Range of β_1							
				0				β_c			∞
[1] $a \geq 4\alpha\bar{v}^2 k$											
[1-1]	$\gamma_1 < 4\alpha\bar{v}k$,	$\beta^{1*} < 0$		(0)	$\searrow$		$\searrow$		$\searrow$		$\searrow$
[1-2]	$\gamma_1 < 4\alpha\bar{v}k$,	$0 \leq \beta^{1*} < \beta_c$			$\nearrow$	(β^{1*})	$\searrow$		$\searrow$		$\searrow$
[1-3]	$\gamma_1 < 4\alpha\bar{v}k$,	$\beta_c \leq \beta^{1*}$			$\nearrow$		$\nearrow$	(β_c)	$\searrow$		$\searrow$
[1-4]	$4\alpha\bar{v}k \leq \gamma_1 < \frac{a}{\bar{v}}$,				$\nearrow$		$\nearrow$	(β_c)	$\searrow$		$\searrow$
[1-5]	$\frac{a}{\bar{v}} \leq \gamma_1$,		$\beta^{M*} < \beta_c$		$\nearrow$		$\nearrow$	(β_c)	$\searrow$		$\searrow$
[1-6]	$\frac{a}{\bar{v}} \leq \gamma_1$,		$\beta_c \leq \beta^{M*}$		$\nearrow$		$\nearrow$		$\nearrow$	(β^{M*})	$\searrow$
[2] $a < 4\alpha\bar{v}^2 k$											
[2-1]	$\gamma_1 < a/\bar{v}$,	$\beta^{1*} < 0$		(0)	$\searrow$		$\searrow$		$\searrow$		$\searrow$
[2-2]	$\gamma_1 < a/\bar{v}$,	$0 \leq \beta^{1*} < \beta_c$			$\nearrow$	(β^{1*})	$\searrow$		$\searrow$		$\searrow$
[2-3]	$\gamma_1 < a/\bar{v}$,	$\beta_c \leq \beta^{1*}$			$\nearrow$		$\nearrow$	(β_c)	$\searrow$		$\searrow$
[2-4]	$a/\bar{v} \leq \gamma_1 < 4\alpha\bar{v}k$,	$\beta_c \leq \beta^{1*}$,	$\beta_c \leq \beta^{M*}$		$\nearrow$		$\nearrow$		$\nearrow$	(β^{M*})	$\searrow$
[2-5]	$a/\bar{v} \leq \gamma_1 < 4\alpha\bar{v}k$,	$\beta^{1*} < 0$,	$\beta_c \leq \beta^{M*}$	(0)	$\searrow$		$\searrow$		$\nearrow$	(β^{M*})	$\searrow$
[2-6]	$a/\bar{v} \leq \gamma_1 < 4\alpha\bar{v}k$,	$0 \leq \beta^{1*} < \beta_c$,	$\beta_c \leq \beta^{M*}$		$\nearrow$	(β^{1*})	$\searrow$		$\nearrow$	(β^{M*})	$\searrow$
[2-7]	$a/\bar{v} \leq \gamma_1 < 4\alpha\bar{v}k$,	$\beta^{1*} \geq \beta_c$,	$\beta^{M*} < \beta_c$		$\nearrow$		$\nearrow$	(β_c)	$\searrow$		$\searrow$
[2-8]	$a/\bar{v} \leq \gamma_1 < 4\alpha\bar{v}k$,	$\beta^{1*} < \beta_c$,	$\beta^{M*} < \beta_c$		$\nearrow$	(β^{1*})	$\searrow$		$\searrow$		$\searrow$
[2-9]	$4\alpha\bar{v}k \leq \gamma_1$,		$\beta^{M*} < \beta_c$		$\nearrow$		$\nearrow$	(β_c)	$\searrow$		$\searrow$
[2-10]	$4\alpha\bar{v}k \leq \gamma_1$,		$\beta_c \leq \beta^{M*}$		$\nearrow$		$\nearrow$		$\nearrow$	(β^{M*})	$\searrow$

*Each figure within a bracket is a critical point, except (0) which is the lower bound.

The problem of ISP-1 can be formulated as the following constrained optimization problem:

$$\max_{\beta_i} \pi_1(\beta_1; p_1^*, \gamma_1) \tag{9}$$

$$\text{sub. to} \quad \beta_1 \in \mathcal{B}, \tag{10}$$

where $\mathcal{B} = \{\beta_1 | \phi(p_1^*) \geq \phi(p_2^*), \phi(p_1^*) \geq 0\}$. The constraint is needed due to competition with ISP-2. If ISP-1 determines β_1 such that $\beta_1 \notin \mathcal{B}$, as CP selects ISP-2, its profit becomes zero.

It turns out that profit function $\pi_1(\beta_1; p_1^*, \gamma_1)$ is either decreasing or unimodal in most cases except [2–4] and [2–5] of Table 1[4]. We found the optimal β_1^* for 16 cases of Table 1. However, the solution does not incorporate the competition constraint. As it becomes too complicated to find the analytic result of the optimization problem (9)–(10) of ISP-1, we rely on numerical studies for the ISP-1's optimal strategy.

3.4 Negotiation of Profit Sharing Rate

The negotiation of revenue sharing ratio γ is a difficult issue in reality and is beyond the scope of this paper. What we would like to see is whether there exists $\gamma > 0$ such that both ISP and CP can be happier than when $\gamma = 0$.

[4] We omit details due to lack of space.

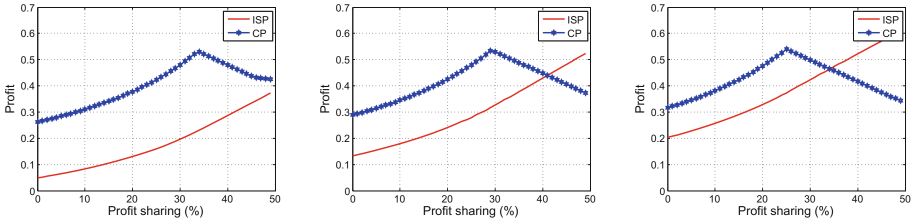
One possible theoretical approach is to use the concept of Nash bargaining solution [12], which can be expressed as

$$\gamma^* = \arg\max_{\gamma} \phi(p_1^*) \times \pi(\beta_1^*; p_1^*, \gamma_1)$$

4 Numerical Study

In this section, we made a numerical study to present the possibility of a ISP-CP collaboration. We assumed that the access fee a is 0.3; the maximum willingness to pay $\bar{v}$ is 10; the quality degradation α is 0.1; and the constant of the monitoring cost κ is 0.2. It is supposed to reflect a market situation with an access fee of middle level ($\alpha^2\bar{v} \leq a < \alpha\bar{v}$) and a low quality degradation level in which we can avoid extreme cases for the levels of access fee and reflect the ease of piracy in real world.

We analyzed the cases; the Internet access fee a is .1, .3, and .5 where $\alpha^2\bar{v} = .1$ and $\alpha\bar{v} = 1$. Figure 3 shows the changes of ISP and CP profits in terms of the profit sharing rates γ from 0 to .5. For all cases, the trends of their profit functions were the same that the profit of CP is unimodal and the profit of ISP increases. The existence a positive profit sharing rate until which the profit functions of ISP and CP commonly increase implies shows a great possibility that the profit sharing of CP can be beneficial to not only ISP, but itself.



(a) $a = 0.1$ (b) $a = 0.3$ (c) $a = 0.5$

Fig. 3. Profit of ISP-1 and CP for different values of α

5 Conclusions

In this paper, we studied a possible collaboration between ISP and CP when two ISPs compete with each other. We formulated the problem as a multi-stage game model of which players are two ISPs and one CP. While ISP-1 provides a piracy monitoring service, ISP-2 does not. In return, ISP-1 requests revenue sharing to CP. CP determines its content price and selects one of the them to maximize its profit.

We characterized equilibrium strategies of ISP and CP. We also found a condition in which ISP and CP may collaborate with each other. When an access fee is small and a revenue sharing ratio is high enough, CP has no incentive to participate in the revenue sharing. Otherwise, (either an access fee is high or a revenue sharing ratio is low enough) there exists a monitoring level that ISP and CP can collaborate.

Further characterization of piracy monitoring level remains as future work as well as that of revenue sharing ratio. In addition, extension of the game model to multiple CPs will be pursued.

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