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Network Neutrality under ISP duopoly: on the ability to assign capacity

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Network Neutrality under ISP duopoly: on the ability to assign capacity*

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Abstract

We analyze the impact of network neutrality regulation on: **(i)** competition between CPs, and on **(ii)** ISPs' incentives to invest. We consider both competition between ISPs and between CPs and show that, if ISPs can offer network services of different quality to CPs, they prefer to sell the highest quality network services to the CP that collects the highest advertising revenues. We further show that the impact of network neutrality regulation on the investment in the quality of network services is potentially ambiguous and depends on: **(i)** whether ISPs are symmetric, and **(ii)** the ISPs' ability to assign network's capacity to CPs. If ISPs are symmetric and have full discretion on how to allocate the level of quality of network services among CPs, investment and welfare are higher under the discriminatory regime.

Keywords: *Network Neutrality*, *Competition*, *Investment.*

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1 Introduction

The ever increasing demand for bandwidth has put *network neutrality* at the center of the telecommunications policy debate. One side argues that *network neutrality* interferes with traffic management and may, thereby, reduce the incentives to upgrade telecommunication networks, hindering the deployment of high quality services. The other side argues that *network neutrality* is necessary to guarantee competition and innovation in content provision.

In this article, we analyze the impact of *network neutrality* on: **(i)** competition in content services, and **(ii)** internet service providers' incentives to invest in their networks. For this purpose, we develop a two-sided model where two rival internet service providers offer access to the internet services to consumers and network services to content providers. Two rival content providers sell advertising services and content services to consumers.

By a *network neutrality* regime we mean a regulatory framework where, regarding network services, internet service providers can neither treat content providers differently, nor charge for those services. By a *discriminatory* regime we mean a regulatory framework where the opposite holds, and in particular, where internet service providers may offer high quality network services to certain content providers and charge for it.

Our model has two important characteristics.

The first characteristic is that there is both competition among internet service providers and content providers.[1] In turn, this assumption forces us, for tractability, to impose that the consumers' choice of internet service provider is independent of the choice of content provider.[2] This is justifiable if consumers use the internet to consume many types of services, of which content is only one.

The second characteristic is that our model is very flexible in terms of the level of discretion that internet service providers have to allocate the additional capacity enabled by the investments in their network among the quality of network services they supply to content providers, encompassing the case where internet service providers may have full discretion and the case where more capacity reduces the ability of an internet service provider to differentiate among content providers. The model's flexibility in terms of the internet service providers' level of discretion, which contrasts with the queueing model commonly used in the literature, is motivated by engineering considerations, and unifies opposing

[1] By competition we mean oligopolistic competition with strategic interaction.

[2] It is possible to have a tractable model where the consumers' valuation of internet services depends on the choice of content provider with a monopolist internet service provider and strategic content providers, or with strategic internet service providers and non-strategic, e.g., perfectly competitive, content providers, but it is challenging to have both strategic internet service providers and strategic content providers.

results in the literature.

We show that both internet service providers offer high quality network services to the content provider that generates the highest advertising revenues. The value internet service providers can charge content providers for high quality network services depends on the content providers' marginal profit of these services. Furthermore, for a content provider the high quality network services of the two internet service providers are complements. Hence, both internet service providers offer high quality network services to the most profitable content provider, and they give him the maximum quality advantage.

In our analysis of the impact of *network neutrality* regulation on internet service providers' incentives to invest in their networks, we find that under the *network neutrality* regime investment only has an *internet services* effect, which allows an internet service provider to increase the quality of access to the internet services it provides to consumers, thereby raising their valuation for this service. Under the *discriminatory* regime, investment has both the *internet services* effect and the *content services* effect, which follows from consumers benefiting from higher quality content services, and also results from a change in the payment from the content provider.

Contrary to the case of *network neutrality* regime, under the *discriminatory* regime the *internet services* effect has a second component which results from the possible asymmetry between the two internet service providers, and which can be positive or negative. This second component is absent for a monopolist internet service provider.[3] Regarding the *content services* effect, if an internet service provider has full discretion to set the level of quality of network services it provides to content providers, investment allows the internet service provider to increase the difference in the quality of network services it provides to content providers. Under these conditions, the *content services* effect is positive since it increases the rents internet service providers are able to collect from the content provider to whom they sell high quality services. This contrasts with the case, commonly assumed in the literature, where traffic is routed mechanically according to a queueing model. In this latter case, investment leads to a decrease in the difference in the quality of the network services an internet service provider offers to the two content providers. This implies that the *content services* effect is negative since investment reduces the fee an internet service provider can charge to the content provider that buys high quality network services.

We then assume the case where the internet service providers are symmetric and have

[3] Moreover, for a monopolist internet service provider business stealing is absent and the incentive to invest relies on the ability of charging consumers a higher price.

full discretion on how to allocate network's quality. In this case, investment is higher under the *discriminatory* regime than under the *network neutrality* regime. In fact, given that they have discretion on how to allocate quality of network services among content providers, investment allows internet service providers to increase the difference of treatment of content providers and thereby to increase the rents they extract from the content provider that gets high quality network services.

The content provider that gets high quality network services from both internet service providers does not get higher profits under the *discriminatory* regime. The reason is that internet service providers extract all the rents from the content provider. In other words, the prices internet service providers charge for high quality network services are such that the content provider is left indifferent between accepting their offer or not. However, the other content provider gets lower profits under the *discriminatory* regime, due to its quality of network services disadvantage. The internet service providers' profits are higher under the *discriminatory* regime as they are able to collect additional revenues from selling high quality of network services which more than compensate for the higher investment costs incurred. Finally, consumer surplus is higher under the *discriminatory* regime as consumers benefit from the higher investment by the internet service provider and the average quality of content consumed is also higher in the *discriminatory* regime, since more consumers buy from the high quality content provider. Social welfare is higher in the *discriminatory* regime.

Our article contributes to the growing literature on *network neutrality*, reviewed, e.g., by Krämer et al. (2012) and Schuett (2010). This literature can be divided in two main branches. One, where *network neutrality* means that internet service providers cannot discriminate content providers, but can charge for network services. Another, where *network neutrality* means that internet service providers can neither discriminate content providers nor charge for network services.

The first branch includes, e.g., Musacchio et al. (2009), Economides and Tag (2012), Njoroge et al. (2012) and Hermalin and Katz (2007). Since we also consider that *network neutrality* implies no payments between internet service providers and content providers, our article fits better in the second branch, which includes, e.g., Bourreau et al. (2012), Choi and Kim (2010), Cheng et al. (2011), Krämer and Wiewiorra (2012), Reggiani and Valletti (2011), Choi et al. (2011), and Economides and Hermalin (2012).

Choi and Kim (2010) and Cheng et al. (2011) consider similar frameworks, based on a queueing model, where a monopolist internet service provider may, under the *discriminatory* regime, create a priority lane which it uses to sell high quality services to two content providers. These papers analyze the investment decision by the internet service provider and conclude that the incentives to expand capacity are lower without *network neutrality* because more capacity leads to less congestion, and with less congestion, the preferential access to network services becomes less valuable.

Krämer and Wiewiorra (2012) study a two-sided monopoly market where content providers do not compete with each other because consumers multi-home. Reggiani and Valletti (2011) extend this approach by assuming that additionally to a fringe of content providers, there is a big content provider that can offer several content services. Both articles show that the *discriminatory* regime allows a better allocation of network services and is thus welfare enhancing. Krämer and Wiewiorra (2012) assume a queueing model and assume also the possibility of entry by content providers. This makes it more likely that investment increases in the *discriminatory* regime, in order to induce the entry of more content providers and allow the internet service provider to obtain higher revenues from selling network services. Reggiani and Valletti (2011) allow content providers to invest in the number of applications offered, which results in higher investment by the internet service provider under a discriminatory regime. On the contrary, Economides and Hermalin (2012) find that *network neutrality* is welfare superior, although, under price discrimination, the incentives to invest are greater, which may alleviate the welfare losses of departures from *network neutrality*.

All these articles on the second branch assume a monopolist internet service provider. Therefore they do not analyze the incentives of internet service providers to discriminate and invest under a competitive environment, as we do. As Krämer et al. (2012) refers, very few articles consider competition between internet service providers. Choi et al. (2011) focus on the interconnection agreements between competing internet service providers in a model without investment and with a fixed continuum of heterogeneous content providers. They show that competition between internet service providers is stronger under the *discriminatory* regime if internet service providers have some market power over content providers. Bourreau et al. (2012), on the other hand, extend the model of Krämer and Wiewiorra (2012) by allowing competition between internet service providers. They focus on the impact of the traffic regime, *network neutrality* versus discrimination, on investment and innovation incentives, and show that a switch from the *network neutrality* regime to the *discriminatory* regime would be beneficial in terms of investments, innovation and total welfare.

We differ from these two articles since we assume competition between internet service providers and between content providers. Regarding Choi et al. (2011), we also differ by focusing on the investment decision of internet service providers. As concerns Bourreau et al. (2012), we consider a different model about the relationship between investment and the quality of network services. In fact, while Bourreau et al. (2012) assume the queueing model, also used in Choi and Kim (2010) and Cheng et al. (2011), we assume a flexible model in terms of the level of discretion that internet service providers have to allocate the additional capacity enabled by their investments among content providers, which encompasses the case where internet service providers have full discretion. Nevertheless, both of our articles show that the internet service providers' investment is higher under the *discriminatory* regime, contrary to what happens in Choi and Kim (2010) and Cheng et al. (2011).[4]

The remainder of the article is organized as follows. In section 2 we present the model and in section 3 we characterize the equilibrium. In section 4 we conduct the welfare analysis. Finally, in section 5 we conclude.

2 Model

2.1 Environment

Consider an industry with two *Internet Service Providers* (ISPs), firms $j = 1, 2$, and two online *Content Providers* (CPs), firms $i = A, B$. Through their broadband networks, ISPs offer network services to CPs, and access to the internet services, "internet services" for short, to consumers. CPs offer content services to consumers through the ISPs' networks.

ISPs may invest in the quality of their networks.

There are two regulatory regimes. Under the *network neutrality* regime, ISPs cannot: **(i)** charge for network services, and **(ii)** treat CPs differently. Under the *discriminatory* regime ISPs may: **(i)** charge for network services, and **(ii)** treat CPs differently. Under both regulatory regimes, ISPs must provide, free of charge, network services of a given minimum quality.

The game has four stages. In stage 1, ISPs choose investments. In stage 2, ISPs and CPs bargain about network services. In stage 3, ISPs set the price of internet services, and consumers choose to which ISP they subscribe. In stage 4, CPs set prices of content services, and consumers choose to which CP they subscribe. Under the *network neutrality* regime there is no stage 2.

[4]In Bourreau et al. (2012) internet service providers are also assumed to be able to sabotage the quality of the network services supplied to the content provider that does not get priority.

2.2 Consumers

There is a large number of consumers, a continuum, whose measure we normalize to 1.

Consumers buy internet services from one of the two ISPs. Regarding preferences for internet services, consumers are uniformly distributed along a line segment of length 1.[5] A consumer whose most-preferred service is x on $[0,1]$ and buys service y on $[0,1]$, has a quadratic disutility cost of $t_n (y-x)^2$, with t_n on $(0,+\infty)$. Denote by u_j the gross utility of internet services of ISP j, and by f_j on $[0,+\infty)$ the price of the internet services of ISP j. The net utility of a consumer whose most-preferred service is x and that subscribes to ISP j with service y is: $U_n = (u_j - f_j) - t_n (y-x)^2$.[6]

After buying internet services, consumers can buy content services from one of the two CPs. Regarding preferences for content services, consumers are uniformly distributed along another line segment of length 1. A consumer whose most-preferred service is x on $[0,1]$ and buys service y on $[0,1]$, has a quadratic disutility cost of $t_c (y-x)^2$, with t_c on $(0,+\infty)$. The gross utility of content services has two components. The first component, u_c, is the same for both CPs. The second component depends on the quality of the network services that ISP j offers CP i. Denote by v_{ji} the gross utility for the quality of the network services that ISP j offers CP i. When talking about v_{ji}, we will refer several times to the quality of network services, instead of the gross utility for the quality of network services.[7] Denote by p_i on $[0,+\infty)$ the price of the content services of CP i. The net utility of a consumer whose most-preferred service is x and that subscribes to ISP j and that subscribes to CP i with service y is: $U_c^{ji} = (u_c + v_{ji} - p_i) - t_c (y-x)^2$.

In their choice of ISP, consumers do not take into account the utility they will later obtain from content services. This assumption is motivated by tractability. In general, the quality of content services provided by CPs may differ across networks, depending on the quality of network services agreements they have with ISPs. However, a consumer's choice of ISP is based mostly in factors such as the ISPs' brand notoriety and quality of internet services. Consumers use the internet to consume many types of services, e.g., e-mail, messaging, social networks, data storage, e-commerce, music, movies, news, etc.[8] Hence, the utility they derive from a particular service, or content, ought to have little, if any, impact on their

[5] See Hotelling (1929).

[6] We assume that u_j is high enough for the market to be covered.

[7] In fact, the higher the quality of network services provided by ISP j to CP i, the higher the utility a consumer subscribed to ISP j derives from the services of CP i.

[8] One could argue that all of these services are content. However, their bandwidth requirements vary a lot, and the debate is only relevant for those that are bandwidth intensive.

choice of ISP.[9]

2.3 Firms

2.3.1 ISPs

ISP 1 is located at point 0 and ISP 2 at point 1 of the line segment where consumers are distributed regarding their preferences for internet services. All of the ISPs' marginal costs are constant and equal to 0.

ISPs may invest to improve the quality of their networks. Denote by V_j on $[0, +\infty)$ the quality of ISP j's network. Denote by $C(V_j)$ the cost of obtaining quality V_j.

Investment has two effects on consumers' welfare.

The first direct effect, the *internet services* effect, follows from consumers benefiting from higher quality internet services, regardless of the content services consumed.[10] This benefit is captured by letting $u_j = u + H(V_j)$, where u is a parameter that measures the initial valuation, assumed to be the same for both ISPs and sufficiently high so that the market is covered, and $H(V_j)$ is a non-decreasing function that translates the quality of ISP j's network in terms of consumers's utility. Assume that $H(0) = 0$ and that $\max_{V_j} H(V_j) \leq 3t_n$.[11] Denote by $\Delta := u_1 - u_2$, the advantage in terms of the utility derived from internet services of ISP 1 relative to ISP 2. It follows that: $\Delta = H(V_1) - H(V_2)$ and $|\Delta| < 3t_n$.

The second indirect effect, the *content services* effect, follows from consumers benefiting from higher quality content services through v_{ji}.[12] Normalize the gross utility of the minimum quality of network services to 0. Let $Z(V_j)$ be a non-decreasing function that translates the quality of network services into the maximum gross utility level from a given content. An ISP can assign $Z(V_j)$ among CP such that: $0 \leq v_{jA} + v_{jB} \leq Z(V_j)$. Let $G(V_j)$ be the maximum difference of the quality of network services that an ISP can offer to CPs. This function, and in particular the sign of $\frac{dG(V_j)}{dV_j}$, represents the level of discretion of an ISP regarding the treatment given to CPs. Assume that $\max_{V_j} G(V_j) \leq 3t_c$.[13] Under the *network neutrality* regime: $0 \leq v_{jA} = v_{jB} \leq \frac{Z(V_j)}{2}$. Under the *discriminatory* regime:

[9] This assumption does not apply to some consumers with special interests, e.g., gamers, for whom the quality of network services provided to their favorite CP is crucial for their choice of ISP.

[10] E.g., better e-mail or data storage services.

[11] The upper bound on $H(V_j)$ ensures that even under maximum ISP asymmetry both ISPs have a positive market share.

[12] E.g., better video streaming services if the consumer's online movies supplier gets better network services from his ISP.

[13] The upper bound on $G(V_j)$ ensures that even under maximum CP asymmetry both CPs have a positive market share. By definition we have $G(V_j) \leq Z(V_j)$.

$0 \leq |v_{jA} - v_{jB}| \leq G(V_j)$. If $v_{ji} > v_{ji'}$ we will say that ISP j sells high quality network services, "premium services" for short, to CP i.

Denote by q_{ji} on $[0, +\infty)$ the price ISP j charges CP i for network services, and by $\delta_j := v_{jA} - v_{jB}$ the difference in the quality of network services provided by ISP j to CP A and to CP B.

Under the *discriminatory* regime, the network services bargaining game unfolds as follows. First, each ISP makes a public take-it-or-leave offer to one CP, composed of a network services quality level and a price: (q_{ji}, v_{ji}). The ISPs can make an offer to the same CP, or to different CPs. Afterwards the CPs decide which offers they accept, if any. If a CP rejects its offers, then we revert to the *network neutrality* regime.

Denote by D_j the total demand of ISP j. The profit of ISP j is:[14]

$$\Pi_j = f_j D_j + q_{jA} + q_{jB} - C(V_j).$$

Our model is very flexible in terms of the level of discretion that ISPs have to allocate the quality of their network, V_j, among the quality of network services it provides to CPs. In particular, it encompasses the case where more network capacity increases the ability of an ISP to differentiate the gross utility consumers derive from content: $\frac{dG(V_j)}{dV_j} > 0$;[15] and the case where more capacity reduces the ability of an ISP to differentiate among CPs: $\frac{dG(V_j)}{dV_j} < 0$. This assumption contrasts with most of the *network neutrality* literature, which assumes that traffic is processed according to a queueing model. These models capture fundamental aspects of how traffic flows across telecommunications networks. However, the very simple versions of the queueing model considered give a very passive role to ISPs. In fact, ISPs have, through engineering, more discretion than these models predict to assign quality of service among users, by either degrading or improving the quality of service of particular users. More importantly, as we show in Section 3.4, the ISPs' level of discretion on how to allocate increased network quality among CPs has an important impact on the marginal benefits of investment under the two regimes, and may determine which regime favours investment.

2.3.2 CPs

CP A is located at point 0 and CP B at point 1 of the line segment where consumers are distributed regarding their preferences for content services. Both CPs' marginal costs

[14] Under the *network neutrality* regime: $q_{jA} = q_{jB} = 0$, for $j = 1, 2$.

[15] ISPs may have full discretion to allocate the additional capacity enabled by their investments in network capacity: $G(V_j) = Z(V_j)$, for all V_j on $[0, +\infty)$.

are constant and equal to c on $[0, \infty)$.[16]

Each CP i has two revenue sources. In addition to the price it charges consumers for content services it also obtains revenue stream, r_i, from advertisers for each consumer it serves. Values r_i on $[0, +\infty)$ are exogenous, determined, possibly, in a competitive advertising market. Let $R := r_A - r_B$. CP A earns at least the same advertising revenue per consumer as CP B, i.e., R is on $[0, 3t_c - G(V)]$.[17]

Let D_i be the total demand of CP i. The profit of CP i is:

$$\Pi_i = (p_i + r_i - c)D_i - q_{1i} - q_{2i}.$$

3 Equilibrium

In this section, we characterize the equilibrium of the game for both the *network neutrality* and the *discriminatory* regimes. We construct the equilibrium by backward induction.

3.1 Content Services

Next, we characterize the equilibrium of the content services's sub-game, presented in the next Lemma. Denote by σ_i on $[0, 1]$ the consumer share of CP i, with $\sigma_A + \sigma_B = 1$ and by σ_j on $[0, 1]$ the consumer share of ISP j, with $\sigma_1 + \sigma_2 = 1$.

Lemma 1: *In equilibrium, CPs:*
(i) *charge prices:*

$$\begin{aligned} p_A &= c + t_c - \frac{1}{3}\left[2r_A + r_B - \sigma_1\delta_1 - \sigma_2\delta_2\right], \\ p_B &= c + t_c - \frac{1}{3}\left[r_A + 2r_B + \sigma_1\delta_1 + \sigma_2\delta_2\right]; \end{aligned}$$

(ii) *have consumer shares:*

$$\begin{aligned} \sigma_A &= \frac{1}{2} + \frac{1}{6t_c}\left[R + \sigma_1\delta_1 + \sigma_2\delta_2\right], \\ \sigma_B &= \frac{1}{2} - \frac{1}{6t_c}\left[R + \sigma_1\delta_1 + \sigma_2\delta_2\right]; \end{aligned}$$

[16] We need to assume that u_c is high enough such that, for a given c, the market is covered.

[17] CP A is better than its rival in attracting the right consumers for its advertisers, and therefore can charge higher advertising fees. Cheng et al. (2011) refer that they find empirical evidence supporting this assumption. The assumptions on R and $\overline{r}$ ensure that both CPs always get a positive consumer share. Alternatively, one could assume that each CP had marginal cost c_i, with $c_B - c_A$ equal to R on $[0, \overline{r}]$. We introduce CP asymmetry in the model because this seems to be the natural setting to discuss discrimination.

(iii) *and have profit, gross of network service charges:*

$$\pi_A = \frac{1}{18t_c}\left[3t_c + R + \sigma_1\delta_1 + \sigma_2\delta_2\right]^2,$$
$$\pi_B = \frac{1}{18t_c}\left[3t_c - R - \sigma_1\delta_1 - \sigma_2\delta_2\right]^2.$$

■

Recall that under the *network neutrality* regime: $\delta_1 = \delta_2 = 0$; and that under the *discriminatory* regime: δ_j belongs to $[-G(V_j), G(V_j)]$.

Under the *network neutrality* regime, a CP's price of content services, p_i, is decreasing in its advertising revenue per consumer, r_i. The higher the advertising revenue per consumer, the higher the profit per consumer. Hence, the more a CP is prepared to reduce its price to increase its consumer share. Since prices are strategic complements, a CP's price is also decreasing in the rival's advertising revenue per consumer. Furthermore, the CP with the highest advertising revenue per consumer, CP A, gets the highest consumer share, and also the highest profit level.

Under the *discriminatory* regime, the prices of content services are also decreasing in advertising revenues per consumer. In addition, for given advertising revenues per consumer, if a CP obtains from an ISP network services of a higher quality than its rival, it can also offer its consumers higher quality content services, and thereby charge them a higher price. In turn, the CP that gets lower quality network services has to reduce the price to compensate consumers. The CP that gets premium services also gets a higher consumer share, in spite of charging a higher price. Hence, its gross profit is also higher.

3.2 Internet Services

Next, we characterize the equilibrium of the internet services sub-game, presented in the next Lemma.

Lemma 2: *In equilibrium, ISPs :*

(i) *charge prices:*

$$f_1 = t_n + \frac{1}{3}\Delta,$$
$$f_2 = t_n - \frac{1}{3}\Delta;$$

(ii) *have consumer shares:*

$$\sigma_1 = \frac{1}{2} + \frac{1}{6t_n}\Delta,$$
$$\sigma_2 = \frac{1}{2} - \frac{1}{6t_n}\Delta;$$

(iii) *and have profits from selling internet services:*

$$\pi_1 = \frac{1}{18t_n}(3t_n + \Delta)^2,$$
$$\pi_2 = \frac{1}{18t_n}(3t_n - \Delta)^2.$$

■

The higher the advantage of a given ISP is, the higher its price, consumer share and profits from selling internet services are.

3.3 Network Services

Next, we characterize the equilibrium of the network services bargaining sub-game, which only occurs under the *discriminatory* regime. Let $G_j := G(V_j)$ and $\Phi := \sigma_1 G_1 + (1-\sigma_1) G_2$. Value Φ represents the average advantage that CP A has over CP B. For those consumers opting for ISP 1, a fraction σ_1, CP A offers an extra utility of $G(V_1)$; for the remaining consumers, those opting for ISP 2, it offers an extra utility of $G(V_2)$. Let $\Lambda := \left[\frac{\sigma_1 G_1}{\Phi}\left(1 - \frac{G_2(1-\sigma_1)}{2R+6t_c+\Phi}\right), \frac{\sigma_1 G_1}{\Phi}\left(1 + \frac{G_2(1-\sigma_1)}{2R+6t_c+\Phi}\right)\right]$.

The next Lemma presents the equilibrium of the bargaining sub-game.

Lemma 3: *There is a continuum of equilibria where both ISPs offer to CP A a quality advantage over CP B on network services equal to G_j, with $j = 1, 2$ respectively, at prices:*

$$q_{1A}^* = \lambda \frac{\Phi(2R + 6t_c + \Phi)}{18t_c},$$
$$q_{2A}^* = (1-\lambda) \frac{\Phi(2R + 6t_c + \Phi)}{18t_c},$$

with λ on Λ. ■

The value ISPs can charge CPs for premium services depends on the CPs' marginal profit of these services. The increase in a CP's profit due to receiving premium services from one ISP is higher when it also receives premium services from the other ISP. In other words, for

CPs, the premium services of the ISPs are complements. In fact, increasing δ_1 affects CP A's profit directly and through p_B. The direct effect refers to the increase in demand among the consumers that selected ISP 1, which has increased CP A's quality, when compared to CP B's. The effect through p_B refers to the fact that after an increase in δ_1, CP B's equilibrium price is lower, which counters the previous effect. The net effect on CP A's demand is positive and the higher p_A, the more will CP A's profit increase. Since CP A cannot price discriminate between consumers who selected ISP 1 and those who selected ISP 2, a higher δ_2 results in a higher equilibrium p_A. This is due to the higher demand for CP A's content services from consumers who selected ISP 2. Hence, since a higher δ_2 leads to a higher equilibrium price p_A, this makes the increase in CP A's demand resulting from a higher δ_1 more profitable. Thus, both ISPs offer premium services to the same CP. In addition, both offer premium services to CP A, because it is the most profitable.

The higher the quality advantage, δ_j, a CP can benefit from, the higher its marginal profit. In addition, ISPs' profits from internet services are invariant to the treatment given to CPs. Thus, ISPs maximize the difference of treatment given to CPs, i.e., each ISP sets $\delta_j = G(V_j)$. Hence, the average advantage of CP A is Φ, which implies a total gain for CP A, compared to the context where no CP gets premium services, of $\frac{\Phi(2R+6t_c+\Phi)}{18t_c}$. The ISPs then charge the total the value that makes CP A indifferent between buying the premium services or competing in equal terms with CP B. There is thus a multiplicity of equilibria where the ISPs divide this amount among them.[18]

In addition, to the multiplicity of equilibria described in Lemma 3, there is also a multiplicity of equilibria where both ISPs make an offer to CP B and divide the rent they collect. However, for the same λ on Λ these equilibria are strictly dominated by the equilibria in which both ISPs make an offer to CP A.[19]

[18] A similar result would hold if the content providers make the take-it-or-leave-it offers. In this case, the content providers would select the level of premium services required from each ISP, δ_j, and offer a price, q_{ji}. For low offers by one content provider, the other one would best respond by to outbiding the offers. As CP A is willing to pay more for premium services than its rival, in equilibrium it will make a bid for the premium services of both ISPs that corresponds to the benefit of CP B having premium services. Although the expressions differ, the qualitative aspects of the discussion in the following section would still hold in this case.

[19] Hence, we use strict dominance as a selection criterion.

3.4 Investment

Next, we characterize the equilibrium of the investment sub-game. In addition, we analyze the impact of the *network neutrality* regime on investment. Let $\lambda_j = \lambda$ if $j = 1$ and $\lambda_j = 1 - \lambda$ if $j = 2$.

For $j = 1, 2$, under the *network neutrality* regime, the first-order condition for V_j is:

$$\frac{\partial \Pi_j}{\partial V_j} = \underbrace{\frac{3t_n + (-1)^{j+1}\Delta}{9t_n}\frac{dH(V_j)}{dV_j}}_{\text{internet services effect 1}} - \underbrace{\frac{dC(V_j)}{dV_j}}_{\text{marginal cost}} = 0;$$

while under the *discriminatory* regime it is:

$$\frac{\partial \Pi_j}{\partial V_j} = \underbrace{\frac{3t_n + (-1)^{j+1}\Delta}{9t_n}\frac{dH(V_j)}{dV_j}}_{\text{internet services effect 1}} + \underbrace{\lambda_j \frac{R + 3t_c + \Phi}{9t_c}\frac{G_j - G_{j'}}{6t_n}\frac{dH(V_j)}{dV_j}}_{\text{internet services effect 2}} +$$

$$\underbrace{\lambda_j \sigma_1 \frac{R + 3t_c + \Phi}{9t_c}\frac{dG(V_j)}{dV_j}}_{\text{content services effect}} - \underbrace{\frac{dC(V_j)}{dV_j}}_{\text{marginal cost}} = 0.$$

Under the *network neutrality* regime, investment only involves the *internet services* effect, which follows from consumers benefiting from higher quality internet services. Under the *discriminatory* regime, investment involves also the *content services* effect through v_{ji}, which follows from consumers benefiting from higher quality content services.

Under both regimes, ISPs invest with the objective of charging consumers a higher price and stealing business from their rival, since the utility from access to their internet services increases. However, under the *discriminatory* regime there is a second term. This additional component comes from the payments of CP A, which does not exist under the *network neutrality* regime. Indeed, even if investment did not change the difference of treatment given to CPs, it would affect Φ, the average advantage CP A has over CP B, by making some consumers shift from one ISP to the other, if ISPs are asymmetric, i.e., if $G_j \neq G_{j'}$. Hence, if ISP j offers a higher advantage to CP A than its rival, i.e., if $G_j > G_{j'}$, then there is an increase in Φ and the second term is positive. The average advantage CP A has over CP B increases and the payments from CP A to both ISPs also increase. If ISP j' offers a higher advantage to CP A, i.e., if $G_j < G_{j'}$, this term is negative and the payments from CP A to both ISPs decrease.

When a monopolist ISP is considered, investment involves only the first of these effects and it will be of a different magnitude. A monopolist ISP would invest to charge consumers a higher price or to bring new consumers to the market, since the utility from access to the internet increases. With competition between ISPs investment also allows for a business stealing effect. Moreover, the second effect resulting from the differences in treatment ISPs give to CPs does not exist in the case of a monopolist ISP.

The *content services* effect also results from a change in the payments of CP A. Again, under the *network neutrality* regime, this effect has no impact on profits since ISPs do not charge for network services. Under the *discriminatory* regime, the marginal revenue of the *content services* effect is given by the third component of the first order condition. Given that the premium services of the ISPs are complements, it is possible that this effect is larger in the presence of competition between ISPs.

Until now, most of *network neutrality* literature assumed that content is processed according to a queueing model. In the versions considered of the queueing model, the additional capacity generated by investment is assigned in a way that reduces relatively more the waiting time of the content of the CP that does not get priority or premium services. As a consequence, investment decreases the quality difference of the network services offered to the two CPs. In our model this would be equivalent to assuming that $\frac{dG(V_j)}{dV_j} < 0$, i.e., more network capacity reduces the ability of an ISP to differentiate the gross utility consumers derive from content. Thereby, by lowering Φ, investment reduces the price an ISP can charge for premium services. Thus, this third term is negative.

However, if $\frac{dG}{dV_j} > 0$, investment may allow an ISP to increase the difference of treatments given to CPs. In particular, investment may allow an ISP to increase the advantage given to CP A, i.e., δ_j can be set at a higher level thus increasing Φ. Under these conditions, and since investment increases the rent ISPs are able to collect from CP A, the third term is positive.

Hence, one may conclude that the impact of the *network neutrality* regime on investment is potentially ambiguous and depends on: **(i)** whether ISPs are symmetric, and **(ii)** the ISPs ability to assign network's capacity to CPs.

The next Proposition considers a particular case of the previous discussion.

Proposition 1: *Assume that ISPs are symmetric, $\lambda = \frac{1}{2}$, and consider a symmetric equilibrium, $V_1 = V_2$. Investment is higher under the* discriminatory *regime compared with the* network neutrality *regime if $\frac{dG}{dV_j} > 0$, and lower otherwise.* ∎

Under the conditions of Proposition 1, considering only the incentives to invest arising from the *internet services* effect, investment is the same under both regimes. If ISPs are symmetric, they will only invest because it allows them to charge higher prices and steal consumers from their rival.

We now consider only the incentives to invest due to the content services effect. If $\frac{dG}{dV_j} > 0$, i.e., investment increases the level of discretion of ISPs to allocate V_j among the quality of network services provided to the two CPs, ISPs can increase the fee they can charge for premium services. As a consequence, investment is higher under the *discriminatory* regime. If, on the other hand, $\frac{dG}{dV_j} < 0$, i.e., investment decreases the level of ISP's discretion as in the queueing model, ISPs will be more limited in the fee they can charge for premium services. Hence, investment is lower under a *discriminatory* regime.

Thus, in the former case, adding up the two effects, investment is higher under the *discriminatory* regime than under the *network neutrality* regime, while in the latter case investment is higher in the *network neutrality* regime.

4 Welfare Analysis

In this section we conduct the welfare analysis for a particular case. We focus on a case where: **(i)** ISPs are symmetric, and **(ii)** $\frac{dG}{dV_j} > 0$. Regarding Assumption (i), it is justifiable because the model does not have a closed form solution under asymmetry. Besides, since ISPs are ex-ante symmetric, the case of symmetry seems the most natural to analyze. Assumption (ii) is justifiable because the alternative assumption, $\frac{dG}{dV_j} < 0$, is similar to the queueing model already analyzed in the literature.

Assume that ISPs divide the rents collected from CP A equally, i.e., $\lambda = \frac{1}{2}$. Hence, one can focus on symmetric equilibria, $V_1 = V_2$. Moreover, and in order to obtain a closed form of the investment level, assume that $C(V_j) = \frac{\beta}{2}V_j^2$, $H(V_j) = \alpha V_j$ and $G(V_j) = Z(V_j) = V_j$.[20]

Under *network neutrality*, we assume that, since ISPs are indifferent between setting any level of network's quality to each CP in the interval $0 \leq v_{jA} = v_{jB} \leq \frac{V_j}{2}$, they will set the maximum possible quality for each CP, i.e. $v_{jA} = v_{jB} = \frac{V_j}{2}$. Similarly, under discrimination, we assume that the ISPs will set the maximum quality on total, i.e. $v_{jA} + v_{jB} = V_j$.

The welfare analysis is presented in the next Proposition.

Proposition 2: *Assume that* $\lambda = \frac{1}{2}$, $V_1 = V_2$, $C(V_j) = \frac{\beta}{2}V_j^2$, $H(V_j) = \alpha V_j$ and $G(V_j) =$

[20] We assume that parameter β is sufficiently large, which is defined formally in the proof of Proposition 2.

$Z(V_j) = V_j$. *In equilibrium:*

(i) *under the* network neutrality *regime, the ISPs invest* $V_N = \frac{1}{3}\frac{\alpha}{\beta}$;

(ii) *under the* discriminatory *regime, the ISPs invest* $V_D = \frac{R+3t_c+12\alpha t_c}{36\beta t_c - 1}$;

Comparing the equilibrium of the network neutrality *regime and the* discriminatory *regime:*

(i) *CP A's profit is the same under both regimes;*

(ii) *CP B's profit is lower under the* discriminatory *regime;*

(iii) *ISPs' profits are higher under the* discriminatory *regime;*

(iv) *Consumer surplus is higher under the* discriminatory *regime.*

(v) *Welfare is higher under the* discriminatory *regime.* ■

Under the *discriminatory* regime CP A gets premium services from both ISPs. This allows CP A to charge a higher price for its content services and to have a higher consumer share. However, ISPs charge a price for the higher quality network service that leaves CP A indifferent between the two regimes. In contrast, under the *discriminatory* regime CP B gets the minimum quality network services from both ISPs. This forces CP B to charge a lower price for its content services, while it still has a smaller consumer share.

For a given investment level, ISPs charge the same price for internet services and have the same consumer share under both regimes. This happens because the consumers's choice of ISP does not depend on the utility they will later obtain from content services. However, the total profit of both ISPs is higher under the *discriminatory* regime, since they collect additional revenues from selling premium services to CP A. Investment may reverse the situation. ISPs invest more under the *discriminatory* regime, which means that they incur in higher investment costs. In our setting, this is dominated by the additional revenues from premium services.

Finally, consumer welfare is higher under the *discriminatory* regime. The utility from internet services is higher because investment is higher under the *discriminatory* regime. However, the price to the internet services is the same under both regimes. The utility from content services is also higher due to investment. In addition, under the *discriminatory* regime consumers are redistributed towards the CP with the quality advantage, thereby increasing the average quality of content services consumed. This more than compensates the increase in transportation costs and the increase in the price of content services. Taking into account the impact on all its components, social welfare decreases with the *network neutrality* regime.

5 Conclusions

We analyze the impact of *network neutrality* regulation on: competition in content services, and internet service providers' incentives to invest in their networks. We developed a two-sided model where two rival internet service providers offer access to the internet services to consumers and network services to content providers. Two rival content providers sell advertising services and content services to consumers.

We show that, if internet service providers can offer network services of different quality to content providers, both internet service providers prefer to sell the highest quality network services to the content provider that collects the highest advertising revenues.

One of the issues at the center of the *network neutrality* debate is the nature of its impact on the incentives to invest. Internet service providers often claim that they will invest less under the *network neutrality* regime because it hinders their ability to manage traffic. However, much of the literature so far showed that investment may be higher precisely under the *network neutrality* regime, since it reduces the value of priority services. We show that the impact of *network neutrality* regulation on the incentives to invest depends on: **(i)** whether internet service providers are symmetric, and **(ii)** the internet service providers' ability to allocate the quality generated by their investments among content providers. This latter effect unifies the opposing results in the literature. Under symmetry, if internet service providers have full discretion on how to allocate quality of network services among content providers, *network neutrality* regulation has a negative impact on investment. The reason is that investment increases the difference in the quality of network services offered to content providers, which implies that internet service providers can collect higher rents from their favoured content provider under the *discriminatory* regime. On the contrast, if investment decreases the difference in the quality of network services offered to content providers, as in the case of the queueing models used in the literature, *network neutrality* regulation has a positive effect on investment.

Comparing the two regimes, we find that the content provider that collects the lowest advertising revenue has lower profits under the *discriminatory* regime, while its rival gets the same profit under both regimes. The internet service providers' profits are higher under the *discriminatory* regime as they are able to additionally collect revenues from selling high quality of network services. Consumers are better off under the *discriminatory* regime, given the higher investment level and the better allocation of quality between content providers. Adding up all these effects, the impact on total welfare of *network neutrality* regulation is negative.

Appendix

Proof of Lemma 1: The consumer that subscribes to ISP j is indifferent between CP A and CP B if:

$$u_c + v_{jA} - p_A - t_c x^2 = u_c + v_{jB} - p_B - t_c (1-x)^2,$$

from where we obtain the consumer share of CP A and CP B in the set of consumers that chose ISP j, respectively:

$$\begin{aligned} \sigma_{Aj} &= \frac{1}{2} + \frac{\delta_j - (p_A - p_B)}{2t_c}, \\ \sigma_{Bj} &= \frac{1}{2} - \frac{\delta_j - (p_A - p_B)}{2t_c}. \end{aligned}$$

The profit of CP A and CP B, gross of network service charges, is respectively:

$$\begin{aligned} \pi_A &= (p_A + r_A - c) \sum_{j=1}^{2} \sigma_j \left[\frac{1}{2} + \frac{\delta_j - (p_A - p_B)}{2t_c} \right], \\ \pi_B &= (p_B + r_B - c) \sum_{j=1}^{2} \sigma_j \left[\frac{1}{2} - \frac{\delta_j - (p_A - p_B)}{2t_c} \right]. \end{aligned}$$

Maximizing profits with respect to prices and solving the system of first-order conditions, one obtains:

$$\begin{aligned} p_A &= c + t_c - \frac{2r_A + r_B - \sigma_1\delta_1 - \sigma_2\delta_2}{3}, \\ p_B &= c + t_c - \frac{r_A + 2r_B + \sigma_1\delta_1 + \sigma_2\delta_2}{3} \end{aligned}$$

and

$$\begin{aligned} \sigma_{Aj} &= \frac{1}{2} + \frac{3\delta_j + (R - 2(\sigma_1\delta_1 + \sigma_2\delta_2))}{6t_c}, \\ \sigma_{Bj} &= \frac{1}{2} - \frac{3\delta_j + (R - 2(\sigma_1\delta_1 + \sigma_2\delta_2))}{6t_c}. \end{aligned}$$

The corresponding equilibrium consumer shares of each CP are:

$$\begin{aligned} \sigma_A &= \sigma_1\sigma_{A1} + \sigma_2\sigma_{A2} = \frac{1}{2} + \frac{R + (\sigma_1\delta_1 + \sigma_2\delta_2)}{6t_c}, \\ \sigma_B &= \sigma_1\sigma_{B1} + \sigma_2\sigma_{B2} = \frac{1}{2} - \frac{R + (\sigma_1\delta_1 + \sigma_2\delta_2)}{6t_c}, \end{aligned}$$

where $\sigma_i \in [0,1]$ should hold for all possible values. As δ_j is at most equal to $G(V_j)$, a sufficient condition to ensure a positive demand for both CPs is that $G(V_j) < 3t_c - R$.

The profits of each CP are given by:

$$\pi_A = \frac{\left(3t_c + R + \sigma_1\delta_1 + \sigma_2\delta_2\right)^2}{18t_c},$$
$$\pi_B = \frac{\left(3t_c - R - \sigma_1\delta_1 - \sigma_2\delta_2\right)^2}{18t_c}.$$

■

Proof of Lemma 2: A consumer is indifferent between ISP 1 and ISP 2 if:

$$(u_1 - f_1) - t_n x^2 = (u_2 - f_2) - t_n (1 - x)^2,$$

from where we obtain the consumer share of ISP 1 and ISP 2, respectively:

$$\sigma_1 = \frac{1}{2} + \frac{\Delta - (f_1 - f_2)}{2t_n},$$
$$\sigma_2 = \frac{1}{2} - \frac{\Delta - (f_1 - f_2)}{2t_n}.$$

The profit of ISP 1 and ISP 2 from selling access is respectively:

$$\pi_1 = f_1 \left[\frac{1}{2} + \frac{\Delta - (f_1 - f_2)}{2t_n}\right],$$
$$\pi_2 = f_2 \left[\frac{1}{2} - \frac{\Delta - (f_1 - f_2)}{2t_n}\right].$$

Maximizing profits with respect to prices and solving the system of first-order conditions, one obtains:

$$f_1 = t_n + \frac{1}{3}\Delta,$$
$$f_2 = t_n - \frac{1}{3}\Delta.$$

The corresponding equilibrium consumer shares of each ISP are:

$$\sigma_1 = \frac{1}{2} + \frac{1}{6}\frac{\Delta}{t_n},$$
$$\sigma_2 = \frac{1}{2} - \frac{1}{6}\frac{\Delta}{t_n},$$

where $\sigma_j \in [0, 1]$ should hold for all possible values. A sufficient condition for this to hold is that $H(V_j) < 3t_n$.

The profits of each ISP, excluding payments from CP's are given by:

$$\pi_1 = \frac{\left(3t_n + \Delta\right)^2}{18t_n},$$
$$\pi_2 = \frac{\left(3t_n - \Delta\right)^2}{18t_n}.$$

■

Proof of Lemma 3: Let $\pi_i(\delta_1, \delta_2)$ denote CP i 's profit, gross of access costs, when it has an advantage of δ_1, δ_2 with ISP 1 and ISP 2, respectively.

Consider first the case in which ISP 1 and ISP 2 make an offer (δ_1, q_{1i}) and (δ_2, q_{2i}), respectively, to CP i.

CP i accepts both offers if $\pi_i(\delta_1, \delta_2) - q_{1i} - q_{2i} \geq \max\{\pi_i(0,0), \pi_i(\delta_1, 0) - q_{1i}, \pi_i(0, \delta_2) - q_{2i}\}$, which is equivalent to:

$$\begin{aligned} q_{2i} &\leq \min\{\pi_i(\delta_1, \delta_2) - \pi_i(0,0) - q_{1i}, \pi_i(\delta_1, \delta_2) - \pi_i(\delta_1, 0)\} \\ q_{1i} &\leq \pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2) \end{aligned}$$

CP i will accept ISP 2's offer and reject the other one iff:

$$\pi_i(0, \delta_2) - q_{2i} \geq \max\{\pi_i(0,0), \pi_i(\delta_1, 0) - q_{1i}, \pi_i(\delta_1, \delta_2) - q_{1i} - q_{2i}\},$$

which is equivalent to:

$$\begin{aligned} q_{2i} &\leq \min\{\pi_i(0, \delta_2) - \pi_i(\delta_1, 0) + q_{1i}, \pi_i(0, \delta_2) - \pi_i(0,0)\} \\ q_{1i} &> \pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2) \end{aligned}$$

Given the offer (δ_1, q_{1i}), ISP 2 will make the highest possible acceptable offer:

If $q_{1i} \leq \pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2)$ it will choose $q_{2i} = \min\{\pi_i(\delta_1, \delta_2) - \pi_i(0,0) - q_{1i}, \pi_i(\delta_1, \delta_2) - \pi_i(\delta_1, 0)\}$ with $\pi_i(\delta_1, \delta_2) - \pi_i(0,0) - q_{1i} \geq \pi_i(\delta_1, \delta_2) - \pi_i(\delta_1, 0)$ iff $q_{1i} \leq \pi_i(\delta_1, 0) - \pi_i(0,0)$.

If $q_{1i} > \pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2)$ it will choose $q_{2i} = \min\{\pi_i(0, \delta_2) - \pi_i(\delta_1, 0) + q_{1i}, \pi_i(0, \delta_2) - \pi_i(0,0)\}$ with $\pi_i(0, \delta_2) - \pi_i(\delta_1, 0) + q_{1i} \geq \pi_i(0, \delta_2) - \pi_i(0,0)$ iff $q_{1i} \geq \pi_i(\delta_1, 0) - \pi_i(0,0)$.

As $\pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2) > \pi_i(\delta_1, 0) - \pi_i(0,0) \Leftrightarrow \frac{1}{9} t_c^{-1} \delta_2 \delta_1 \sigma_2 \sigma_1 > 0$, the highest acceptable offer to CP i by ISP 2 is:

$$q_{2i} = \begin{cases} \pi_i(\delta_1, \delta_2) - \pi_i(\delta_1, 0) & q_{1i} \leq \pi_i(\delta_1, 0) - \pi_i(0,0) \\ \pi_i(\delta_1, \delta_2) - \pi_i(0,0) - q_{1i} \quad if & \pi_i(\delta_1, 0) - \pi_i(0,0) < q_{1i} \leq \pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2) \\ \pi_i(0, \delta_2) - \pi_i(0,0) & q_{1i} > \pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2) \end{cases}$$

It is also straightforward to check that q_{2i} is increasing in δ_2 and therefore, if ISP 2 decides to make an offer to CP i it should set the highest possible δ_2. As $\frac{\partial(\pi_i(\delta_1, \delta_2) - \pi_i(0, \delta_2))}{\partial \delta_2} = \frac{1}{9} t_c^{-1} \delta_1 \sigma_2 \sigma_1 > 0$, increasing δ_2 also makes it more likely, given (δ_1, q_{1i}), that a higher q_{2i} will be accepted.

The same holds for q_{1i} if one swaps the arguments of the profit function.

Consider now that given (δ_1, q_{1i}) to CP i, ISP 2 deviates by making an offer to CP j. Both offers are accepted if:

$$\begin{aligned} \pi_i(\delta_1, -\delta_2) - q_{1i} &\geq \pi_i(0, -\delta_2) \Leftrightarrow \pi_i(\delta_1, -\delta_2) - \pi_i(0, -\delta_2) \geq q_{1i}, \\ \pi_j(-\delta_1, \delta_2) - q_{2j} &\geq \pi_j(-\delta_1, 0) \Leftrightarrow \pi_j(-\delta_1, \delta_2) - \pi_j(-\delta_1, 0) \geq q_{2j}. \end{aligned}$$

CP j accepts its offer and CP i rejects its offer if:

$$\begin{aligned} \pi_i(\delta_1, -\delta_2) - q_{1i} &< \pi_i(0, -\delta_2) \Leftrightarrow \pi_i(\delta_1, -\delta_2) - \pi_i(0, -\delta_2) < q_{1i}, \\ \pi_j(0, \delta_2) - q_{2j} &\geq \pi_j(0, 0) \Leftrightarrow \pi_j(0, \delta_2) - \pi_j(0, 0) \geq q_{2j}. \end{aligned}$$

Hence, if ISP 2 makes an offer to CP j it will be the highest acceptable offer, that is:

$$q_{2i} = \begin{cases} \pi_j(-\delta_1, \delta_2) - \pi_j(-\delta_1, 0) & \text{if} \quad \pi_i(\delta_1, -\delta_2) - \pi_i(0, -\delta_2) \geq q_{1i}, \\ \pi_j(0, \delta_2) - \pi_j(0, 0) & \phantom{\text{if}} \quad \pi_i(\delta_1, -\delta_2) - \pi_i(0, -\delta_2) < q_{1i}. \end{cases}$$

Again, increasing δ_2 leads to a higher q_{2i}. As $\pi_j(-\delta_1, \delta_2) - \pi_j(-\delta_1, 0) < \pi_j(0, \delta_2) - \pi_j(0, 0)$ and $\frac{\partial(\pi_i(\delta_1, -\delta_2) - \pi_i(0, -\delta_2))}{\partial \delta_2} < 0$, δ_2 should be set at the highest possible level.

Therefore, if $\pi_j(0, \delta_2) - \pi_j(0, 0) < \pi_i(0, \delta_2) - \pi_i(0, 0)$ the best scenario when making an offer to CP j is not as good as the worse scenario when making an offer to CP i. This inequality always holds when $i = A$ and $j = B$. Hence, if ISP 1 makes an offer to CP A, ISP 2 will best respond with an acceptable offer to CP A. The equilibrium offers are such that:

$$q_{1A} + q_{2A} = \pi_A(\delta_1, \delta_2) - \pi_A(0, 0)$$

with $\pi_A(\delta_1, 0) - \pi_A(0, 0) < q_{1A} \leq \pi_A(\delta_1, \delta_2) - \pi_A(0, \delta_2)$.

Using

$$\pi_A = \frac{1}{18t_c} \left[3t_c + R + \sigma_1\delta_1 + \delta_2 (1 - \sigma_1)\right]^2,$$

letting $\delta_1 = G(V_1) \equiv G_1$ and $\delta_2 = G(V_2) \equiv G_2$, i.e. assuming each δ_j is set at the maximum possible level, and defining $\Phi \equiv \sigma_1 G_1 + (1 - \sigma_1) G_2$ we obtain

$$q_{1A} + q_{2A} = \frac{1}{18t_c} [3t_c + R + \Phi]^2 - \frac{1}{18t_c} [3t_c + R]^2 = \frac{(2R + \Phi + 6t_c) \Phi}{18t_c}$$

with

$$\frac{(2R + 6t_c + G_1\sigma_1) G_1\sigma_1}{18t_c} < q_{1A} \leq \frac{(G_2 (1 - \sigma_1) + \Phi + 6t_c + 2R) G_1\sigma_1}{18t_c}.$$

Writing q_{1A} as $\lambda (q_{1A} + q_{2A})$ we have that

$$\frac{\sigma_1 G_1}{\Phi} \left(1 - \frac{G_2 (1 - \sigma_1)}{2R + 6t_c + \Phi}\right) < \lambda \leq \frac{\sigma_1 G_1}{\Phi} \left(1 + \frac{G_2 (1 - \sigma_1)}{2R + 6t_c + \Phi}\right).$$

Note that the discussion above rules out the possibility of an equilibrium where each ISP makes an offer to a different CP. We now turn to the possibility of an equilibrium where both ISPs make offers to CP B. The analysis is similar to the one above meaning that, if it exists, there will be a multiplicity of equilibria in which both offers are made to CP B and verify

$$q_{1B} + q_{2B} = \pi_B(\delta_1, \delta_2) - \pi_B(0, 0)$$

The equilibrium where both ISPs make an offer to CP A dominates the equilibrium where both make an offer to B. In fact, given $r_A > r_B$, we find that:

$$\pi_A(\delta_1, \delta_2) - \pi_A(0, 0) > \pi_B(\delta_1, \delta_2) - \pi_B(0, 0).$$

meaning that for a given λ in the interval above, both ISPs will have a higher profit when making offers to CPA. ■

Proof of Proposition 1: Follows from the discussion in the text.

Proof of Proposition 2: We start by determining the investment levels in equilibrium under the two regimes. Consider first the *discriminatory* regime. Each ISP's profit is given by:

$$\Pi_j = \pi_j + q^e_{jA} - C = \frac{[3t_n + \alpha(V_j - V_i)]^2}{18t_n} + \frac{(2R + 6t_c + V_j\sigma_j + V_i\sigma_i)(V_j\sigma_j + V_i\sigma_i)}{36t_c} - \frac{\beta V_j^2}{2},$$

where $\sigma_j = \left(\frac{1}{2} + \frac{1}{6}\frac{\alpha(V_j - V_i)}{t_n}\right)$.

The first-order condition for profit maximization is given by $\frac{d(\pi_j + q^e_{jA} - C)}{dV_j} = 0$ and assuming a symmetric equilibrium, $V_i = V_j = V_D$, we have:

$$V_D = \frac{R + 3t_c + 12\alpha t_c}{36\beta t_c - 1}$$

with $\beta > \frac{1}{36t_c}$. Second-order conditions are verified at V_D if and only if

$$2592\beta^2 t_c^2 t_n - 12\left(4R\alpha + 9t_n + 12\alpha t_c + 24\alpha^2 t_c\right)\beta t_c + t_n - 8\alpha^2 t_c > 0$$

which holds if β is large.

Consider now the *network neutrality* regime. Then, each ISP's profit is given by:

$$\Pi_j = \pi_j - C = \frac{[3t_n + \alpha(V_j - V_i)]^2}{18t_n} - \frac{\beta V_j^2}{2}.$$

First order conditions are:

$$\frac{3t_n(\alpha - 3\beta V_j) + \alpha^2(V_j - V_i)}{9t_n} = 0,$$

from where we obtain $V_i = V_j = V_N = \frac{1}{3}\frac{\alpha}{\beta}$.

Second-order conditions are:

$$\frac{\partial \Pi_j}{\partial V_j^2} = \frac{1}{9} t_n^{-1}\left(\alpha^2 - 9\beta t_n\right) < 0 \Leftrightarrow \beta > \frac{\alpha^2}{9t_n}.$$

In a symmetric equilibrium, there is more investment under the *discriminatory* regime than under *network neutrality*. This follows from:

$$V_D - V_N = \frac{\alpha + 3R\beta + 9\beta t_c}{3\beta\left(36\beta t_c - 1\right)} > 0.$$

Note that to ensure that market shares are on $[0,1]$ and that all second-order conditions hold we need that:

(i) $V_D < 3t_c - R \Leftrightarrow \beta > \frac{2\alpha+1}{6(3t_c-R)}$.

(ii) $V_D < \frac{3t_n}{\alpha} \Leftrightarrow \beta > \frac{R\alpha + 3t_n + 3t_c\alpha(4\alpha+1)}{108 t_c t_n}$.

(iii) $\beta > \frac{1}{36t_c}$ and $\beta > \frac{\alpha^2}{9t_n}$.

(iv) $2592\beta^2 t_c^2 t_n - 12\left(4R\alpha + 9t_n + 12\alpha t_c + 24\alpha^2 t_c\right)\beta t_c + t_n - 8\alpha^2 t_c > 0$.

We now turn to the impact of imposing the *network neutrality* regime on profits, consumer surplus and welfare.

The impact on CPs' profits is straightforward, given Lemma 3.

Consumer surplus can be divided in the surplus generated from internet services and from content services. With respect to internet services, consumer surplus is given by:

$$\begin{aligned} CS_{ISP} &= \int_0^{\frac{1}{2}+\frac{\alpha(V_1-V_2)}{6t_n}} \left\{u + \alpha V_1 - \left[t_n + \frac{1}{3}\alpha(V_1 - V_2)\right] - t_n(x)^2\right\} dx + \\ &\quad \int_{\frac{1}{2}+\frac{\alpha(V_1-V_2)}{6t_n}}^1 \left\{u + \alpha V_2 - \left[t_n - \frac{1}{3}\alpha(V_1 - V_2)\right] - t_n(1-x)^2\right\} dx \\ &= u + \alpha\frac{V_1+V_2}{2} + \frac{1}{36} t_n^{-1}\left(V_2 - V_1\right)^2 \alpha^2 - \frac{13}{12} t_n. \end{aligned}$$

With respect to contents, the consumer surplus from a consumers choosing ISP j is given by:

$$\begin{aligned} CS_{CP} &= \int_0^{\frac{1}{2}+\frac{3\delta_j + R - 2(\sigma_1\delta_1+\sigma_2\delta_2)}{6t_c}} \left\{u_c + v_{jA} - \left[c + t_c - \frac{2r_A + r_B - \delta_2\left(1-\sigma_1\right) - \sigma_1\delta_1}{3}\right] - t_c(x)^2\right\} dx + \\ &\quad \int_{\frac{1}{2}+\frac{3\delta_j + R - 2(\sigma_1\delta_1+\sigma_2\delta_2)}{6t_c}}^1 \left\{u_c + v_{jB} - \left[c + t_c - \frac{r_A + 2r_B + \delta_2\left(1-\sigma_1\right) + \sigma_1\delta_1}{3}\right] - t_c(1-x)^2\right\} dx \end{aligned}$$

where $\delta_j = v_{jA} - v_{jB}$ and $\sigma_1 = \frac{1}{2} + \frac{\alpha(V_1 - V_2)}{6t_n}$.

In a symmetric equilibrium, we have $\delta_j = V_D$, $v_{jA} = V_D$ and $v_{jB} = 0$ under the *discriminatory* regime and $\delta_j = 0$, $v_{jA} = v_{jB} = \frac{V_N}{2}$ under *network neutrality*. Hence:

$$CS_{CP}^D = u_c - c + \frac{1}{2}\left(r_A + r_B\right) - t_c - \frac{1}{12}t_c + \frac{1}{2}V_D + \frac{\left(R + V_D\right)^2}{36t_c},$$

and

$$CS_{CP}^{N}=u_c-c+\frac{1}{2}\left(r_A+r_B\right)-t_c-\frac{1}{12}t_c+\frac{1}{2}V_N+\frac{R^2}{36t_c}.$$

The differences are given by:

$$\begin{aligned}CS_{ISP}^{D}-CS_{ISP}^{N} &= \alpha\left(V_D-V_N\right)>0\\ CS_{CP}^{D}-CS_{CP}^{N} &= \frac{18t_c\left(V_D-V_N\right)+V_D\left(2R+V_D\right)}{36t_c}>0.\end{aligned}$$

We now turn to ISP's profits:

$$\Pi_j^D-\Pi_j^N=\frac{\left(2R+V_D+6t_c\right)V_D}{36t_c}-\frac{\beta}{2}\left(V_D^2-V_N^2\right).$$

Substituting the expressions for V_D and V_N and simplifying we have

$$\begin{aligned}\Pi_j^D-\Pi_j^N &= \frac{\beta^2 54t_c\left(R+3t_c\right)\left(R+3t_c+8\alpha t_c\right)-\left(R+3t_c\right)^2\beta+2\alpha^2t_c}{36\left(36\beta t_c-1\right)^2\beta t_c}\\ &> \frac{\beta\left(R+3t_c\right)^2\left(54\beta t_c-1\right)+2\alpha^2t_c}{36\left(36\beta t_c-1\right)^2\beta t_c}>0.\end{aligned}$$

We now consider the change in welfare. Note that if one excludes the *network service charges*, the variation in ISPs' aggregate profits is

$$\Pi_1^D-\Pi_1^N+\Pi_2^D-\Pi_2^N=t_n-\beta V_D^2-\left(t_n-\beta V_N^2\right)=\beta\left(V_N^2-V_D^2\right).$$

As for CPs' aggregate profits, gross of any *network service charges*, we have:

$$\begin{aligned}\Pi_A^D-\Pi_A^N &= \frac{1}{18t_c}\left[3t_c+R+V_D\right]^2-\frac{1}{18t_c}\left[3t_c+R+0\right]^2=\frac{1}{18}t_c^{-1}\left(2R+6t_c+V_D\right)V_D\\ \Pi_B^D-\Pi_B^N &= \frac{1}{18t_c}\left[3t_c-R-V_D\right]^2-\frac{1}{18t_c}\left[3t_c-R-0\right]^2=\frac{1}{18}t_c^{-1}\left(2R-6t_c+V_D\right)V_D\\ \Pi_A^D-\Pi_A^N+\Pi_B^D-\Pi_B^N &= \frac{1}{9}t_c^{-1}\left(2R+V_D\right)V_D\end{aligned}$$

Aggregating consumer surplus and the four firms' profit variation and excluding advertising revenues, the welfare variation is

$$W^D-W^N=\left(\alpha+\frac{1}{2}\right)\left(V_D-V_N\right)+\frac{V_DR}{9t_c}+\frac{5}{36t_c}V_D^2-\beta V_D^2+\beta V_N^2$$

Substituting the expressions for V_D and V_N and simplifying we obtain:

$$W^D-W^N=\frac{R^2\beta\left(108\beta t_c+1\right)+36\left(\alpha+12t_c\beta\left(5\alpha+2\right)\right)\beta t_cR+t_cK(\beta t_c)}{36\left(36\beta t_c-1\right)^2\beta t_c}$$

with $K(\beta t_c)\equiv 324\left(4\alpha+5\right)\beta^2t_c^2+9\left(52\alpha+96\alpha^2-1\right)\beta t_c-2\alpha\left(4\alpha+3\right)$. Start by noting that, as $\beta>\frac{1}{36t_c}$, we have

$$\begin{aligned}\frac{\partial K(\beta t_c)}{\partial \beta t_c} &= 9\left(72\left(4\alpha+5\right)\beta t_c+52\alpha+96\alpha^2-1\right)\\ &> 9\left(72\left(4\alpha+5\right)\frac{1}{36}+52\alpha+96\alpha^2-1\right)\\ &= 27\left(8\alpha+3\right)\left(4\alpha+1\right)>0.\end{aligned}$$

Thus,

$$K(\beta t_c) > K(1/36) = (4\alpha + 1)^2 > 0,$$

which is a sufficient condition for $W^D - W^N > 0$. ■

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