Internet Pricing and Network Neutrality: How Internet Pricing Schemes Affect the Incentives of Internet Service Providers*

Junseok Hwang\(^a\), Daeho Lee\(^a\), and Kayeong Lee\(^a\)**

**ABSTRACT**

Exponential growth of data packets and the related rising costs of network operations have brought with them the issues of network neutrality and Internet pricing. So far, Internet pricing schemes have not been considered seriously in the network neutrality literature. In order to show the importance of pricing schemes, we compare Internet service provider (ISP) discrimination incentives under two different pricing schemes: flat-rate pricing and usage-based pricing. We found that applying different pricing schemes results in a significant change in ISP discrimination incentives. Under a flat-rate pricing scheme, the ISP generally has an incentive to discriminate against certain content providers’ packets by increasing the packet delay. However, under a usage-based pricing scheme, the ISP has no incentive to discriminate against packets. There are two key policy implications drawn from the results. One is that Internet pricing should be considered a prime concern in network-neutrality regulations. The other is that switching pricing schemes from flat-rate to usage-based can be considered a method of network neutrality regulation.

Key words: Network neutrality, Flat-rate pricing, Usage-based pricing

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I . INTRODUCTION

Currently, most Internet networks are neutral: data packets passing through the network are not managed, but are simply transferred with a “best-effort” system. At the beginning of the Internet Age, network neutrality was considered to be the natural state of a network. There was no need to manage networks because at that time, Internet services were similar in traffic levels and network management technology had not yet matured. However, the development of new Internet services, with their large bandwidth requirements and high QoS (Quality of Service) expectations brought about the argument that it is necessary for Internet network service providers to manage the passage of data packets through their networks. Recently developed Internet services like VoIP (Voice over Internet Protocol) and IPTV (Internet Protocol Television) are readily distinguishable from traditional Internet services in that they place more of a traffic burden on the network and their consumers are much more sensitive to delay than consumers of traditional web services. In that context, ISPs argue that they should manage network traffic by treating different packets in different ways. Concerning this situation, network-neutrality proponents maintain that network neutrality is necessary to maintain content innovation on the Internet, on the reasoning that ISPs have an incentive to abuse their network-management powers. On the contrary, the opponents of network neutrality claim that there is no need for new regulations. Rather, they insist that enactment of network-neutrality regulations does not boost, but harms Internet innovation by reducing ISP investment.

Internet pricing is another issue that is arising with Internet-traffic increases. Today, many countries, including Korea and the United States, are using flat-rate pricing schemes for wired internet networks. Under flat-rate pricing, the network operator charges every user the same price, regardless of packet usage. Flat-rate pricing is widely used because of its simplicity. However, flat-rate pricing fails to provide a price signal to Internet users, resulting in a congested network. To overcome this problem, various pricing schemes are suggested. Due to technical problems, only two pricing schemes are now used: flat-rate pricing and usage-based pricing. Under usage-based pricing schemes, ISPs charge users based on their packet usage.
Until now, Internet pricing and network neutrality have been considered as two different research problems. There has been no network-neutrality research that examines Internet pricing schemes as a main consideration. Nevertheless, we assume that the network-neutrality problem is closely related to the Internet pricing scheme issue, and this paper considers Internet pricing schemes as a key factor affecting the form of network-neutrality regulations. In fact, the Korean Information Society Development Institute (KISDI), in a recent report, mentioned Internet pricing-scheme changes as one means of protecting network neutrality. However, the KISDI does not give a firm explanation of how Internet pricing affects network neutrality.

In order to show the influence of Internet pricing on network neutrality, we compare ISP discrimination incentives under different pricing schemes. Our results suggest that Internet pricing does have a significant effect on ISP discrimination incentives. Under flat-rate pricing schemes, ISPs are likely to discriminate against content providers (CPs) with large bandwidth requirements and relatively low marginal consumer utility by increasing the packet delay of the CP’s service. Under usage-based pricing schemes, however, ISPs that operate in a region where price exceeds marginal cost have no incentive to delay packets from any CPs.

The remainder of this paper is organized as follows. In section 2, previous studies are reviewed. Section 3 introduces the model and compares ISP discrimination incentives under two different pricing schemes: flat-rate pricing and usage-based pricing. We summarize and offer a brief conclusion in section 4. Proofs not in the text can be found in the appendix.

II. THE NETWORK NEUTRALITY DEBATE AND NETWORK NEUTRALITY LITERATURE

The term “network neutrality” was coined by Tim Wu, a professor at Columbia Law School. Wu (2003) defines network neutrality as a web-design principle suggesting that a maximally useful public information network is one that treats all content, sites, and platforms equally.¹ The proponents of the idea insist that

network operators should be regulated by rules to maintain neutral networks. On the other side, opponents of the idea claim that network-neutrality regulation is unnecessary.

Network neutrality has only been a serious topic of scholarly attention for a short time, but recently, it has grown to one of the harshest debates in the Internet-service industry. There are three main reasons for the recent growth of interest in network neutrality. The first is political the U.S. Federal Communications Commission (FCC) has reclassified broadband network service from a telecommunications service to an information service. This reclassification means that broadband network service is not regulated under telecommunications law. The second is the development of new types of content and applications like IPTV. Those services require wide bandwidth and high-QoS guarantees, which cause increases in network operation costs. The last reason is that development in network management technology enabling network operators to distinguish data packets has raised concerns regarding packet discrimination. Network-neutrality issues are not only an academic debate; there are actual cases of network-neutrality violations. For example, in 2005, a regional ISP in the United States, Madison River, blocked packets of Vonage’s VoIP service. For an example of a Korean case, an ISP company LG Powercom blocked Hana TV’s IPTV service.

According to Schuett (2010), network-neutrality literature has two branches: one branch pertains to a “non-discrimination rule” and the other to a “zero price rule” (ZPR). Research on the non-discrimination rule deals with issues related to ISP discrimination toward certain CPs. Of those two branches of net-neutrality research, this paper focuses on the non-discrimination rule. For that reason, in this section we mainly discuss the literature on the non-discrimination rule.

Schuett (2010) classifies research on non-discrimination into two categories: research on vertical integration cases and research on cases of an ISP offering services of inconsistent quality to different CPs. Of this work, research on vertical-integration cases analyzes the effect of a non-discrimination rule when there is a CP that is vertically integrated to the ISP. It has been debated whether the ISP has any incentive to discriminate against other CPs under this situation. The Chicago school’s traditional vertical international theory, the One Monopoly Rent Theory, argues that if good A and good B are complements and used as a system, a monopoly provider of good A that also provides good B would perform better under a competitive B market than under a monopolized B market, because it would
increase the price of good A if good B increased in quality as a result of competition. In that sense, the monopoly provider of good A does not have an incentive to deter competition in market B. Applying the One Monopoly Theory to the Internet-service industry, opponents of network neutrality insist that an ISP does not generally have an incentive to discriminate against non-vertically integrated CPs even if it owns a content-providing company, because network providers can be considered a monopoly for its subscribers (Musacchio, 2009) and network and Internet content is complementary. Opponents of non-discrimination regulation back their arguments by applying traditional one monopoly theory to the Internet market. For example, Yoo (2005) opposes this justification of non-discrimination regulation by the fact that the One Monopoly Theory can be applied to the Internet industry. On contrary, proponents of network neutrality insist that the One Monopoly Theory has limitations. Lessig (2006) insists that a ban on vertical integration of ISPs and CPs is the best solution for maintaining Internet neutrality. van Schewick (2007) also supports network neutrality regulation, pointing out that the One Monopoly Theory has limitations when applied to the Internet-service industry. van Schewick applies a cost-benefit analysis to show that vertically integrated ISPs could increase profit by hindering competition in the CP market.

As mentioned before, another issue related to the non-discrimination rule is the effect of ISP product diversification. If an ISP diverts its product lines, it may charge CPs for better services. Hermalin & Katz (2007) show that in many cases, non-discrimination regulation could result in a reduced social surplus. Cheng et al. (2011) and Choi & Kim (2010) analyzed the effects of non-discrimination regulation by applying a similar model to that of Hermalin and Katz. They assumed that an ISP charges CPs for priority lane services. In Cheng et al.’s (2008) model, there exist two different equilibria: a case where only the most efficient CP subscribe to the priority service, and a case where all CPs subscribe to the priority service. Cheng et al. show that social welfare would increase under the first case but does not change for the latter.

### III. MODEL

To show how ISP discrimination incentives cause Internet pricing scheme variations, we applied a model that can describe changes in ISP equilibrium profit. For
analyzing the model, we assume that the ISP is not subject to network-neutrality regulation. Under this assumption, the ISP can choose the delay level of service for each CP in order to maximize its own profit.

We present analyses for ISP-monopoly and duopoly cases. For the monopoly case, we assume that there is an ISP that has monopoly power over its subscribers. For the duopoly case, we assume that users can choose between two ISPs in the market. In that case, we assume that users have a utility that distributes under the Linear Hotelling model. In both monopoly and duopoly cases, there exist $n$ CPs that offer services to users that subscribed to the ISPs. We assume that the CPs do not charge their customers, but make profit by selling advertisements. Figure 1 illustrates our model.

Figure 1. Model

1. Monopoly ISP

1.1. Model description and variables

We start our analysis by looking at a case in which an ISP has monopoly power over its consumers. In this market, there exist $n$ CPs. We denote these as CP$_1$ to CP$_n$ and assume a monopoly ISP and a representative user that have the utility function $U_i(q_i)$. We restrict our analysis to the case of a representative user because ISP discrimination incentives depends on aggregated packet usage rather than each user’s packet usage. Each player’s detailed characteristics are described below.

**CP:** No CPs in the market charge their consumers; instead, they make profit from advertisements. This form of CP is a popular form of Internet-based business, as mentioned by Varian (2009) and Krugman (2008). Cheng et al. (2011) and
Economides and Tåg (2009) also employed this kind of CP in their model. For one consumer request, a CP requires bandwidth $\lambda_i$ for one consumer request. This required bandwidth varies with the type of CP. For example, an Internet video service has a larger $\lambda_i$ than a text service. Table 1 shows the required bandwidth of various services.

### Table 1. Required Bandwidth

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Required Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommunication (VoIP)</td>
<td>17.066Kbps</td>
</tr>
<tr>
<td>(Sharafeddine, Riedl, Glasmann, &amp; Totzke, 2003)</td>
<td></td>
</tr>
<tr>
<td>Real time Video and Voice (IPTV)</td>
<td>10Mbps</td>
</tr>
<tr>
<td>(Held, 2006)</td>
<td></td>
</tr>
<tr>
<td>Interactive (Web Service)</td>
<td>5.825Kbps</td>
</tr>
<tr>
<td>(Dunaytsev, Krendzel, Koucheryavy, &amp; Harju, 2004)</td>
<td></td>
</tr>
<tr>
<td>Streaming (VOD)</td>
<td>30Kbps</td>
</tr>
<tr>
<td>(Pouwelse, Garbacki, Epema, &amp; Sips, 2005)</td>
<td></td>
</tr>
</tbody>
</table>

**ISP:** The ISP has cost function $C(\mu)$, which is an increasing function of $\mu$, the total packet amount through the network during a set unit of time. By definition, $\mu$ is equal to $\sum_{i=1}^{n} \lambda_i q_i$. We denote $F$ as the service price for ISP service under flat-rate pricing. Thus, the ISP’s profit function under a flat-rate pricing scheme is $\max_F F - C(\mu)$. Under usage-based pricing, we denote the packet price as $p$; then the ISP’s profit function is $\max_p p\mu - C(\mu)$.

In this model, an ISP can control the packet delay according to each CP’s service. $\delta_i$ is the level of delay for the CP. Note that there is naturally a delay even in network-neutrality cases, caused by the distance from CP to consumer. We denote $\delta$ as the delay under network neutrality; it is the same for all CPs.

**User:** The representative user’s utility function $U_i(q_i)$ satisfies the condition that the first derivation is positive and the second derivation is negative. $q_i$ is the demand for CP’s service. User request is a function of delay level $\delta_i$. The user recognizes $\delta_i$ as a cost, causing them to reduce their demand on CP’s service as $\delta_i$ increases. There exists a maximum number of requests during this unit of time. Therefore, if we denote the maximum request as $q_{imax}(\delta_i)$ then, $q_{imax}(\delta_i) < \infty$.

For convenience, Table 2 shows the definition of the variables we mentioned above.
Table 2. Definition of variables—Monopoly ISP

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_i$</td>
<td>CP$_i$’s required bandwidth for one request</td>
</tr>
<tr>
<td>$q_i$</td>
<td>User’s service request for unit time</td>
</tr>
<tr>
<td>$q_{\text{imax}}(\delta_i)$</td>
<td>User’s maximum service request for CP$_i$ under the delay level $\delta_i$</td>
</tr>
<tr>
<td>$M$</td>
<td>The amount of packets through network for unit time</td>
</tr>
<tr>
<td>$\delta_i$</td>
<td>Packet delay for CP$_i$’s service</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Packet delay under network neutrality</td>
</tr>
<tr>
<td>$F$</td>
<td>ISP’s service price under flat-rate pricing scheme</td>
</tr>
<tr>
<td>$p$</td>
<td>ISP’s service price for packet under usage-based pricing scheme</td>
</tr>
</tbody>
</table>

1.2. Assumptions

**Assumption 1:** Consumer does not prefer variety:

$$U(q_1, \ldots, q_N, M) = \sum_{i=1}^{n} U_i(q_i) - M$$

where M is total payment of the user. M varies with price scheme. Under a flat-rate pricing scheme M is a fixed fee regardless of the quantity of packet usage. Under usage-based pricing scheme M can be represented as unit packet price times quantity.

**Assumption 2:** The consumer reduces request for an increase in the delay:

$$\frac{dq_i}{d\delta_i} < 0$$

**Assumption 3:** CP$_j$’s request is not affected by the CP$_i$’s delay:

$$\frac{dq_j}{d\delta_i} = 0$$

**Assumption 4:** Consumer’s request is a reduction function of the packet price:

$$\frac{dq_i}{dp} < 0$$

**Assumption 5:** The ISP’s cost function is concave with the packet amount through the network:

$$C'(\mu) > 0$$

$$C''(\mu) < 0$$
Assumption 1 means that the consumer utility of CP's service is unaffected by the number of CPs that the consumer uses. If the consumer feels better as a result of using a variety of CPs, then the usage of multiple CPs will provide more utility than the simple sum of utility from each CP. Thus, this assumption means that there is no synergy from using various services. This may seem rather unrealistic, but we assigned Assumption 1 on the grounds that each CP represents a group of internet services (for example it can be VoIP service but it cannot be Skype), so that the consumer can achieve the full utility of the service with each CP. For example, there is only a small change to the user’s utility for a VoIP service if a mail service is or is not used. Assumption 2 says that if the CP packet delay increases, the user will reduce the number of requests for the CP’s service because users consider the delay to be a cost for using the service. Considering the delay as a cost also means that the service is not a Giffen good. Assumption 3 says that the delay of a certain CP does not affect other service requests. If we see the delay as a cost, then Assumption 3 means that the CP’s services are independent goods. Assumption 4 is predicated on the law of demand. Service requests reduce in response to increases in packet price. Assumption 5 means that the cost increases along with the amount of packets through the network, and the ISP enjoys an economy of scale.

1.3. Flat-rate Pricing
1.3.1. Consumer utility maximization
Under a flat-rate pricing scheme, consumer utility can be represented with formula (1):

\[
\max_{q_i} \sum_{i=1}^{n} U_i(q_i) - F, \quad \text{s.t. } q_i \leq q_{\text{imax}}(\delta_i)
\]  

(1)

We denote \( q_i = q_{i}^*(\delta_i) \), where \( q_{i}^*(\delta_i) \) is the quantity of requests for unit time that satisfies (1).

1.3.2. ISP profit maximization
Formula (2) describes ISP profit maximization under a flat-rate pricing scheme.

\[
\pi = \max_{F} F - C \left( \sum_{i=1}^{n} \lambda_i q_i^* \right)
\]  

(2)

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Because there is only one type of consumer in the market, the ISP would choose a value for $F$ that makes the consumer surplus zero. Thus, the profit-maximizing price $F^*$ is $\sum_{i=1}^{n} U_i(q_i^*)$ leading to a situation where ISP profit is represented as formula (3).

$$\pi = F^* - C(\mu^*) = \sum_{i=1}^{n} U_i(q_i^*) - C \left( \sum_{i=1}^{n} \lambda_i q_i^* \right)$$  (3)

1.3.3. ISP discrimination incentive with price stickiness

In equilibrium, the ISP would increase the delay $\delta_i$, if it were more profitable for an increase in $\delta_i$ to take effect. Since equation (3) is satisfied in the equilibrium, we can see the ISP’s discrimination incentive by deriving equation (3) with $\delta_i$. In this section, we focus on a case assuming price stickiness, which refers to a situation where the ISP cannot change its price simultaneously to make the decision to delay packet movement in the short term.

Equation (4) is a derivation of equation (3).

$$\frac{d\pi}{d\delta_i} = \frac{dF^*}{d\delta_i} - C'(\mu^*) \frac{d\mu^*}{d\delta_i}$$  (4)

From a price stickiness, $\frac{dF^*}{d\delta_i} = 0$ in the short term, equation (4) can be simplified to equation (5).

$$\frac{d\pi}{d\delta_i} = -C'(\mu^*) \frac{d\mu^*}{d\delta_i} = -C'(\mu^*) \lambda_i \frac{dq_i^*}{d\delta_i}$$  (5)

From Assumptions 2 and 5, it is established that $\frac{dq_i^*}{d\delta_i} < 0$ and $C'(\mu^*) > 0$. Thus, equation (5) is always positive. Thus, under a flat-rate pricing scheme, the ISP has an incentive to increase the delay for all CP’s packets so as to increase its profit. The magnitude of the incentive increases with $\lambda_i$.

1.3.4. ISP discrimination incentive without price stickiness

In this section, we look at the case where price is flexible ($\frac{dF^*}{d\delta_i} \neq 0$). As in the last analysis, we derive equation (3) with $\delta_i$ to get equation (6).
Internet Pricing and Network Neutrality

\[
\frac{d\pi}{d\delta_i} = U'_i(q_i^*) \frac{dq_i^*}{d\delta_i} - C' \left( \sum_{i=1}^{n} \lambda_i q_i^* \right) \lambda_i \frac{dq_i^*}{d\delta_i}
\]

\[
= [U'_i(q_i^*) - C'(\mu^*)] \frac{dq_i^*}{d\delta_i}
\]

(6)

where \( \mu^* = \sum_{i=1}^{n} \lambda_i q_i^* \)

Suppose that equation (6) is positive; in that case, the ISP will apply a bigger delay than \( \delta \) to discriminate against CP\(_i\). As equation (6) shows, the amount of discrimination incentive depends on the required bandwidth \( \lambda_i \). Equation (7) describes the condition that makes equation (6) positive.

\[
\frac{U'_i(q_i^*)}{\lambda_i} < C'(\mu^*)
\]

(7)

Equation (7) means that if the ratio of the consumer’s marginal utility to required bandwidth is larger than the marginal cost, then the ISP has incentive to increase the CP’s delay. On the contrary, if the ratio is smaller than marginal cost, the ISP has incentive to decrease the CP’s delay.

In other words, there is the probability of discrimination towards a CP with wider required bandwidth and smaller marginal benefit for the user. If all CPs in the market offer similar services, then an ISP could maximize its profit by controlling its investment size. However, if the CPs in the market offer heterogeneous services, then the ISP would have incentive to discriminate against certain CPs.

1.4. Usage-based Pricing

1.4.1. Consumer Utility Maximization

The consumer’s utility-maximization problem under usage-based pricing is expressed in formula (8).

\[
\max_{q_i} \sum_{i=1}^{n} u_i(q_i) - \sum_{i=1}^{n} p_i q_i, \text{ s.t. } q_i \leq q_{\text{imax}}(\delta_i)
\]

(8)

The main difference from the case of flat-rate pricing is that under usage-based pricing, user requests for CP is a function of ISP service price, where consumer
request for CP service is unchanged by ISP service price under flat-rate pricing. Thus, we can write the solution to formula (8) as $q_i = q_i^*(p, \delta_i)$.

1.4.2. ISP profit maximization

The ISP profit maximization problem can be represented as equation (9).

$$\pi = \max_p \sum_{i=1}^{n} p\lambda_i q_i^* - C \left( \sum_{i=1}^{n} \lambda_i q_i^* \right)$$

(9)

To find the value for $p$ that satisfies equation (9), we derive equation (9) using $p$. We then get the first order condition, which is written as equation (10).

$$\frac{\partial \pi}{\partial p} = \sum_{i=1}^{n} \lambda_i q_i^* + \sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp} - C'(\mu^*) \sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp} = 0$$

(10)

From equation (10), we can determine the profit maximization price $p^*$ and obtain equation (11).

$$p^* = C'(\mu^*) - \frac{\sum_{i=1}^{n} \lambda_i q_i^*}{\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}} > C'(\mu^*)$$

(11)

The inequality of equation (11) derived from $\sum_{i=1}^{n} \lambda_i q_i^*$ is negative in order to make $p^*$ always bigger than $C'(\mu^*)$. If we put profit-maximizing value for price $p^*$ to equation (9), we obtain equation (12), which represents the maximized profit in equilibrium.

$$\pi = p^*\lambda_i q_i^* - C \left( \sum_{i=1}^{n} \lambda_i q_i^* \right)$$

(12)

where $p^* = C'(\mu^*) - \frac{\sum_{i=1}^{n} \lambda_i q_i^*}{\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}} > C'(\mu^*)$

1.4.3. ISP's discrimination incentive with price stickiness

As in the case of flat-rate pricing schemes, we consider that the ISP has incentive to
create more delays if increasing $\delta_i$ would bring more profit to the ISP. We derive equation (12) and obtain equation (13) to see the discrimination incentive.

$$\frac{d\pi}{d\delta_i} = \frac{dp^*}{d\delta_i} \mu^* + \left(p^* - C'(\mu^*)\right)\frac{d\mu^*}{d\delta_i}$$ (13)

By price stickiness, we mean that $\frac{dp^*}{d\delta_i} \mu^* = 0$. So we simplify equations (13) to (14).

$$\frac{d\pi}{d\delta_i} = \left(p^* - C'(\mu^*)\right)\frac{dq^*_i}{d\delta_i}$$ (14)

From equation (12) we know that $p^* > C'(\mu^*)$, and that Assumption 2 has $\frac{dq^*_i}{d\delta_i}$, a negative value. Thus, equation (14)’s right side is always negative. From the results, we can see that there is only one reason to reduce delays from the ISP’s perspective under usage-based pricing.

1.4.4. ISP discrimination incentive without price stickiness

In the last section, we checked that there is no incentive to delay packets for a monopoly ISP when prices are sticky under a usage-based pricing scheme. Since we only focus on ISP discrimination incentive, in this section we find the condition under which an ISP would probably increase delays of certain CP’s services. By doing this, we can show the effects of price stickiness on the ISP’s decision. Since it is guaranteed that the ISP would not delay any CP’s packet under the condition of price stickiness, we would focus on the case where the ISP’s incentive to delay increases with increased price flexibility.

If the price is flexible, the term $\frac{dp^*}{d\delta_i}$ is not zero in equation (13). Since the second term in equation (13)’s right side is the same as in the case with price stickiness, the effect of price stickiness depends on the first term, $\frac{dp^*}{d\delta_i} \mu^*$. If $\frac{dp^*}{d\delta_i} > 0$, the magnitude of equation (13) will grow, in order to create a bigger incentive to delay. But if $\frac{dp^*}{d\delta_i} < 0$, then the ISP’s incentive to delay will be reduced as compared to the case of price stickiness.

To determine the sign for $\frac{dp^*}{d\delta_i}$, we can derive equation (11) with $\delta_i$ to achieve equation (15).
\[
\frac{dp^*}{d\delta_i} = C''(\mu^*) \frac{dq_i^*}{d\delta_i} - \lambda_i \frac{dq_i^*}{d\delta_i} + \frac{1}{\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}} \lambda_i \frac{d\left(q_i\right)}{dp} \frac{\sum_{i=1}^{n} \lambda_i q_i^*}{\left(\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}\right)^2}
\]  
(15)

From Appendix A, we see that
\[
\frac{d\left(q_i\right)}{dp} = -\left(\omega_i\right)^2 \frac{U_i'''(q_i)}{U_i''(q_i)^2} \frac{dq_i^*}{d\delta_i}
\]
We use this result in equation (15) to derive equation (16).

\[
\frac{dp^*}{d\delta_i} = \left\{C''(\mu^*) - \frac{1}{\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}} \frac{(p_i)^2 U_i'''(q_i)}{U_i''(q_i)^2} \frac{\sum_{i=1}^{n} \lambda_i q_i^*}{\left(\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}\right)^2}\right\} \frac{\lambda_i}{d\delta_i} dq_i^* = \{\alpha - \beta(\lambda_i)^2\} \frac{dq_i^*}{d\delta_i}
\]  
(16)

where \[\alpha = C''(\mu^*) - \frac{1}{\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}} = C''(\mu^*) - \frac{1}{dp^*/dp}, \text{ where } \frac{U_i'''(q_i)}{U_i''(q_i)^2} \frac{\sum_{i=1}^{n} \lambda_i q_i^*}{\left(\sum_{i=1}^{n} \lambda_i \frac{dq_i^*}{dp}\right)^2} = \frac{U_i'''(q_i)}{(U_i''(q_i))^2} \frac{\mu^*}{(dp^*/dp)^2}
\]

Because \[\frac{dq_i^*}{d\delta_i} < 0\], equation (17) is positive when \[\{\alpha - \beta(\lambda_i)^2\} < 0\], and negative when \[\{\alpha - \beta(\lambda_i)^2\} > 0\]. If equation (17) is positive, then the ISP’s incentive to delay would become bigger than is the case with price stickiness. On the contrary, if equation (17) is negative, the ISP’s incentive to delay would become smaller compared to the case with price stickiness.

In short, the condition under which the ISP would increase the delay is \[\alpha - \beta(\lambda_i)^2 < 0\]; if we solve the inequality then we have two solutions: (18-1), (18-2).

\[
\sqrt{\frac{\alpha}{\beta}} < \lambda_i, \text{ when } \lambda_i > 0
\]  
(18-1)

\[
\sqrt{\frac{\alpha}{\beta}} > \lambda_i, \text{ when } \lambda_i < 0
\]  
(18-2)
Equation (18-1) can only be satisfied when \( \alpha > 0 \). If there is a certain CP that satisfies inequality (18-1), then the ISP’s incentive to delay the CP’s service is bigger when the price is flexible. With \( \alpha > 0 \), \( \beta > 0 \), the ISP’s incentive to delay is bigger when the price becomes flexible for a CP that has characteristic of \( \sqrt{\frac{\alpha}{\beta}} < \lambda_i \).

By definition, \( \alpha = C''(\mu^*) - \frac{1}{\Sigma_{i=1}^{n} \lambda_i \frac{d q_i}{dp}} = C''(\mu^*) - \frac{1}{d\mu^*/dp} \cdot \frac{U''(q_i)}{(U''(q_i))^2} \). Thus, the condition for \( \beta > 0 \) is \( U'''(q_i) > 0 \) and the condition for \( \alpha > 0 \) is \( \left| \frac{1}{d\mu^*/dp} \right| > |C''(\mu^*)| \), as we know from Assumptions 4 and 5. In other words, when \( U'''(q_i) > 0 \), the ISP’s discrimination incentive to a CP with large required bandwidth grows as the cost function’s second derivative and the absolute value of change demand becomes smaller.

In similar analysis, inequality (18-2) has meaning only in the case where \( \alpha < 0 \); if there is a CP that satisfies inequality (18-2), then the ISP’s discrimination incentive increases and the ISP is likely to delay packets of CPs whose bandwidth is narrower than \( \sqrt{\frac{\alpha}{\beta}} \). Since \( \alpha < 0 \), we only consider the case where \( \beta < 0 \) for making \( \sqrt{\frac{\alpha}{\beta}} \) positive. The condition for \( \beta < 0 \) is \( U'''(q_i) < 0 \), and for \( \alpha < 0 \) is \( \left| \frac{1}{d\mu^*/dp} \right| < |C''(\mu^*)| \); thus, the ISP’s incentive to delay narrow-bandwidth CPs grows as the absolute value of the second derivative of the ISP’s cost function and the absolute value of packet request changes with increases in prices becoming larger.

2. Duopoly ISPs

2.1. Model description and variables

As in the monopoly case, there are \( n \) CPs in the market in the duopoly case. The difference from the monopoly case is that there are two ISPs and users can choose between either ISP. The profit function of the ISP is the same as in the monopoly case. To model the duopoly case, we use a typical Linear Hotelling model. That is, there are two ISP’s that are located for the values of 0 and 1, and consumers who are distributed on the line \([0, 1]\). The distance between the consumer and each ISP is equivalent to the gap between the consumer’s ideal ISP and the real ISP’s on the points 0 and 1. Thus, the consumers choose an ISP service that is geologically near
their position. To compare this with the monopoly case, we assume that there is only one type of consumer for a CP’s service. The reason that we set one type of consumer is the same reason we set a representative user in the monopoly case.

The mathematical expression of consumer utility is shown below. In the formula, \( U^1 \) represents the utility of ISP\( ^i \)'s user. \( x \) is the coordination of the consumer and \( a \) is the disutility that the consumer feels about the unit which is farther from their ideal service. \( M \) is the total payment that the consumer expends for using the service.

\[
U^1 = \sum_{i=1}^{n} U_i(q_i) - ax - M
\]

\[
U^2 = \sum_{i=1}^{n} U_i(q_i) - a(1-x) - M
\]

Under the above setting, ISP1 and ISP2 compete under a Bertrand model. The steps of the game are 1. ISP’s price decision; 2. Choice of an ISP; 3. The ISP’s decision on the delay level. Considering that the user cannot switch ISPs instantly after their subscription, we assume that the ISP’s delay-level decision does not affect a consumer’s ISP choice. For convenience, we rewrite the variables and functions in Table 3.

**Table 3. Definition of Variables—Duopoly ISP**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_i )</td>
<td>CP( _i )'s required bandwidth for one request</td>
</tr>
<tr>
<td>( q_{ij} )</td>
<td>User’s service request for unit time</td>
</tr>
<tr>
<td>( \mu^i )</td>
<td>The amount of packets through ISP( _i )'s network for unit time</td>
</tr>
<tr>
<td>( \delta_{ij} )</td>
<td>Packet delay for CP( _i )'s service on ISP( _j )'s network</td>
</tr>
<tr>
<td>( \delta )</td>
<td>Packet delay under network neutrality</td>
</tr>
<tr>
<td>( F^j )</td>
<td>ISP( _j )'s service price under flat-rate pricing scheme</td>
</tr>
<tr>
<td>( p^j )</td>
<td>ISP( _j )'s service price for packet under usage based pricing scheme</td>
</tr>
<tr>
<td>( x^j )</td>
<td>ISP( _j )'s demand function</td>
</tr>
<tr>
<td>( a )</td>
<td>Disutility of consumer for one unit of distance</td>
</tr>
</tbody>
</table>

**2.2. Assumptions**

Assumptions 1 to 5 that we describe in chapter 1.2 are also applied in an analysis of the duopoly case. But we added one other assumption in analyzing the duopoly case.
The assumption is that the user’s choice of network provider does not depend on the change in delay that the ISP decides on after user’s subscription. As we discussed before, this assumption amounts to a consumer lock-in effect. From the characteristics of network service-providing businesses, consumer’s switching costs are larger than for other businesses. Thus, there exists a significant lock-in effect in the short run. The mathematical expression for Assumption 6 is presented below.

**Assumption 6:** Consumer lock-in

\[
\frac{dx^j}{d\delta_i^j} = 0
\]

where \(x^j\) is demand for ISP\(^j\)'s service in equilibrium

### 2.3. Flat-rate pricing

#### 2.3.1. Consumer utility maximization

Equations (19-1) and (19-2) represent the consumer utility-maximization problem under flat-rate pricing. Equation (19-1) represents the utility-maximization problem of a user on point \(x\) using ISP1. Similarly, Equation (19-2) shows the utility-maximization problem of a user using ISP2.

\[
U^1 = \max_{q_i} \sum_{i=1}^{n} U_i(q_i) - ax - F^1, \quad \text{s.t. } q_i \leq q_{imax}(\delta_i^1) \tag{19-1}
\]

\[
U^2 = \max_{q_i} \sum_{i=1}^{n} U_i(q_i) - a(1 - x) - F^2, \quad \text{s.t. } q_i \leq q_{imax}(\delta_i^2) \tag{19-2}
\]

Let the solution of utility maximizing problem (19-1) be represented as \(q_i^1 = q_i(\delta_i^1)\). Similarly, we denote the solution (19-2) as \(q_i^2 = q_i(\delta_i^2)\).

Users would choose ISP1 in the case that \(U^1 > U^2\), and vice versa. From symmetry, \(q_i^1 = q_i^2 = q_i^*\) in equilibrium. ISPs' demand functions, \(x^1\) and \(x^2\), can be expressed as (20-1) and (20-2) respectively.

\[
x^1 = \frac{1}{2} - \frac{F^1 - F^2}{2a} \tag{20-1}
\]
\[ x^2 = 1 - x^1 = \frac{1}{2} + \frac{F^1 - F^2}{2a} \]  

(20-2)

### 2.3.2. ISP profit maximization

(21-1) and (21-2) represent the ISP profit-maximization problem under flat-rate pricing. \( \pi^j \) is the profit function of ISP\(^j\).

\[ \pi^1 = \max_{F^1} F^1 x^1 - C(x^1 \sum_{i=1}^{n} \lambda_i q_i^1) = \max_{F^1} F^1 x^1 - C(x^1 \mu^1) \]  

(21-1)

where \( \mu^1 = \sum_{i=1}^{n} \lambda_i q_i^1 \)

\[ \pi^2 = \max_{F^2} F^2 x^2 - C(x^2 \sum_{i=1}^{n} \lambda_i q_i^2) = \max_{F^2} F^2 x^2 - C(x^2 \mu^2) \]  

(21-2)

where \( \mu^2 = \sum_{i=1}^{n} \lambda_i q_i^2 \)

By symmetry, the demand level that satisfies (21-1) and (21-2) is the same. We thus denote the quantity of demand in equilibrium as \( x^* \); then, \( x^1* = x^2* = x^* \). Since consumer \( x^* \) pays only if \( \sum_{i=1}^{n} U_i(q_i) - ax^* - F^j \) is positive, \( F^j \leq \sum_{i=1}^{n} U_i(q_i) - ax^* - F^j \) should be satisfied. Then, a profit-maximizing ISP would charge a price that makes \( \sum_{i=1}^{n} U_i(q_i) - ax^* - F^j \) zero. We let the ISP’s profit maximizing price be \( F^j^* \); then the ISP’s profit in equilibrium can be expressed as equation (22).

\[ \pi^j = F^j^* x^j^* - C(x^j^* \mu^j) = \sum_{i=1}^{n} U_i(q_i) - ax^* - C(x^j^* \mu^j^*) \]  

(22)

where \( \mu^j^* = \sum_{i=1}^{n} \lambda_i q_i^j^* \)

#### 2.3.3. ISP discrimination incentive with price stickiness

If ISP’s profit increases with \( \delta_i^j \), then ISP\(^j\) would have an incentive to delay packets to CP\(^i\). By Assumption 6, ISP demand remains unchanged even if ISP\(^j\) changes the delay level \( \delta_i^j \). Because one ISP’s delay decision does not affect the
other ISP's demand, $\frac{d\pi_k}{d\delta_i} = 0, k \neq j$. Using these facts, we derive equation (22) to obtain equation (23).

$$\frac{d\pi_j}{d\delta_j} = \frac{dF_j^*}{d\delta_j}x^*_j + F_j^*\frac{dx_j^*}{d\delta_j} - C'(x_j^*\mu^*) \left\{ \frac{dx_j^*}{d\delta_j} \mu^* + x_j^* \frac{d\mu^*}{d\delta_j} \right\}$$

$$= - C'(x_j^*\mu^*)x_j^* \frac{d\mu^*}{d\delta_j}$$

(23)

The second equality of (23) is satisfied because of price stickiness and Assumption 6. Equation (23) is always positive, because $\frac{d\mu^*}{d\delta_j}$ is negative due to Assumption 2 and $C'(x_j^*\mu^*)$ is always positive due to Assumption 5. Thus, the ISP has an incentive to make a delay for all CPs' packets.

### 2.3.4. ISP discrimination incentive without price stickiness

We obtain equation (24) by deriving equation (22) with $\delta_j$ in equilibrium.

$$\frac{d\pi_j}{d\delta_j} = U_i'(q_i^*) \frac{dq_i}{d\delta_j} - C'(x_i^*\mu^*)x_i^* \frac{d\mu_i}{d\delta_j}$$

$$= U_i'(q_i^*) \frac{dq_i}{d\delta_j} - C'(x_i^*\mu^*)x_i^* \frac{dq_i}{d\delta_j} \lambda_i$$

$$= [U_i'(q_i^*) - C'(x_i^*\mu^*)x_i^*\lambda_i] \frac{dq_i}{d\delta_j}$$

(24)

The ISP will have discrimination incentive when there exists a CP that makes equation (24) positive. The condition for this case is described in equation (25).

$$\frac{U_i'(q_i^*)}{\lambda_i} < x_i^*C'(x_i^*\mu^*)$$

(25)

From equation (25) we see that the ISP has an incentive to delay CPs with larger required bandwidth and smaller marginal utility. Thus, if CPs with different bandwidths exist in the market, then the ISP’s discrimination incentive would get bigger. We also find that, in general, there would be more CPs to delay in a duopoly case as compared to the case of a monopoly.
2.4. Usage-based pricing

2.4.1. User utility maximization

We write the consumer’s utility-maximization problem as in equation (26).

\[ U_j = \max_{q_i} \sum_{i=1}^{n} U_i(q_i) - ax^j - \sum_{i=1}^{n} p^j \lambda_i q_i, \quad j=1,2 \]  

(26)

The difference from the flat-rate pricing case is that the user’s request also depends on \( p_j \) along with \( \delta_i^j \). Thus, we denote the utility-maximization solution of ISP\( j \)'s user as \( q_i^j = q_i(p_j, \delta_i^j) \).

2.4.2. ISP demand function

The consumer would choose ISP1 if \( U^1 > U^2 \) and ISP2 if \( U^1 < U^2 \). Accordingly, we write ISP 1 and ISP 2’s demand function \( x^1, x^2 \) as in equation (27).

\[ x^j = \frac{1}{2} + \frac{1}{2a} \left( \sum_{i=1}^{n} U_i(q_i^j) - \sum_{i=1}^{n} U_i(q_i^j) \right) - \frac{1}{2a} \left( \sum_{i=1}^{n} p^j \lambda_i q_i^j \right) \right)

(27)

\[ - \sum_{i=1}^{n} p^j \lambda_i q_i^j), \quad j = 1,2 \]

The demand function is different from that of the flat-rate pricing case because we should consider \( q_i^j \) in the usage-based pricing case.

2.4.3. ISP profit maximization

Equation (28) represents ISP 1 and ISP 2’s profit-maximization problem.

\[ \pi = \max_{p^j} p^j x^j \sum_{i=1}^{n} \lambda_i q_i^j - C(x^j \sum_{i=1}^{n} \lambda_i q_i^j) = \max_{p^j} p^j x^j \mu^j - C(x^j \mu^j) \]  

(28)

where \( \mu^j = \sum_{i=1}^{n} \lambda_i q_i^j \)

The first order condition of (28) is (29).

\[ \frac{\partial \pi^j}{\partial p^j} = x^j \mu^j + p^j \frac{\partial x^j}{\partial p^j} \mu^j + p^j x^j \frac{\partial \mu^j}{\partial p^j} - C'(x^j \mu^j) \left( \frac{\partial x^j}{\partial p^j} \mu^j + x^j \frac{\partial \mu^j}{\partial p^j} \right) = 0 \]  

(29)
We define equilibrium price, quantity of demand and total packet amount of ISP\(^j\) as \(p^j\ast\), \(\mu^j\ast\), and \(x^j\ast\). Substituting (29) with \(p^j = p^j\ast\), \(\mu^j = \mu^j\ast\), \(x^j = x^j\ast\), and solving for \(p^j\ast\), we obtain (30).

\[
p^j\ast = \left(\frac{-x^j\ast\mu^j\ast}{\partial x^j\ast + \partial x^j\ast \frac{\partial \mu^j\ast}{\partial p^j\ast}}\right) + C'(x^j\ast\mu^j\ast) \tag{30}
\]

By symmetry, there is an equilibrium where \(p^1 = p^2\) and \(x^1 = x^2 = 1/2\). Substituting equation (30) with equilibrium values and solving for price, we get equation (31).

\[
p^j\ast = \frac{\mu^j\ast}{\mu^j\ast / a - \partial \mu^j\ast / \partial p^j\ast} + C'(\frac{1}{2} \mu^j\ast) \tag{31}
\]

In equilibrium, \(p^j\ast > MC\), since the term \(\frac{\mu^j\ast}{\mu^j\ast / a - \partial \mu^j\ast / \partial p^j\ast}\) is positive by Assumption 4 and \(C'(\frac{1}{2} \mu^j\ast)\) is also positive by Assumption 5. The ISP’s profit function, when in equilibrium, can be expressed as equation (32).

\[
\pi^j\ast = p^j\ast x^j\ast \mu^j\ast - C(x^j\ast\mu^j\ast) \tag{32}
\]

where \(p^j\ast = \frac{\mu^j\ast}{\mu^j\ast / a - \partial \mu^j\ast / \partial p^j\ast} + C'(x^j\ast\mu^j\ast)\).

\[2.4.4.\text{ ISP’s discrimination incentive with price stickiness}\]

We derive equation (32) with \(\delta^j\ast\) and obtain equation (33).

\[
\frac{d\pi^j\ast}{d\delta^j\ast} = \frac{dp^j\ast}{d\delta^j\ast} x^j\ast \mu^j\ast + p^j\ast \frac{dx^j\ast}{d\delta^j\ast} \mu^j\ast + p^j\ast x^j\ast \frac{d\mu^j\ast}{d\delta^j\ast} + C'(x^j\ast\mu^j\ast) \left(\frac{dx^j\ast}{d\delta^j\ast} \mu^j\ast + x^j\ast \frac{d\mu^j\ast}{d\delta^j\ast}\right) \tag{33}
\]

We simplify (33) by using Assumption 6 and price stickiness to obtain equation (34).
\[
\frac{d\pi^j}{d\delta_i} = p^j x^j \frac{d\mu^j}{d\delta_i} - C'(x^j \mu^j) \left( x^j \frac{d\mu^j}{d\delta_i} \right)
\] (34)

In (34), substitute \( \frac{d\mu^j}{d\delta_i} \) to \( \lambda_i \frac{dq_i}{d\delta_j} \).

\[
\frac{d\pi^j}{d\delta_i} = \{p^j - C'(x^j \mu^j)\} x^j \lambda_i \frac{dq_i}{d\delta_j}
\] (35)

We observe the same results in the case of monopoly. If we substitute \( x^j = 1 \) then we obtain equation (14) which represents ISP’s incentive to delay a certain CP. As in the case of monopoly, there is only a delay-reducing incentive for ISP in the duopoly case under usage-based pricing. Note that the amount of incentive changes by \( x^j \). Since \( x^j \) is less than unity in the duopoly case, an ISP in the duopoly market has less incentive to reduce delays than the ISP in a monopoly market.

2.4.5. ISP’s discrimination incentive-without price stickiness

We start with equation (33). Unlike in the case of price stickiness, \( \frac{dp^j}{d\delta_i} \) is not zero when the price is flexible. We obtain (36) by simplifying (33) and applying Assumption 6.

\[
\frac{d\pi^j}{d\delta_i} = \frac{dp^j}{d\delta_i} x^j \mu^j + \{p^j - C'(x^j \mu^j)\} x^j \lambda_i \frac{dq_i}{d\delta_j}
\] (36)

The second term of equation (36) is the same as (35). From that, we know that the first term is the only term that is affected by the price stickiness. If \( \frac{dp^j}{d\delta_i} x^j \mu^j > 0 \), then the ISP would delay packets more as compared to the case of price stickiness. If \( \frac{dp^j}{d\delta_i} x^j \mu^j < 0 \), then the ISP would delay packets less as compared to the price-stickiness case.

Since there is no incentive to delay packets under usage-based pricing with price stickiness, the necessary condition for the ISP to discriminate against the CP is \( \frac{dp^j}{d\delta_i} x^j \mu^j > 0 \). In that manner, we only focus on this case. We derive (31-1) and (31-2) with \( \delta_i \) and obtain (37).
\[
\frac{dp^j}{d\delta_i} = \frac{-\mu^i}{(\mu^i/a - \partial \mu^i/\partial p^i)^2} \left\{ \frac{d\mu^i}{d\delta_i} - \frac{d \partial \mu^i}{d\delta_i} \right\} + \frac{1}{\mu^i/a - \partial \mu^i/\partial p^i} \frac{d\mu^i}{d\delta_i} + x^i C''(x^i \mu^i) \frac{d\mu^i}{d\delta_i} \tag{37}
\]

From Appendix A, \(\frac{d}{d\delta_i} \frac{\partial \mu^i}{\partial p^i} = -\frac{(\lambda_0)^2 U_i''(q_i)}{(U_i(q_i))^2} \frac{dq_i}{d\delta_i} = -\frac{\lambda_0 U_i''(q_i)}{(U_i(q_i))^2} \frac{d\mu^i}{d\delta_i} \). Using this fact, we rewrite (37) as (38).

\[
\frac{dp^j}{d\delta_i} = \left\{ -\frac{\partial \mu^i}{\partial p^i} - \frac{\mu^i \lambda_1 U_i'''(q_i)/(U_i''(q_i))^2}{(\mu^i/a - \partial \mu^i/\partial p^i)^2} + \frac{1}{2} C'' \left( \frac{1}{\mu^i} \right) \right\} \frac{d\mu^i}{d\delta_i} \tag{38}
\]

In (38), we substitute

\[
-\frac{\partial \mu^i}{\partial p^i} + x^i C''(x^i \mu^i) = \gamma / (\mu^i/a - \partial \mu^i/\partial p^i) = \varepsilon
\]

to get (39).

\[
\frac{dp^j}{d\delta_i} = (\gamma - \varepsilon \lambda_i) \frac{d\mu^i}{d\delta_i} \tag{39}
\]

\[
\frac{d\mu^i}{d\delta_i} < 0 \text{ by Assumption 2 and the sign of (39) depends only on } \gamma - \varepsilon \lambda_i.
\]

Specifically, the condition that makes (39) positive can be derived as (40-1) and (40-2).

\[
\frac{\gamma}{\varepsilon} < \lambda_i, \text{ where } \varepsilon > 0 \tag{40-1}
\]

\[
\frac{\gamma}{\varepsilon} > \lambda_i, \text{ where } \varepsilon < 0 \tag{40-2}
\]

Since \(\lambda_i\) is positive, (40-1) and (40-2) only have meaning when \(\gamma > 0\) and \(\gamma < 0\), respectively. (40-1) is satisfied when \(U_i'''(q_i) > 0\) and \(|C''(x^i \mu^i)| < \frac{-\partial \mu^i/\partial p^i}{x^i (\mu^i/a - \partial \mu^i/\partial p^i)^2}\) because the condition of \(\varepsilon > 0\) is \(U_i'''(q_i) > 0\) and the condition that makes \(\gamma > 0\) is \(|C''(x^i \mu^i)| < \frac{-\partial \mu^i/\partial p^i}{x^i (\mu^i/a - \partial \mu^i/\partial p^i)^2}\), from the definition of \(\gamma\) and \(\varepsilon\). If (40-1) is satisfied by certain CPs, there is a probability...

39
that ISP will discriminate against CPs with high bandwidth requirements by delaying their packets.

Similarly, equation (40-2) is satisfied when \( U_i'''(q_i) < 0 \) and \( |C''(x^i\mu^i)| > \frac{-\partial\mu^i/\partial p^i}{x^i(\mu^i/a-\partial\mu^i/\partial p^i)} \). If there are certain CPs that satisfy (40-2), the ISP has incentive to delay CPs with narrower bandwidth.

To sum up, when \( |C''(x^i\mu^i)| \) is small and the user’s packet usage is sensitive to price, there is a possibility of discrimination (increasing the delay) for CPs with large required bandwidth and vice versa.

3. **Analysis of the results**

As discussed above, an ISP’s discrimination incentive is clearly affected by its Internet pricing scheme, regardless of whether the ISP operates as a monopoly or duopoly provider. Under a flat-rate pricing scheme, the ISP’s discrimination incentive mainly depends on the CP’s characteristics. Since the ISP has a bigger incentive to delay CPs with higher levels of required bandwidth, the possibility of discrimination increases as new services with more required bandwidth are launched. This explains the increased concern regarding network neutrality. In the past, web services were similar to each other in terms of required bandwidth. For example, e-mail and web browsing services did not have significant differences in required bandwidth. However, the Internet grew to include various services such as IPTV and VoIP services. The services now delivered online have a larger range of required bandwidth and QoS. This provides increased incentive by ISPs to discriminate between CPs. Without network neutrality regulations, an ISP’s discrimination can bring significant harm to content innovation. As Internet services are become more wide ranging, we would expect there to be more possibility of discrimination towards brand-new Internet services with larger required bandwidth. For the most part, new services are likely to bring less consumer utility than traditional services because they do not yet have a sufficient consumer base or business experience. Considering this fact, network neutrality regulation is expected to be good for content-side innovation in a flat-rate pricing scheme.

Under usage-based pricing, an ISP’s discrimination incentive mainly depends on the ISP’s profit margin. If the ISP is operating in a situation such that the price is bigger than the marginal cost, which is a necessary condition for a firm operating
under no price regulation, there is only a slight possibility of ISP discrimination under a usage-based pricing scheme. In addition, if the profit margin is sufficiently large, then the ISP would have no incentive to discriminate against certain CPs but would increase network investment to meet consumer needs. Considering that, network-neutrality regulation is not likely to bring significant differences to ISP discrimination incentive, but competition regulation and price regulation would have serious effects on an ISP’s discrimination incentive.

IV. CONCLUSION

Internet pricing schemes have not been a concern in the network-neutrality research. In the beginning of the network neutrality debate, network neutrality was only a concern for nations under a flat-rate pricing scheme, particularly the United States. Nowadays, however, network neutrality is a global concern. The European Union is also considering enacting network-neutrality regulation although many European countries are under usage-based Internet pricing schemes. In this context, there is a need to reexamine whether former network neutrality-regulation research can be applied to usage-based pricing cases.

As this research determines, Internet pricing schemes have a significant effect on ISP discrimination incentives. Considering that one of the main objects of network neutrality regulation is to ban discrimination on certain types of content, our research is leading to the conclusion that there should be consideration of Internet pricing when network neutrality is discussed.

The result can also be a lesson for countries under flat-rate pricing schemes if the government calls for network-neutrality regulation for non-discrimination of CPs or a direct non-discrimination policy is achieved by switching the country’s Internet pricing scheme. One thing the government should consider is maintaining packet prices above the marginal cost. The KISDI suggests Internet-price switching as a type of network-neutrality regulation (Hee-Su Kim, 2010). This research can be considered as theoretical background for the claim.

In that context, this research provides policy implication for the Korean government. As Korean wired networks charge a flat-rate price per month, local ISPs are expected to have an incentive to apply delays on packets for some CP’s services. Therefore, the Korean government should consider network neutrality
implementation in order to maintain internet neutrality. If the government sees the cost of network neutrality rules exceed the benefits from the neutral network, it can switch to usage based pricing to obtain a similar goal.

Our result also can be applied to wireless data services charging a flat-rate for using unlimited amount of data packets. As development of smart devices such as smart phones and tablet PCs continues, Korean telecommunication companies are switching their data service pricing schemes from usage based to flat-rate pricing, with KT even announcing they would block heavy users. Korean internet users do not prefer usage-based pricing with the costs of switching pricing schemes too burdensome. Therefore the Korean government should consider implementation of network neutrality regulations for incubating services like IPTV.

One limitation of the research is that it cannot fully explain the effect of changing price schemes towards network neutrality because it only covers the case of purely flat-rate pricing and pure packet usage-based pricing. In the real world, there are many pricing schemes which fall in between. Thus, further research is required for defining the full effect of pricing schemes on ISP’s discrimination incentive. We also want to note that the research does not cover the case where a user prefers one of the pricing schemes. In reality, users have their own preference of pricing schemes.

REFERENCES


Appendix A: Deriving $\frac{d}{d\delta_i} \left( \frac{\partial q_i}{\partial p} \right)$

The condition for consumer utility maximization is (A-1)

$$U_i'(q_i^*) - p \lambda_i = 0 \quad (A-1)$$

We differentiate (A-1) with $p$ to obtain (A-2).

$$U_i''(q_i^*) \frac{dq_i^*}{dp} - \lambda_i = 0 \quad (A-2)$$

We rearrange (A-2) for $\frac{dq_i^*}{dp}$ and obtain (A-3).

$$\frac{dq_i^*}{dp} = \frac{\lambda_i}{U_i''(q_i^*)} \quad (A-3)$$

$q_i^*$ is a function of $p$ and $\delta_i$, since $p$ and $\delta_i$ are independent to each other,

$$\frac{dq_i^*}{dp} = \frac{\partial q_i^*}{\partial p}.$$ 

Replace $\frac{d\mu^*}{d\delta_i}$ to $\lambda_i \frac{dq_i}{\partial \delta_i}$.

$$\frac{\partial \mu^*}{\partial p} = \frac{\partial \sum \lambda_i q_i^*}{\partial p} = \sum_{i=1}^{n} \lambda_i \frac{\partial q_i}{\partial p} = \sum_{i=1}^{n} \left( =_i \right)^2 U_i''(q_i^*) \quad (A-4)$$

Differentiate (A-4) with $\delta_i$.

$$\frac{d}{d\delta_i} \frac{\partial \mu^*}{\partial p} = - \frac{(p_i)^2 U_i'''(q_i)}{(U_i''(q_i))^2} \frac{dq_i}{\partial \delta_i} = - \frac{\lambda_i U_i'''(q_i) \partial \mu^*}{(U_i''(q_i))^2 \partial \delta_i} \quad (A-5)$$