Net Neutrality, Boon or Bane for Free File Sharing Service?

(preliminary draft)

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Abstract

In this paper, we establish a simple framework relying on queuing theory to analyze the net neutrality on file sharing service users. We find that net neutrality regulation does not necessarily improve consumer surplus as well as the social welfare; it depends heavily on the extra traffic generated by file sharing service and the distribution cost of the content produced by the content provider, we also find that, if we allow the Internet Service Provider charging the Content Provider for content distribution, the Internet Service Provider could obtain the optimal level of the industrial profit by successfully manipulating the pricing strategy of the Content Provider.

1 Introduction

File sharing service frees people from the constraints of specific content providers and give great convenience and liberty to achieve various of musics, videos and games, with less cost than from the traditional way. However, it also results in the unstoppable up/downloading which occupies a large proportion of ISPs' bandwidth (Perényi, Dang, Gefferth, and Molnár 2006). Moreover, it also brings litigation issues with organizations of intellecture property right protection. In 2002, Napster, who developed a Peer-to-Peer technology to facilitate the exchange and download of music, announced to shutdown their servers forever after a failed litigation with RIAA (Recording Industry Association of America). From then on, file sharing software developers decided to make their product open-source so that their software could live under the protection of GPL license to avoid litigation problems as Napster ever had. Therefore, the IPR protection organizations adjust their target from "prohibiting the development of file sharing technology" to "preventing the end users using such software". A situation involving Comcast, an American ISP, and the Federal Communications Commission (FCC) in the United States, encountered the similar contradiction of file sharing service and net neutrality in 2008. In this case, The ISP no longer stood for net neutrality principle, in fact, Comcast attempted to decrease the network responding priority of its customers who use file sharing file sharing technology, which begot an intervention of FCC immediately and followed with a litigation between them. Finally, the court's decision overthrew the regulation of FCC and opened the gate for the ISPs to discriminate connection qualities according to different content on their networks.

Here the problems rise: Does net neutrality principle really improve the social efficiency or consumer surplus? Should the regulator compulsorily implement net neutrality principle or hold a laisse-faire attitude to the ISPs? To answer these questions, we first look through related literature.

According to the survey of Schuett (2010), net neutrality has two different interpretations: a zero-price rule or a non-discrimination rule. Zero-price rule means that the CP should not be charged a termination fee (Lee and Wu 2009) for delivering their content to customers. Economides and Tag (2007) considers a monopolistic ISP, a continuum of CPs and end-users, but focus on whether the ISP should be allowed to charge both the CP and end-users or only the end-users. They find that net neutrality regulation is not so desirable for the monopoly ISP but may lead to an improvement of the social welfare. Musacchio et al. (2009) extend the framework to an N-ISP scheme, and show that termination charge (positive or negative) is social optimal when advertisement revenue is low or the subscription elasticity is high.

It is the externalities among parties which makes zero-price rule debatable. Therefore, these analyses, based on a two-sided market framework, are quite insightful, since they formalize the internal externalities between CPs, consumers and probably the advertisers. Moreover, two-sided market framework is not only compatible with the analysis of zero-price rule, it but also can be used to analyze another interpretation of net neutrality, that is, the non-discrimination constraint.

Hermalin and Katz (2007) analyze a quality product-line restriction. In their framework, the ISP is a monopoly platform, and a continuum of CP and end-users stand aside and the end-users will buy the content from vertically-differentiated CPs. The ISP can either provide single quality of network connection to all types of CPs (with net neutrality regulation), or provide different quality to different CPs by using incentive-compatible contract (without net neutrality regulation), and they found that with net neutrality regulation, CPs of low profitability are excluded from the market while CPs of high profitability are harmed since they must use less efficient network quality than the should have; only the situation of CPs of middle level profitability are improved.

Hermalin and Katz's framework allows for varies of network qualities to be offered, However, it does not formally modelize the externalities among the network qualities, which, in another word, means network congestion, which play a significant role when we regard net neutrality as a non-discrimination rule. Therefore, researchers begin to introduce queuing theory into their analysis to explicitly endogenize the network congestion. Besides welfare concerns, this catalogue of papers often investigate the investment incentive of the ISP on the network capacity and that of the CP on the content innovation. Depending on different settings, the results and policy implications still varies.

In Choi and Kim (2010), the ISP decides whether to discriminate two CPs who compete à la Hotelling in a straight line of end-users. The ISP has two revenue sources: the access charge to end-users and the priority fee charged to one of the CPs. The ISP then faces a trade-off between charging higher access fee to the end-users and extracting rent from the CPs from the priority fee. From a long-term perspective, when the ISP can invest to increase the bandwidth capacity, whether net neutrality regulation can have a chilling effect on the ISPs also depends on this trade-off. In particular, when the rent extraction effect does not exist, the ISP under net discrimination has less incentive to invest on the bandwidth expansion under net discrimination than under net neutrality. In Cheng et al. (2010), the content value depends on the total arrival rate, and the ISP can charge a priority fee to the CP, based on the number of customers that the CP serves. In contrast to Choi and Kim, they find that the social welfare increases when net discrimination is applied, while investment incentives are unambiguously high under net neutrality than net discrimination. Kramer and Wiewiorra push the argument for net discrimination even further, their main idea is that net discrimination allows the sensitive-to-delay content and non-sensitive-to-delay content adopting different network qualities, and thus make network resource allocation more efficient and improve social welfare in both short term and long term.

One recent paper of Reggiani and Valletti (2010) also constructs a model including an Internet service provider, a dominant content provider and a fringe, and a continuum of consumers. they show that in short run, non-discrimination rule favors the fringe while decreases the application number of the dominant content provider. In the long run, the ISP's investment on the network capacity can increase if the advertising rate is insensitive to the network congestion.

Most of these works assumes a rather homogeneous action pattern of end-users. However, in realities, file sharing users and normal users are quite different (Anagnostakis and Greenwald 2004). Moreover, file sharing users yields a significant proportion of the whole network traffic, and the tendency is continuously increasing (Index 2010). Therefore, In our model, we have two different types of users: file sharing users and traditional downloaders, whose action pattern and network delay can also be different due to different regulatory regimes. To modelize the network congestion, we also uses queuing theory, but the net content value does not only depend on the total arrival rate, but also on the delaying time itself: priority customers (traditional downloaders) thus can enjoy higher value from the content. Based on this framework, we analyze the effect of net neutrality regulation on the industry profit, consumer surplus and social welfare and then give some policy implications. We find that the ISP will adopt net neutrality rules "less often" from the social point of view, and net neutrality, is more likely to be enforced if the regulator put much weight on the consumer surplus.

The rest of the paper is as follows, in section 2, we present a basic model to formalize the relationship between a unique ISP, a content provider, and a continuum of users. Section 3 studies the equilibrium of the model and gives out some propositions. Section 4 presents some extensions and Section 5 concludes.

2 Basic Model

There are three types of agents: an Internet Service Provider (ISP), who has obligation to provide Internet access to the content provider and end-users; a Content Provider (CP), who produces the content valuable for the end-users and distribute it via Internet; and a unit mass type of consumers who buy the Internet connection service to enjoy the content. Particularly, consumers can do so in two ways: either they can buy it from the content provider, or they use file sharing.

We first define the meanings of net neutrality (policy N) in our settings, that is, the ISP must treat all data packets equally, regardless of whether they are generated by file sharing or traditional downloading; the time of delay is then w_N. If instead net discrimination (policy D) is applied, the ISP can establish a multi-tier network that grants priority to legal downloaders; this results in a shorter delay for traditional downloaders, $\underline{w} < w_N$, and a longer delay for file sharing users, $\overline{w} > w_N$. We will talk more on the determination of w_N and $\overline{w}$ in the next subsection.

The CP produces the content with a constant marginal cost c, content with an average delay w gives any consumer a utility $\frac{V}{w}$. To benefit from content, end-users can either pay content price p and download it from the content provider's website or use file sharing; in that case, they waive the content price but incur a cost θ, which represents the technology cost of using file sharing. In both cases, users must pay A for the access to the Internet. Consumers have unitary demand and their technical cost θ satisfies a uniform distribution $U[0, 1]$.

We define $\widehat{\theta}$ as the type of the customer who is indifferent between file sharing and traditional downloading. Therefore, a proposition $\widehat{\theta}$ of the end users are file sharing users, and $1-\widehat{\theta}$ are the traditional downloaders. Referred to the above definitions, the utility function of traditional downloaders U_T is:

$$U_T = \frac{V}{w_T} - p - A \tag{1}$$

The first term is the utility originated from the content; correspondingly, the buyers must pay p for the content as well as the access price A for the Internet connection. In contrast, file sharing users waive the price p and incurs a type-dependent technology cost θ:

$$U_F = \frac{V}{w_F} - \theta - A \tag{2}$$

3 Introduction of $M/M/1$ Theory

We adopt $M/M/1$ queuing theory as the micro-foundation for the relationship between the number of users, the capacity of the network and waiting times.

Given the capacity of the network μ and an arrival rate of requests per instant λ, under net neutrality, the waiting time is $w_N = \frac{1}{\mu-\lambda}$. In case of discrimination, traditional downloaders have a higher network priority; therefore they face a waiting time $\underline{w} = \frac{1}{\mu-\lambda_1}$, where λ_1 is the arrival rate of high priority request; since the traditional downloaders form only part of the customers, $\lambda_1 < \lambda$, and thus $\underline{w} < w_N$; free file sharing users must instead endure a longer waiting time

$\overline{w} = \frac{\mu}{\mu-\lambda}\underline{w} = \frac{\mu}{\mu-\lambda}\frac{1}{\mu-\lambda_1} > w_N$.

This model has two useful properties:

- Efficiency Neutrality. If a proportion α of end-users is granted high priority (that is, $\lambda_1 = \alpha$ and $\lambda = 1$), the total utility delivered to the end users is

$$V-[\alpha\underline{w}+(1-\alpha)\overline{w}] = V-[\alpha\frac{1}{\mu-\alpha}+(1-\alpha)\frac{\mu}{\mu-1}\frac{1}{\mu-\alpha}] = V-\frac{1}{\mu-1} = V-w_N,$$

which means that choosing between net discrimination and net neutrality does not yield any efficiency gains. This will be very important for analysis; if, instead, discrimination (or neutrality) itself generated some efficiency gains (or loss), we would have to distinguish what is due to the technology itself and what is due to the strategic action of players.

- $(\overline{w} - \underline{w})'_{\lambda_1} < 0$ and $\underline{w}'_{\lambda_1} > 0$: the waiting time of high priority becomes longer and the differences between high and low priority become smaller, when there are more subscribers.

To simplify the analysis we will assume that $\mu >> \lambda$, so that $\frac{\lambda\lambda_1}{\mu} \simeq 0$ and thus $\overline{w} \simeq \frac{1}{\mu-(\lambda+\lambda_1)}$. If the waiting time still affected the utility in an additive way, as is usually assumed in the literature, the efficiency neutrality would then be violated. To restore this property, we thus adopt another form of gross utility, $\frac{V}{w}$, instead of $V - w$. In this way, the total utility received by the end-users are equal under net discrimination regimes:

$$\alpha\frac{V}{\underline{w}} + (1-\alpha)\frac{V}{\overline{w}} = \alpha(\mu-\alpha)V + (1-\alpha)(\mu-\alpha-1)V = (\mu-1)V = \frac{V}{w_N}$$

While the process described in this model is dynamic and complex, our model can be treated as a static reduce-form representation. The arrival rate λ is related to volume and we assume that file sharing generate more data exchanges and more network traffic than downloading directly from the website of the content provider.[1]

We thus denote the arrival rate for traditional downloaders by a and the arrival rate for a file sharing user by $(1+\tau)a$, where $\tau > 0$. The arrival rate of high-priority requests can then be expressed as a function of a and of the group size $1-\widehat{\theta}$, therefore $\lambda_1 = (1-\widehat{\theta})a$. Following the same logic, the total arrival rate is $\lambda = (1+\tau)a\widehat{\theta} + (1-\widehat{\theta})a = (1+\tau\widehat{\theta})a$.

The waiting times are therefore given by:

- Under net neutrality, all users face the same delay: $w_N = \frac{1}{\mu-\lambda} = \frac{1}{\mu-(1+\tau\widehat{\theta})a}$
- Under net discrimination, traditional downloaders face a shorter delay $\underline{w} = \frac{1}{\mu-\lambda_1} = \frac{1}{\mu-(1-\widehat{\theta})a}$,while file sharing users have to put up with a prolonged delay: $\overline{w} = \frac{1}{\mu-\lambda-\lambda_t} = \frac{1}{\mu-\left[2-(1-\tau)\widehat{\theta}\right]a}$

Options for net discrimination now enhances efficiency, which is aligned with the results of Musacchio et al. (2009):

[1] Since some file sharing software, such as file sharing software, must continuously broadcast inquiry signals through Internet to find their Peers and establish dynamic connections with them, a lot of network traffics are generated in this process. This property of file sharing has been proved by some comparative analysis of net traffic (Basher, Mahanti, Williamson, and Arlitt 2008).

$$(1-\widehat{\theta})\frac{V}{\underline{w}}+\widehat{\theta}\frac{V}{\overline{w}} \geq \frac{V}{w_N}$$

Other things equal, net discrimination deliver higher utility to end users. This is because our assumption that, compared with traditional downloading, file sharing service generates extra traffic and thus is an inferior technology; net discrimination policy confines the effect of this extra traffics within file sharing users, instead of the whole group of end users.

4 Equilibrium

4.1 Integration

We first consider the benchmark case in which a social planner sets the policy scheme (net neutrality and net discrimination), as well as the content price p and the access charge A, so as to maximize the social welfare.

Let us first characterize the type $\widehat{\theta}$ of the consumer indifferent between file sharing users and traditional downloaders. Any internal solution of $\widehat{\theta}$ must satisfy the condition: $U_T = U_F(\widehat{\theta})$. Denoting w_T and w_F as the delaying time for traditional downloaders and file sharing users respectively, the indifferent condition becomes:

$$\frac{V}{w_T} - p - A = \frac{V}{w_F} - \widehat{\theta} - A, \tag{3}$$

Which yields,

$$\widehat{\theta} = p - (\frac{1}{w_T} - \frac{1}{w_F})V. \tag{4}$$

Also, the traditional downloaders and file sharing users' net utility, U_T and $U_F(\theta)$ must be at least equal to 0 to guarantee their participation. By construction, $U_F(\theta) > U_F(\widehat{\theta})$ for any $\theta < \widehat{\theta}$, and $U_F(\widehat{\theta}) = U_T$ whenever $\widehat{\theta} \leq \theta \leq 1$. Thus for the ISP, the optimal access charge to the end-users should only leave 0 to the type-$\widehat{\theta}$ consumer and all the traditional downloaders as well; if the type-$\widehat{\theta}$ consumer had positive utility, the ISP could charge a little bit more without excluding any end-users. Formally speaking, the two participation constraints can be simplified into one equation, that is, $U_F(\widehat{\theta}) = 0$, or:

$$A = \frac{V}{w_F} - \widehat{\theta}. \tag{5}$$

We define $\widetilde{\theta}$ as the indifferent consumer's type if the access charge is not binding (unconstrained case), the content provider's profit thus is $\pi = (p-c)(1-\widetilde{\theta}) = [(\frac{1}{w_T}-\frac{1}{w_F})V+\widetilde{\theta}-c](1-\widetilde{\theta})$. The optimal $\widetilde{\theta}^*$ must satisfy $\widetilde{\theta}^* \in \arg\max_{\widetilde{\theta}}[(\frac{1}{w_T}-\frac{1}{w_F})V + \widehat{\theta} - c](1-\widehat{\theta})$. Notice that under discrimination, $w_T = \underline{w}$ and $w_F = \overline{w}$; while under net neutrality $w_F = w_T = w_N$, simple algebra immediately leads to $\widetilde{\theta}^*_N > \widetilde{\theta}^*_D$. The intuition is that under net discrimination, the original content is vertically differentiated with copies from file sharing service, therefore other things equal, more consumers will thus choose to buy from the content provider.

The industry profit is the sum of the profit of CP and ISP:

$$\Pi(\widehat{\theta}) = [(\frac{1}{w_T} - \frac{1}{w_F})V + \widehat{\theta} - c](1 - \widehat{\theta}) + \frac{V}{w_F} - \widehat{\theta}$$

That $\widehat{\theta}$ also appears in the function of A implies that there exists some externalities between the access charge (ISP's revenue from the consumers) and the content price (CP's revenue from the consumers). Moreover, these externalities are different between the two regulation regimes.

Under net neutrality $A_N(\widehat{\theta}_N) = \frac{V}{w_N} - \widehat{\theta}_N = [\mu - (1+\tau\widehat{\theta}_N)a]V - \widehat{\theta}_N$, therefore $\frac{\partial A_N}{\partial \widehat{\theta}_N} = -\tau aV - 1 < 0$. The presence of binding access charge exert a negative externality on $\widehat{\theta}$. For instance, when $\widehat{\theta}_N$ declines, less end-users use file sharing service and the corresponding extra traffic throughout the whole network is alleviated, the utility $\frac{V}{w_F}$ delivered to every end-users increases; moreover, pushing the threshold towards the left also decreases the marginal consumer's technical cost, which increase the access charge of the ISP indirectly. These two factors have the same direction. Consequently, to maximize the industry profit instead of only the content revenue, the integrated firm tends to increase the number of traditional downloaders, that is, the industry optimal level $\theta_N^* < \widetilde{\theta}_N^*$.

Under net discrimination, $A_D(\widehat{\theta}_D) = \frac{V}{w} - \widehat{\theta}_D = \mu - \left[2 - (1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D$ and $\frac{\partial A_D}{\partial \widehat{\theta}_D} = aV - \tau aV - 1 = aV + \frac{\partial A_N}{\partial \widehat{\theta}_N}$. The presence of aV indicates that there is another but positive factor influent the determination process of $\widehat{\theta}_D$. This factor rises from the fact that under net discrimination, replacing a traditional downloader with a file sharing user now has dual effects: the first one is the same as before, since extra network volume will always aggravate the traffic problem and decrease the utility of file sharing users; however, the second effect is reverse: since compared with a traditional downloader, a file sharing user occupy less capacity, some network resources will be released when a traditional downloader becomes a file sharing users, and correspondingly, every end-user within the network will share these additional resources, which drives the utility of file sharing users increases. Therefore, depending on the relative strength of these three factors, θ_D^* can be either larger or smaller than $\widetilde{\theta}_D^*$. Furthermore, we have proposition 1:

Proposition 1 *If the extra network traffic indicator τ is high, there are less file sharing users involved under industry optimal states than those under the unconstrained case.*

This proposition is an immediate inference of the above discussion since τ only appears as a negative factor in both expression of $\frac{\partial A_N}{\partial \widehat{\theta}_N}$ and $\frac{\partial A_D}{\partial \widehat{\theta}_D}$. The intuition is also straightforward: if file sharing users generated too much extra traffic so that the whole network was slowed down, The integrated firm should induce more end-users to become traditional downloaders so as to ameliorate the network condition and thus charge more access fee.

Now we look into the detail of industry optimality and the social welfare. The social welfare is simply the industry profit plus consumer surplus with a non-negative weight k, since traditional downloaders have 0 net utility in equilibrium, the consumer surplus is the net utility of all the file sharing users, that is:

$$CS = \int_0^{\widehat{\theta}} (\widehat{\theta} - \theta) d\theta = \frac{1}{2}\widehat{\theta}^2.$$

We take a general form of the objective function of the regulator, that is $W = \Pi + kCS = [(\frac{1}{w_T} - \frac{1}{w_F})V + \widehat{\theta} - c](1 - \widehat{\theta}) + \frac{V}{w_F} - \widehat{\theta} + \frac{k}{2}\widehat{\theta}^2$. When $k = 0$, W is in fact the industry profit; when $k = 1$, W is the social surplus. Since $CS'(\widehat{\theta}) = k\widehat{\theta} \geq 0$, denote θ^{**} as the social optimal level, it is easy to know that under whatever regulation regimes, $\theta^{**} \geq \theta^*$.[2] To do comparative statics between net discrimination and net neutrality, we substitute the corresponding values of w_T and w_F respectively for the two regimes, and obtain the expression of the social welfare:

$$\begin{aligned}
W_D &= [(1 + \tau aV)\widehat{\theta}_D + aV - c](1 - \widehat{\theta}_D) + \mu V - \left[2 - (1 - \tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D + \frac{k}{2}\widehat{\theta}_D^2, \\
W_N &= (\widehat{\theta}_N - c)(1 - \widehat{\theta}_N) + \mu V - (1 + \tau\widehat{\theta}_N)aV - \widehat{\theta}_N + \frac{k}{2}\widehat{\theta}_N^2.
\end{aligned}$$

After simple calculation[3], we can obtain the equilibrium values:

$$\begin{aligned}
\theta_D^{**} &= \frac{c}{2(1 + \tau aV) - k}, \\
\theta_N^{**} &= \frac{c - \tau aV}{2 - k}.
\end{aligned}$$

Proposition 2 *When τ is high enough, net discrimination induces more file sharing users than net neutrality.*

[2] By definition, $\Pi'(\widehat{\theta}^*) = 0$, therefore for any internal solution of $\widehat{\theta}^*$, $W'(\widehat{\theta}^*) = \Pi'(\widehat{\theta}^*) + CS'(\widehat{\theta}^*) \geq 0$. The social optimal requires $W'(\theta^*) = 0$, which implies $\Pi'(\theta^*) \leq 0$, therefore $\widehat{\theta}^* \leq \theta^*$.

[3] See Appendix.

Proof. We have $\theta_D^{**} - \theta_N^{**} = \frac{2(1+\tau aV)-k-2c}{[2(1+\tau aV)-k](2-k)}\tau aV$,[4] which immediately leads to $\tau \lesseqgtr \frac{\frac{k}{2}+c-1}{aV} \Longrightarrow \theta_D^{**} \lesseqgtr \theta_N^{**}$. ■

This conclusion is surpurising, since an important anti-neutrality reason is that net neutrality leads excessive file sharing users. However, our analysis show that such a statement is true only when τ is small; particularly, when τ is large, we have the reverse result: net discrimination leads to more file sharing users. To figure ou the reason, we first look at again the externalities between access charge and content revenue. In fact, although the externalities differs, the marginal effect of τ on $\frac{\partial A_i}{\partial \widehat{\theta}_i}$ is the same: $\frac{\partial A_i}{\partial \widehat{\theta}_i \partial \tau} = -aV < 0$, $i = D, N$, the vital differences thus is the content revenue.

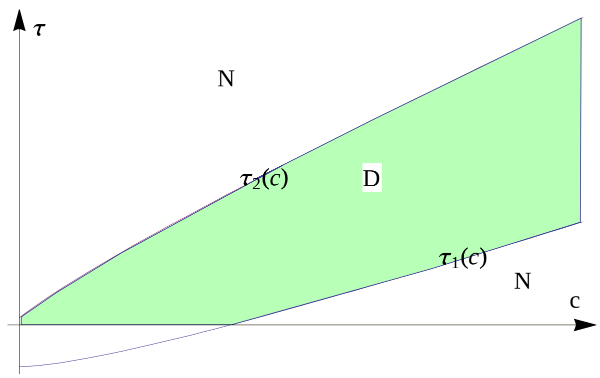
Notice that $\pi_D = [(\frac{1}{w_T} - \frac{1}{w_F})V + \widehat{\theta} - c](1-\widehat{\theta})$ and $\pi_N = (\widehat{\theta} - c)(1-\widehat{\theta})$, the marginal effect of $\widehat{\theta}$ is different. Since $\frac{\partial(\frac{1}{w_T} - \frac{1}{w_F})}{\partial \widehat{\theta}} > 0$, under net discrimination, when τ changes, the CP is reluctant to gobble up more market share since it does increase some revenue while it also reduce the advantages of first-priority. Remember that in the unconstrained equilibrium, $\widetilde{\theta}_N^* > \widetilde{\theta}_D^*$, along with the increase of τ, both θ^{**} decreases, while θ_N^{**} declines faster than θ_D^{**}. Therefore, there must be a threshold of τ, at which $\theta_N^{**} = \theta_D^{**}$, and any τ which is larger than this threshold leads to $\theta_D^{**} > \theta_N^{**}$.

Substituting θ_i^{**} into $W_i, i \in \{D, N\}$ and solving the equation $W_D = W_N$, we have three real roots: $\tau_1 = \frac{4c-(2-k)-\sqrt{8(2-k)c+(2-k)^2}}{4aV}$, $\tau_2 = \frac{4c-(2-k)+\sqrt{8(2-k)c+(2-k)^2}}{4aV}$ and $\tau_3 = 0$. Therefore it is optimal for the regulator[5] to implement net discrim-

[4] Here we only discuss the situation that $k \leq 2$, since $\theta^* = 1$, when $k > 2$.

[5] We can regard the integrated firm as a regulator with $k = 0$.

ination for any $\tau \in (\min\{0, \tau_1\}, \tau_2)$, and enforce net neutrality in all other cases, as is shown in the following graph:



Here c is the direct cost of website maintenance and distributing the content, while τ can be regarded as a "cost" for uncovering of the market.[6] Therefore, when c is large and τ is small, θ_D^{**} is more like to be smaller than θ_N^{**}, distributing the content directly to the end-users is not very efficient while extra traffic is not significant, it is a natural choice for the social planner to implement net neutrality so as to induce more file sharing and less traditional downloading; Another similar situation involves a large τ and small c, θ_D^{**} is more like to be larger than θ_N^{**}, for social efficiency, less end-users should be allocated to use file sharing service, net neutrality should still be implemented to deduce the number of file sharing users. In all the other situations in between, net discrimination is superior.

Moreover, $\tau_1'(k) > 0$ and $\tau_2'(k) < 0$ implies that higher weight on con-

[6] Transparently, if all the consumers legally download from the content provider, τ does not matter:

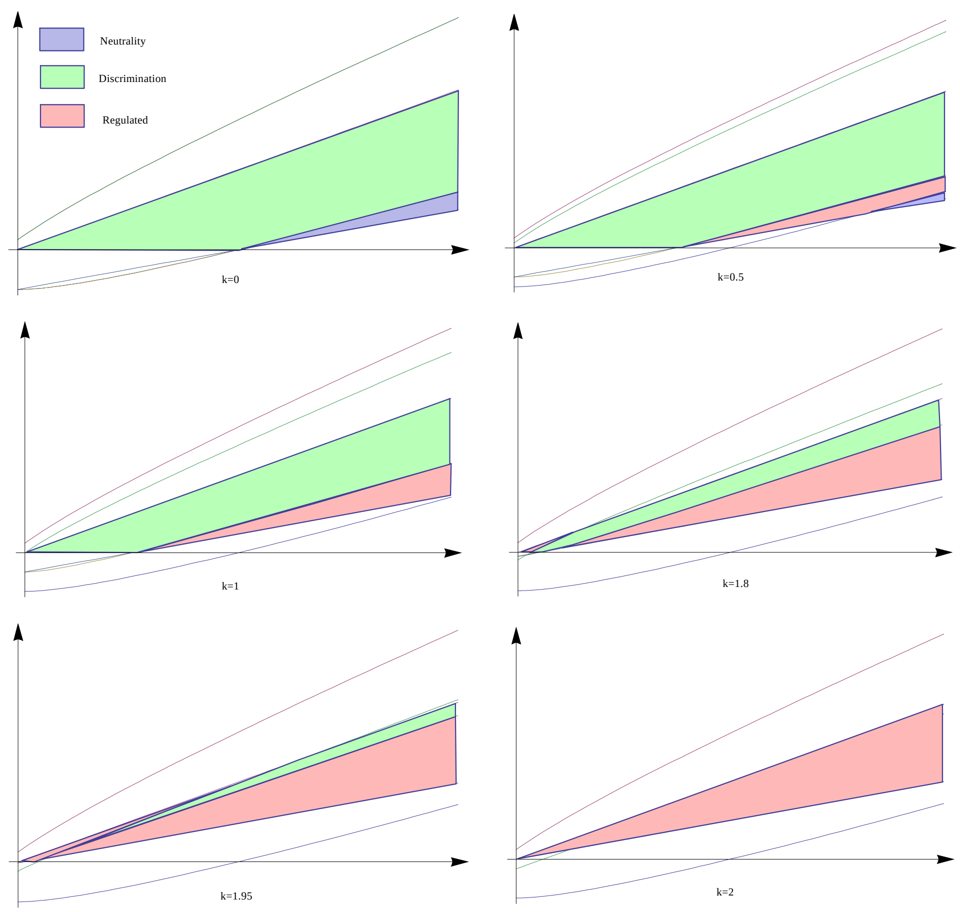
sumer surplus leads to more narrower range of parameters for net discrimination. Particularly, when $k = 2$, $\tau_1 = \tau_2$, the area of net discrimination disappears and net neutrality regulation is implemented regardless of parameters. Since all the above analyses requires the soulutions to be internal, that is, $1 > \theta_i^{**} > 0, i \in \{D, N\}$, the parameter range of τ is $\frac{c}{aV} > \tau > \frac{\frac{c+k}{2}-1}{aV}$.

Putting these results and internal solution constraints together, we have the following proposition:

Proposition 3 *Net discrimination regime is equally or less adopted when the regulator put more weight on the consumer surplus.*

Proof. The upper bound of $\tau, \overline{\tau} = \min\{\frac{c}{aV}, \tau_2\} = \frac{c}{aV}$, and the lower bound of $\tau, \underline{\tau} = \max\{\frac{\frac{c+k}{2}-1}{aV}, \tau_1\}$. Define $\triangle\tau = \overline{\tau} - \underline{\tau}$, since $\tau_1'(k) > 0$, $\triangle\tau'(k) \leq 0$, the range suitable for net discrimination from the social point of view is a non-increasing function of k, while the integrated firm is always a social planner whose $k = 0$, at which point $\triangle\tau$ is maximized. ■

The following graph series illustrate the changes from $k = 0$ to $k = 2$.



4.2 Independent Suppliers

We consider that the ISP and CP are independent from each other and the ISP is permitted to charge the CP a subscription fee F. The timing is as follows:

- The regulatory agency picks one policy settings from the policy set $\{D, N\}$,
- The ISP sets the access charge A to the end-users and subscription fee F to the CP,
- The CP sets content price p,

- End-users finalize their choices.

We solve this problem from the last stage. The CP's maximizes

$$\pi_{cp} = \max_{\widehat{\theta}} (p(\widehat{\theta}) - c)(1 - \widehat{\theta}) - F$$
$$s.t. U_T(p(\widehat{\theta})) \geq 0.$$

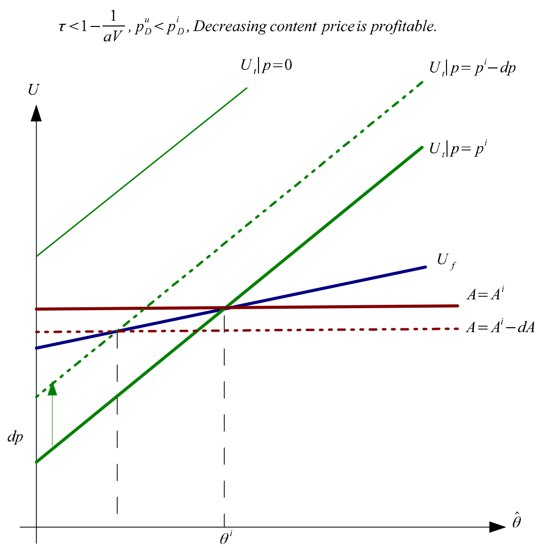
Under net neutrality regime, $U_T(p(\widehat{\theta}_N)) = \mu V - (1 + \tau\widehat{\theta})aV - \widehat{\theta}_N$, therefore $\frac{\partial U_T(\widehat{\theta}_N)}{\partial \widehat{\theta}_N} = -\tau aV - 1 < 0$, the constraint $U_T(p(\widehat{\theta}_N)) \geq 0$ implies $\widehat{\theta}_N \leq \overline{\overline{\theta}}_N(A_N)$, where $\overline{\overline{\theta}}_N(A_N)$ is the upper-limit of $\widehat{\theta}_N$ implicitly determined by A_N. Let $\widehat{\theta}^*_N(A_N)$ and $\widehat{p}^*_N(A_N)$ denote the optimal threshold and content price for the CP, Rationally expecting $\widehat{\theta}^*_N$ and $\widehat{p}^*_N(A_N)$, the ISP chooses A_N and F_N in the first stage:

$$\max_{A_N, F_N} A_N + F_N$$
$$s.t. (\widehat{p}^*_N(A_N) - c)(1 - \widehat{\theta}^*_N(A_N)) - F_N \geq 0$$

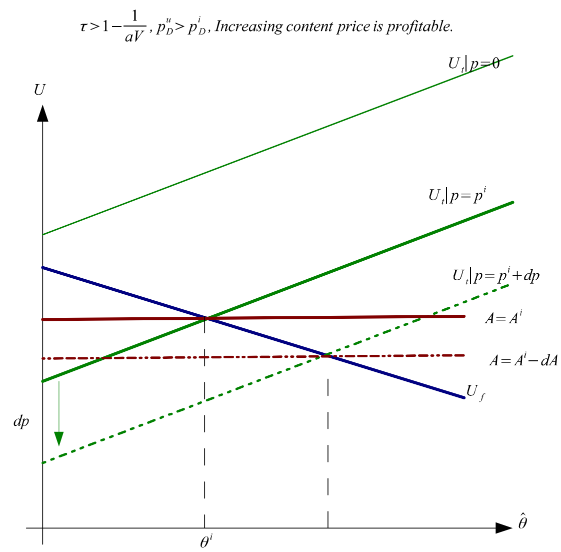
In equilibrium, the constraint is binding, so that $(\widehat{p}^*_N(A_N) - c)(1 - \widehat{\theta}^*_N(A_N)) = F_N$. the ISP then maximizes $A_N + (\widehat{p}^*_N(A_N) - c)(1 - \widehat{\theta}^*_N(A_N))$, which is in fact the whole industry profit. A natural equilibrium candidate is the industry optimum, that is, $p_N = p^*_N$ and $A_N = A^*_N$. Now we show that this is a unique equilibrium.

According to the argument of proposition 1, $\theta^*_N < \widetilde{\theta}^*_N$, which leads to $p^*_N < \widetilde{p}^*_N$, therefore the profitable deviation for the CP is to increase the content price. However, an increasing of the content price leads to a decreasing of traditional downloaders and θ_N increases. However, since $\frac{\partial U_T(\widehat{\theta}_N)}{\partial \widehat{\theta}_N} < 0$, a larger θ_N implies $U_T(p(\widehat{\theta}_N)) < 0$, which violates the participation constraint of the end-users, thus such a deviation is profitable but not feasible. In another word, A_N implicitly set a price cap for the CP.

Under net discrimination, $U_T(p(\widehat{\theta}_D)) = \mu - \left[2 - (1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D$ and $\frac{\partial U_T(\widehat{\theta}_D)}{\partial \widehat{\theta}_D} = (1-\tau)aV - 1$, if $\tau > 1 - \frac{1}{aV}$, $\frac{\partial U_T(\widehat{\theta}_D)}{\partial \widehat{\theta}_D} < 0$, we can directly apply the argument above and prove that there is no profitable deviation available for the CP; if $\tau < 1 - \frac{1}{aV}$, $\frac{\partial U_T(\widehat{\theta}_D)}{\partial \widehat{\theta}_D} > 0$. a marginal increase of file sharing users benefits the traditional downloaders so that the ISP can charge more access charge. In such a case, the industry optimal level induce higher usage of file sharing service, that is, $\theta_D^* > \widetilde{\theta}_D^*$, and the price follows the same order $p_D^* > \widetilde{p}_D^*$. The profitable deviation for the CP is no longer to increase but to decrease the content price so as to be more close to $\widetilde{p}_D^*$. However, a drop of p_D leads to a declination of θ_D, which in turn reduces the utility of traditional downloaders so that the participation constraint is violated again. That is to say, A_D plays a role of price floor. The following graphs illustrate such price ceiling/price floor effect of A_D :



Price Floor Effect



Price Cap Effect

As we argue above, under both regimes and all ranges of parameter settings, the CP cannot make any profitable deviation. Therefore, the candidate equilibrium is indeed an equilibrium, and the uniqueness directly follows from the fact that the industry optimum is unique (due to the strict concavity of $\pi_{cp}(\widehat{\theta})$).

We conclude our findings in the following proposition:

Proposition 4 *Without integration, If we allow for the lum-sum transfer payment from the CP to the ISP, the ISP can successfully manipulate the CP's pricing strategy and achieve the profit of industrial optimal level; moreover, in net discrimination regime, the transfer payment from CP to ISP can be negative or positive, while in net neutrality regime, such transfer payment is negative. In other words, the hold-up condition is deteriorated under net neutrality regime.*

Proof. A more technical proof is in appendix 2. Since the equilibrium is on the industry optimal level, the price $p_D^* = (1 + \tau aV)\theta_D^* + aV = \frac{c}{2} + aV$ and $p_N^* = \theta_N^* = \frac{c - \tau aV}{2}$. the per-user profit of the CP is $aV - \frac{c}{2}$ under net discrimination and $-\frac{c + \tau aV}{2}$ under net neutrality. Obviously the latter one is definitely negative.

■

Particularly, the ISP subsidizing the CP is due to the fact that under net neutrality, the CP faces more fierce competition from file sharing service; without the support from ISP, the CP must pricing his content at least equal to the cost, so that only a very small proportion of end users will choose traditional downloading. This phenomenon, if happened, has two negative effects for the ISP: first, it generates a large amount of extra traffic, which slows the whole network, decrease the reservation utility of the end-users and consequently, decrease the access fee A that the ISP could charge; secondly, the marginal customer will be pushed closed to 1, since the maximal access charge $A = \frac{V}{w_F} - \widehat{\theta}$,which also leads to a lower access charge A. Therefore, under net neutrality regime, the ISP is more likely to subsidize the CP.

4.3 Consumer-based Charge

Now we consider another situation. Specifically we keep the timing as the same as before: the ISP moves first, and it still set the access charge A to all end-users, but instead of a lum-sum transfer payment F, the ISP now charge the CP an additional fee f, for every connected traditional downloader. That is to say, at the last stage, the CP's maximization problem becomes:

$$\pi_{cp} = \max_{\widehat{\theta}}(p(\widehat{\theta}) - c - f)(1 - \widehat{\theta})$$
$$s.t. U_T(p(\widehat{\theta})) \geq 0.$$

Correspondingly, the ISP maximizes:

$$\max_{A,f} A + f(1 - \widehat{\theta})$$
$$s.t.(p - c - f)(1 - \widehat{\theta}) \geq 0$$

Before we introduce our next proposition, we prove the following lemma:

Lemma 1 *In equilibrium, the constraint* $\pi_{cp} \geq 0$ *is binding and* f^e *satisfies* $f^e = p^e - c$, *where* p^e *is the equilibrium price.*

Proof. If $\pi_{cp} \geq 0$ is not binding and $f^e < p^e - c$, in which p^e is the equilibrium price set by the CP, the ISP can charge $\widehat{f}^e = p^e - c$ and obtain a strictly positive extra profit $(\widehat{f}^e - f^e)(1 - \widehat{\theta})$. Therefore, $\pi_{cp} > 0$ is not possible in equilibrium, and $f^e = p^e - c$. ■

The difference between lum-sum and consumer based charges is that lum-sum charge does not alter the pricing strategy of CP while consumer based charge does. Therefore we need to re-check the validity of price cap/floor effects. One immediate observation is that, the price cap effect still apply and the argument is simple: the CP cannot decrease the content price otherwise he/she earns negative profit per downloading, since f has already been set to exploit all his/her surplus, the only possible deviation for the CP thus is to increase the price, which is just prevented by the price cap effect.

The price floor effect takes place under net discrimination regime when $p_D^* > \widetilde{p}_D^*$ follows from $\tau < 1 - \frac{1}{aV}$. However, this property does not hold when $f = p_D^* - c$.[7] Consequently, the price floor effect is no more effective and deviating from the industry optimal state by increasing the content price is profitable for the CP. While an increasing of content price decreases the number of traditional downloaders and in turn stipulate the ISP to increase f and A[8], such a trend will not stop until $\widehat{\theta}_D$ reaches its maximum.[9]

This result implies that the equilibrium price $p_D^e > p_D^*$ and $\theta_D^e = 1 > \theta_D^*$; namely, compared with the industry optimum, the content price is higher and there are excessive file sharing users in equilibrium.

Proposition 5 *When τ is small, consumer-based charge leads to excessive file sharing users and overpriced content (compared with the industry optimal level) under net discrimination regime; while it yields industry optimal outputs under all the other situations and regimes.*

---

[7] If $f = p_D^* - c$, the new unconstrained optimal content price is $\widetilde{p}_D^* = \frac{1+p_D^*+(1+\tau)aV}{2}$ and the industry optimal price is still $p_D^* = aV + \frac{c}{2}$. $\widetilde{p}_D^* - p_D^* = \frac{1+\tau aV}{2} - \frac{c}{4} = \frac{1}{2}(1-\theta_D^*) > 0$.

[8] since $\frac{\partial U_T}{\partial \widehat{\theta}} > 0$.

[9] A more detailed proof see appendix 3.

5 Extensions

5.1 Content Innovation

We keep all the settings and timing in the subsection "independent suppliers", but now the CP can offer an extra content at cost $\frac{v^2}{2\sigma}$ which generates a utility v (independent from V) exclusively for the traditional downloader. The indifferent condition becomes:

$$\frac{V}{w_T} + v - p - A = \frac{V}{w_F} - \widehat{\theta} - A$$

The maximization problem of the CP and ISP are respectively:

$$\max_{\widehat{\theta},v} \pi_{cp} = (p(\widehat{\theta}, v) - c)(1 - \widehat{\theta}) - \frac{v^2}{2\sigma} - F \tag{6}$$

$$s.t. U_T(p(\widehat{\theta}, v)) \geq 0$$

and:

$$\max_{F,A} \Pi = A + F \tag{7}$$

$$s.t. \pi_{cp} \geq 0$$

We need the following lemma to proceed our analysis:

Lemma 2 *With content innovation and lum-sum subscription fee, the ISP can still manipulate the access charge A and achieve the whole industry optimal profit.*

Proof. Since the indifferent condition $U_T(p(\widehat{\theta}, v)) = U_F(\widehat{\theta})$ still holds, therefore $\widehat{\theta}$ continues to be fully determined by the access charge A. Moreover, v only appears in the profit function of the CP, therefore given the same $\widehat{\theta}$, the industry optimal innovation level $v^*(\widehat{\theta}) = \widetilde{v}^*(\widehat{\theta})$, where $\widetilde{v}^*$ represents the unconstrained optimal level of v.

Assuming that the industry optimal states involves A^*, F^*, p^*, v^* and θ^*; then by choosing A^* and F^*, the ISP implicitly designates θ^* and, through the indifferent condition, designates the value of $p - \widetilde{v}^*$ as well. Since $v(\theta^*) = \widetilde{v}(\theta^*)$, $p = p^*$. The ISP successfully fixes the content price at the industry optimal level and use F^* to expropriate the whole surplus of CP. ■

According to lemma 2, the equilibrium state is still the industry optimum, as if the ISP and CP are integrated. In what follows, we will compare the industry optimal states under different regulatory regimes. Since the algebra is similar, we put the full calculation process into appendix[10].

The optimal file sharing users and innovation levels are respectively: $\theta_D^* = \frac{c-\sigma}{2(1+\tau aV)-\sigma}, \rho_D^* = \frac{2(1+\tau aV)-c}{2(1+\tau aV)-\sigma}\sigma$ and $\theta_N^* = \frac{c-\sigma-\tau aV}{2-\sigma}, \rho_N^* = \frac{2+\tau aV-c}{2-\sigma}\sigma$. Obviously file sharing users are fewer than those in the basic model under both regimes, this is because the innovation enhances the content value delivered to traditional downloaders so that compared with the basic model where v is fixed to be 0, more end-users choose to buy content legally. Furthermore, the innovation level also relates to the size of the group of traditional downloaders, as described in the following proposition:

[10] See appendix 4.

Proposition 6 *The level of content innovation depends on the size of traditional downloaders' group. Particularly, a large σ and a small τ implies that net discrimination regulation stipulates higher innovation level; On the contrary, a small σ with a large τ implies that net neutrality induces more extra content.*

Proof. See appendix 5. ■

The innovation level is actually customer-based. If under a certain regulatory regime, there are more end-users who choose to be traditional downloaders, in equilibrium, the corresponding innovation level is higher. The intuition follows that since only the traditional downloaders can enjoy this extra benefit and the consumer surplus of traditional downloaders are totally exploited by the ISP through the access charge A, more traditional downloaders implies that the ISP can obtain more profit from such an innovation, in turn the ISP will induce a higher innovation level.

To understand the relationship between σ and regulatory regimes, we first try to figure out the demand function under different regimes:

According to the indifferent condition, $\widehat{\theta}_N = p_N - v - (\frac{V}{w_T} - \frac{V}{w_F})$.under net neutrality regime is $D_N(p_N) = 1 - \widehat{\theta}_N = 1 + v - p_N$; while under net discrimination regime, $\widehat{\theta}_N = v + \frac{V}{w_T} - \frac{V}{w_F} - p_N$ and $D_D(p_D) = 1 + \frac{aV+v}{1+\tau aV} - \frac{p_D}{1+\tau aV}$. Since $\frac{\partial D_N(p_N,v)}{\partial v} = 1 > \frac{1}{1+\tau aV} = \frac{\partial D_D(p_D,v)}{\partial v}$, the innovation's marginal effect is larger when net neutrality is implemented. The intuition follows that under net discrimination, the CP has two ways to compete with file sharing service: first-priority content and content innovation, and the consumers are more "loyal" to the CP; while under net neutrality, the CP does a head-to-head competition with file sharing service, and consumers are more sensitive to the new content.

Therefore, if σ is small while τ is large, net neutrality is not very attractive and the innovation mechanism is relatively inefficient, implementing net discrimination leads to more traditional downloaders and higher innovation level as well; Otherwise, if σ is large while τ is small, due to a larger marginal effect, net neutrality stipulates higher innovation level.

5.2 Network Effect

Many file sharing systems have positive externalities (Asvanund, Clay, Krishnan, and Smith 2004) to their users (e.g. Bit Torrent, E-Mule and etc.), in this subsection, we try to add some network effect among file sharing users. More specifically, the utility form of the file sharing users is: $U_F = \frac{V}{w_F} + b\widehat{\theta} - \theta - A$,here b represents the positive externality between file sharing users. Under net discrimination regime, the indifferent condition becomes:

$$\frac{V}{w_F} + b\widehat{\theta} - \widehat{\theta} - A = \frac{V}{w_T} - p - A,$$

$$\widehat{\theta}_D = \frac{1}{1-b}(\frac{V}{w_F} - \frac{V}{w_T} + p).$$

The maximization problems of ISP and CP are the same as those in previous cases: $\theta^*_D = \frac{c}{2(1+\tau aV-b)}, p^*_D = aV + \frac{c}{2}$ and $\theta^*_N = \frac{c-\tau aV}{2(1-b)}, p^*_N = \frac{c-\tau aV}{2}$.[11]

[11] See appendix.

Since $b > 0$, The thresholds of file sharing users, $\widehat{\theta}_D$ and $\widehat{\theta}_N$, under any regulatory polices are larger than those in the basic model. This result is quite intuitive since network effect between file sharing users makes file sharing service more attractive than that of the basic model. However, it creates two effects on the content price: first, it makes the demand function more elastic, other things equal, the content price has an intention to decline; secondly, that the threshold is pushed forwards implies that there are more reservation utilities hold by the marginal consumer, and the ISP will set a higher access charge A to exploit this surplus. These two effects counterbalance each other, and the content price remains the same as if there is no network effect. The following proposition concludes our findings:

Proposition 7 *Compared with the standard case, network effect among file sharing users increases the number of file sharing users in any regulatory regime, but it does not alter the content price p.*

6 Policy Discussions

Our analysis offers at least three insights about the debate of net neutrality and file sharing service. First of all, in the integration case, we reveal that if we have the ISP to choose which regime should be implemented, net neutrality is less often adopted than social optimum. If we get back again to the case of Comcast that we mention in introduction, the litigation between FCC and

Comcast provides a vivid example of a contradiction between the ISP and the regulator. Particularly, when the regulator put more weight on the consumer side, such contradictions will become more serious.

Secondly, we also throw some light on the debate of another interpretation of net neutrality — zero-price rule, by comparing a lum-sum subscription fee and per-usage fee charged to the CP. Our first result is that allowing for a side-payment between the CP and the ISP is necessary, since to achieve the industry optimum, the externalities between access charge and content price should be internalized. Furthermore, According to the argument of Lee and Wu (2009), zero-price rule just means that the ISP cannot charge the CP by the number of consumers or network volume. We find that the lum-sum subscription fee mechanism indeed weakly dominants the per-usage fee mechanism in the sense of social efficiency, which is aligned with the points of Lee and Wu (2009) and Economides (2008).

One interesting observation from the realities is that the ISP are continuously demanding the regulators to permit them negotiating with the CPs about the side-payment. However, according to our analysis, such transfer payment is negative when net neutrality regulation is implemented. Since the recent FCC vote (2010) favors "enforceable net neutrality", if such a regulation rule can be successfully implemented, we may predict that the "demand for bargaining" voice from the ISPs would be weaken.

Thirdly, about the content innovation, our results indicate that the innovation level does not only depend on the regulatory regime but also has a close relationship with the extra network traffic and innovation efficiency. In realities, the CPs are in a R&D-intensified industry, therefore σ is likely to be large, and net neutrality thus becomes of the CP's interests so that they can occupy more market shares and offer their legal users more extra benefit. Actually, it is indeed the CPs who compose an active part of advocates for net neutrality.

7 Conclusions and Further Developments

This paper does an economic analysis of net neutrality[12] and its effects on file sharing service. We develop our model based on the queuing theory to represent the effect of net discrimination and net neutrality. We find that the ISP has less intention to implement net neutrality than the social planner does, and there are indeed some area which need the intervention of the regulator to maximize the social welfare. We also shows that the ISP can successfully manipulate the CP's pricing strategy and achieve the industrial optimal profit, even when the ISP and CP are not integrated.

We also through some light on the compatibility issues (Farrell and Saloner 1985). we can regard the ISP be a producers who provides two kinds of goods, and these two goods can be full compatible (net neutrality case), or partial compatible (discrimination case), consequently we can apply our analysis to these types of market and draw interesting conclusions.

We nevertheless omit three important issues related to net neutrality which

[12] Start with (Hahn and Wallsten 2006)

should be considered in future research. One of those issues is that the ISP's incentives to invest on the capacity of broadband under different regulation regimes may be also different, however, since the access charge A is a linear function of μ, the incentives remains the same regardless of the regulation regimes. Secondly, in our framework, we have only one ISP who plays against the file sharing network; it would be interesting to combine duopoly ISP[13] and file sharing networks together and see what would happen.

Thirdly, it may be interesting to add some asymmetric information between ISP and CP to see if some results of our paper would change or remain. One idea is, content produced by different CPs can be capacity-intensive or non capacity-intensive, that is to define that the utility generated by certain content is sensible to corresponding waiting time or not (e.g. on-line movies are capacity intensive application while news and online pictures are not).

Another important aspect is the diversity of the content. In our model, we have only one CP and he/she always participates in the game and in our model, we only consider only the quality improvement of the content. Compared with models of continuous CPs, we may ignore the externalities between the entrance decision of the CP and/or the content diversity and numbers of traditional downloaders, which is explicitly modelized in most of the two-sided market framework.

[13](Laffont, Marcus, Rey, and Tirole 2001) and (Cremer, Rey, and Tirole 2000).

8 Appendix

8.1 Appendix 1

The total surplus is defined by the industry profit plus a weighted consumer surplus.

$$
\begin{aligned}
W_D &= [(1+\tau aV)\widehat{\theta}_D + aV - c](1-\widehat{\theta}_D) + \mu V - \left[2-(1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D + \frac{k}{2}\widehat{\theta}_D^2, \\
W_N &= (\widehat{\theta}_N - c)(1-\widehat{\theta}_N) + \mu V - (1+\tau\widehat{\theta}_N)aV - \widehat{\theta}_N + \frac{k}{2}\widehat{\theta}_N^2.
\end{aligned}
$$

F.O.C.s lead to:

$$
\begin{aligned}
(1-\widehat{\theta}_D)(1+\tau aV) - [(1+\tau aV)\widehat{\theta}_D + aV - c] + (1-\tau)aV - 1 + k\widehat{\theta}_D &= 0, \\
1 - \widehat{\theta}_N - (\widehat{\theta}_N - c) - \tau aV - 1 + k\widehat{\theta}_N &= 0.
\end{aligned}
$$

$\theta_D^* = \frac{c}{2(1+\tau aV)-k}, \theta_N^* = \frac{c-\tau aV}{2-k}$. Substituting θ_N^* and θ_D^* back to the expression of W_D and W_N,

$$
\begin{aligned}
W_D &= ((1+\tau aV)\widehat{\theta}_D + aV - c)(1-\widehat{\theta}_D) + \mu V - \left[2-(1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D + \frac{k}{2}\widehat{\theta}_D^2 \\
&= -(1-\frac{k}{2}+\tau aV)\widehat{\theta}_D^2 + c\widehat{\theta}_D + \mu V - aV - c \\
&= \frac{1}{2}\frac{c^2}{(2-k+2\tau aV)} + \mu V - aV - c, \\
W_N &= (\widehat{\theta}_N - c)(1-\widehat{\theta}_N) + \mu V - (1+\tau\widehat{\theta}_N)aV - \widehat{\theta}_N + \frac{k}{2}\widehat{\theta}_N^2 \\
&= -(1-\frac{k}{2})\widehat{\theta}_N^2 + (c-\tau aV)\widehat{\theta}_N + \mu V - aV - c \\
&= \frac{1}{2}\frac{(c-\tau aV)^2}{2-k} + \mu V - aV - c
\end{aligned}
$$

$$
\begin{aligned}
W_D - W_N &= \frac{c^2(2-k) - (c-\tau aV)^2(2-k+2\tau aV)}{2(2-k+2\tau aV)(2-k)} \\
&= \frac{(2c-\tau aV)(1-\frac{k}{2}+\tau aV) - c^2}{(2-k+2\tau aV)(2-k)}\tau aV
\end{aligned}
$$

Solving the equation $W_D - W_N = 0$ yields $\tau_1 = \frac{4c-(2-k)-\sqrt{8(2-k)c+(2-k)^2}}{4aV}$, $\tau_2 = \frac{4c-(2-k)+\sqrt{8(2-k)c+(2-k)^2}}{4aV}$ and $\tau_3 = 0$.

8.2 Appendix 2

Under net discrimination, the maximization problem of the CP is:

$$
\begin{aligned}
&\max_{p_D}(p_D - c)D(p_D) - F_D \\
&s.t. \mu V - \left[2-(1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D \geq A_D
\end{aligned}
$$

The Lagrange equation is:

$$L = (p_D(\widehat{\theta}_D) - c)(1 - \widehat{\theta}_D) - F_D + \phi(\mu V - \left[2 - (1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D - A)$$

The F.O.C is:

$$\frac{\partial p_D(\widehat{\theta}_D)}{\partial \widehat{\theta}_D}(1 - \widehat{\theta}_D) - p_D(\widehat{\theta}_D) + c + \phi[(1-\tau)aV - 1] = 0$$

If the participation constraint is binding, $\mu V - \left[2 - (1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D = A_D$, $\widehat{\theta}_D = \frac{2aV + A_D - \mu V}{(1-\tau)aV - 1}$, and $p_D = p_D(\widehat{\theta}_D)$. In the next step, the ISP maximizes:

$$\max_{A_D, F_D} A_D + F_D$$

$$s.t. \pi_{cp} \geq 0$$

F_D will be set as the rational expectation of the total profit of CP, thus the participation constraint of π_{cp} is always binding. From the ISP's perspective of view, maximizing $A_D + F_D$ is to choose appropriate A_D to maximize the joint profit of ISP and CP. Since setting a certain A_D in fact implicitly nominate a certain $\widehat{\theta}_D$, as we have proved before, the ISP would set $A_D = A_D^*$, which is the industry optimal level of access charge as we have calculated in the integrated case, then $\widehat{\theta}_D = \theta_D^*$, and $p_D = p_D^*$.

If the participation constraint is not binding, that is, $\phi = 0$ and $\mu V - \left[2 - (1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D > A_D^*$. We define $\widehat{\widehat{\theta}}_D \in \arg\max_{\widehat{\theta}_D} \pi_{cp}(\widehat{\theta}_D)$ as the solution. We then introduction the function of CP's profit $\pi_{cp}(\widehat{\theta}_D) = (p(\widehat{\theta}_D) - c)(1 - \widehat{\theta}_D)$, check the concavity, we have $\frac{\partial^2 \pi_{cp}(\widehat{\theta}_D)}{\partial \widehat{\theta}_D^2} < 0$. By definition, the industry optimal $\theta_D^* \in \arg\max_{\widehat{\theta}_D} \pi_{cp}(\widehat{\theta}_D) + A(\widehat{\theta}_D)$, which means $\frac{\partial \pi_{cp}(\theta_D^*)}{\partial \theta_D^*} + \frac{\partial A(\theta_D^*)}{\partial \theta_D^*} = 0$.

If $\widehat{\widehat{\theta}} \neq \theta^*_D$. $\frac{\partial A(\theta^*_D)}{\partial \theta^*_D} > 0$, then $\frac{\partial \pi_{cp}(\theta^*_D)}{\partial \theta^*_D} < 0$, because of the concave property of π_{cp}, $\widehat{\widehat{\theta}} < \theta^*_D$, so that $A(\theta^*_D) > A(\widehat{\widehat{\theta}})$, contradiction with the participation constraint.

If $\widehat{\widehat{\theta}} \neq \theta^*_D$. $\frac{\partial A(\theta^*_D)}{\partial \theta^*_D} < 0$, then $\frac{\partial \pi_{cp}(\theta^*_D)}{\partial \theta^*_D} > 0$, because of the concave property of π_{cp}, $\widehat{\widehat{\theta}} > \theta^*_D$, still we have $A(\theta^*_D) > A(\widehat{\widehat{\theta}})$, contradiction with the participation constraint again.

Therefore the only solution is $\widehat{\widehat{\theta}} = \widehat{\theta}^*$.

8.3 Appendix 3

First of all, f^e solves the fix point problem:

$$f^e = p(f^e, \theta^e) - c.$$

Secondly, in equilibrium the CP can no more deviate by increasing the content price, therefore the constrained optimal price must be larger or equal to the unconstrained one, so that the price floor could be effective. However, as we argue before, since the externality between A and p are positive, it cannot be optimal for the ISP to limit the constrained optimal price larger than the unconstrained price, that is to say, these two prices must be equal. Therefore we have another equation (LHS is the constrained price derived from the indifferent condition, and RHS is the unconstrained price):

$$aV + (1 + \tau aV)\theta^e = \frac{1 + c + f^e + (1 + \tau)aV}{2}.$$

Solving the equations above, we obtain $f^e = 1 + (1+\tau)aV - c$, $\theta^e = 1$ and $p^e = 1 + c + (1+\tau)aV$.

8.4 Appendix 4

Since the ISP can achieve the industry optimal level, the profit function of the ISP is in fact the industry profit:

$$\begin{aligned}\Pi_D &= [(1+\tau aV)\widehat{\theta}_D + aV + v_D - c](1-\widehat{\theta}_D) + \mu V - \left[2 - (1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D - \frac{v_D^2}{2\sigma}, \\ \Pi_N &= (\widehat{\theta}_N + v_N - c)(1-\widehat{\theta}_N) + \mu V - (1+\tau\widehat{\theta}_N)aV - \widehat{\theta}_N - \frac{v_N^2}{2\sigma}.\end{aligned}$$

The F.O.C.s are:

$$\begin{aligned}(1-\widehat{\theta}_D)(1+\tau aV) - [(1+\tau aV)\widehat{\theta}_D + aV + v_D - c] + (1-\tau)aV - 1 &= 0 \\ \sigma\left(1-\widehat{\theta}_D\right) - v_D &= 0 \\ 1 - \widehat{\theta}_N - (\widehat{\theta}_N + v_N - c) - \tau aV - 1 &= 0 \\ \sigma(1-\widehat{\theta}_N) - v_N &= 0\end{aligned}$$

The solutions are: $\theta_D^* = \frac{c-\sigma}{2(1+\tau aV)-\sigma}, \rho_D^* = \frac{2(1+\tau aV)-c}{2(1+\tau aV)-\sigma}\sigma$ and $\theta_N^* = \frac{c-\sigma-\tau aV}{2-\sigma}, \rho_N^* = \frac{2+\tau aV-c}{2-\sigma}\sigma$.

8.5 Appendix 5

We first calculate the difference between θ_D^* and θ_N^*:

$$\theta_D^* - \theta_N^* = \frac{c-\sigma}{2(1+\tau aV)-\sigma} - \frac{c-\sigma-\tau aV}{2-\sigma} = \frac{2(1+\tau aV)-2c+\sigma}{(2(1+\tau aV)-\sigma)(2-\sigma)}\tau aV,$$

The difference between ρ_D^* and ρ_N^* is

$$\begin{aligned}\rho_D^* - \rho_N^* &= \frac{2(1+\tau aV)-c}{2(1+\tau aV)-\sigma}\sigma - \frac{2+\tau aV-c}{2-\sigma}\sigma \\ &= \frac{2c-\sigma-2(1+\tau aV)}{(2(1+\tau aV)-\sigma)(2-\sigma)}\sigma\tau aV\end{aligned}$$

Therefore $\frac{\theta_D^*-\theta_N^*}{\rho_D^*-\rho_N^*} = -\sigma < 0$.

Moreover, if $\sigma > 2(c-1-\tau aV)$, $\rho_D^* - \rho_N^* < 0$; if $\sigma < 2(c-1-\tau aV)$, $\rho_D^* - \rho_N^* > 0$.

8.6 Appendix 6

The expressions of industry profit are:

$$\begin{aligned}\Pi_D &= [(1+\tau aV)\widehat{\theta}_D + aV - c](1-\widehat{\theta}_D) + \mu V - \left[2-(1-\tau)\widehat{\theta}_D\right] aV - \widehat{\theta}_D, \\ \Pi_N &= [(1-b)\widehat{\theta}_N - c](1-\widehat{\theta}_N) + \mu V - (1+\tau\widehat{\theta}_N)aV - \widehat{\theta}_N.\end{aligned}$$

The F.O.C.s are:

$$\begin{aligned}(1-\widehat{\theta}_D)(1+\tau aV) - [(1-b+\tau aV)\widehat{\theta}_D + aV - c] + (1-\tau)aV - 1 &= 0 \\ (1-b)(1-\widehat{\theta}_N) - [(1-b)\widehat{\theta}_N - c] - \tau aV - 1 &= 0\end{aligned}$$

The solutions are: $\theta_D^* = \frac{c}{2(1+\tau aV-b)}, p_D^* = aV + \frac{c}{2}$ and $\theta_N^* = \frac{c-\tau aV}{2(1-b)}, p_N^* = \frac{c-\tau aV}{2}$.

References

Anagnostakis, K., and M. Greenwald (2004): “Exchange-based incentive mechanisms for peer-to-peer file sharing,” in *Distributed Computing Systems, 2004. Proceedings. 24th International Conference on*, pp. 524–533. IEEE.

Asvanund, A., K. Clay, R. Krishnan, and M. Smith (2004): “An empirical analysis of network externalities in peer-to-peer music-sharing networks,” *Information Systems Research*, 15(2), 155–174.

Basher, N., A. Mahanti, C. Williamson, and M. Arlitt (2008): “A comparative analysis of web and peer-to-peer traffic,” pp. 287–296.

Cheng, H., S. Bandyopadhyay, and H. Guo (2010): “The debate on net neutrality: A policy perspective,” *Information Systems Research*, 22, 60–82.

Cremer, J., P. Rey, and J. Tirole (2000): “Connectivity in the commercial Internet,” *The Journal of Industrial Economics*, 48(4), 433–472.

Economides, N., and J. Tåg (2008): “Net Neutrality on the Internet: A Two-sided Market Analysis,” *Working Paper Series*.

Farrell, J., and G. Saloner (1985): “Standardization, compatibility, and innovation,” *The RAND Journal of Economics*, pp. 70–83.

Hahn, R., and S. Wallsten (2006): “The economics of net neutrality,” *The Economists' Voice*, 3(6), 8.

Hermalin, B., and M. Katz (2007): "The economics of product-line restrictions with an application to the network neutrality debate," *Information Economics and Policy*, 19(2), 215–248.

Index, C. (2010): "Forecast and methodology, 2009–2014," *White paper, CISCO, June*, 2.

Laffont, J., S. Marcus, P. Rey, and J. Tirole (2001): "Internet peering," *American Economic Review*, pp. 287–291.

Lee, R., and T. Wu (2009): "Subsidizing creativity through network design: Zero-pricing and net neutrality," *The Journal of Economic Perspectives*, 23(3), 61–76.

Musacchio, J., G. Schwartz, and J. Walrand (2009): "A two-sided market analysis of provider investment incentives with an application to the net-neutrality issue," *Review of Network Economics*, 8(1), 3.

Perényi, M., T. Dang, A. Gefferth, and S. Molnár (2006): "Identification and analysis of peer-to-peer traffic," *Journal of Communications*, 1(7), 36–46.

Pil Choi, J., and B. Kim (2010): "Net neutrality and investment incentives," *The RAND Journal of Economics*, 41(3), 446–471.

Reggiani, C., and T. Valletti (2010): "Net neutrality and innovation at the core and at the edge," .

Schuett, F. (2010): "Network neutrality: A survey of the economic literature," *Review of Network Economics*, 9(2), 1.