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# Network Neutrality and Quality of Service: A two-sided market analysis

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## Abstract

In this paper, we examine welfare implications of switching from a neutrality regime to a network management regime. While in the former a network provider or an integrated ISP should transmit data with *a-bit-is-a-bit* principle, in the latter it is allowed to differentiate its connection quality considering economic value of data packets transmitted from content or application providers to end-users. The differentiation indicates allowing the ISP to apply QoS arrangements for quality-sensitive contents or applications. The above issues are first examined with a model in which there is a monopolist ISP, and later it is extended through introducing duopoly competition. Our results refer some potential gains that can be captured through network management regime. Although the overall effect of deviation from neutrality regime on total surplus may not defined clearly, both in monopoly and in duopoly models we have found that end-users and quality-sensitive content or application providers benefit from network management regime, in case of enough increase in quality of connection offered by ISP(s). And, regular content or application providers suffer with decreasing connection quality because of fixed network capacity.

**JEL codes:** L12, L13, L15, L51, L96

**Keywords:** Telecommunications, Internet, Network Neutrality, Network Management Two-Sided Market, Quality of Service

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# 1 Introduction

Internet, and recently broadband Internet, has become an indispensable part of our daily life. Through the broadband Internet, end-users(EUs) can benefit different kinds of applications such as streaming media, on-line games, VoIP, etc. along with traditional services such as mail services or web-browsing. Bandwidth need for the mentioned quality-sensitive applications, and growing user demand on such content provoke network providers to invest more on their networks. On the other hand, it has been largely argued that increasing marginal value of bandwidth for the Internet services incites network providers, or integrated internet service providers (ISPs) to discriminate against content or application providers (CAPs). These kinds of actions are claimed to be threatening the *neutral architecture* of the Internet. And, it is commonly argued that this *neutral architecture* or network neutrality is the primary rule of the Internet that ensures open and equal access for any CAP. The debate has a growing importance, since the famous Madison River case in 2005. And, with the recent proposal by Google and Verizon it gains another dimension about managing internet traffic.

Although the debate seems mostly technical, in practice it indicates some important short-run and also long-run issues. For instance, while advocates of neutrality regime claim that network neutrality ensures the users' access freedom and gives incentives to CAPs for innovation at the edge, opponents argue that mandated network neutrality discourages network providers incentives to invest on their networks. Hence, as Peha et.al. [8] suggest the debate may greatly influence the variety of CAPs available for users, business models for service providers, and modes of development of social communication.

In fact, the network neutrality debate contains basically two distinct issues: discrimination and quality of service (QoS) [7]. Network neutrality is a non-discriminatory regime, and any deviation from it should be considered as a discriminatory action. Discrimination may contain a large scale of actions, from blocking to charging different prices for the same service. Although the economic theory addresses some welfare enhancing results of certain types of price discrimination, practices like blocking reduce competition and economic welfare.

On the other hand, a network neutrality regime would not allow differentiation between data packets according to their economic value. In other words, no matter what the data contains it would be transmitted with the

same effort, generally called *best-effort*. More technically, the data packets are conveyed considering *a-bit-is-a-bit* principle. Actually, economic value of a content or an application is closely related with its utility for the users, and the revenue derived by its providers. However, under a regime of network neutrality this phenomenon is ignored, and all contents or all applications are treated equally. For instance, data for web browsing or for an e-mail message and data quality-sensitive applications such as VoIP or on-line games are subject to the same QoS. Thus, one can argue a potential welfare loss may occur with this equal treatment.

This paper specifically considers this issue with a formal model. Particularly, it aims to examine welfare implications of a network neutrality regime substituted with a network management regime. While in the former ISP(s) should transmit data from CAPs with *a-bit-is-a-bit* principle, in the latter it is allowed to differentiate its service. The differentiation indicates allowing ISP(s) to serve with a different connection quality for quality-sensitive contents or applications. The above issues are first examined with a model in which there is a monopolist ISP, and later it is extended through introducing duopoly competition.

To avoid misleading implications, the model is constructed considering the two-sided nature of the Internet. Allowing for an ISP as a platform which enables interaction between EUs on one side, and CAPs on the other side; render the Internet as a two-sided market. In addition, the fundamental features of a two-sided market cited by Rochet and Tirole [10] are valid for the Internet as well. Furthermore, competition issues examined by Rochet and Tirole [9] and Armstrong [1] for the two-sided markets would also be a guide for the extended version of our model with duopoly competition.

After modeling the Internet as a two-sided market, we compute the market equilibrium for both regimes: network neutrality and network management. Then, we examine the incentive of the monopolist ISP to deviate from neutrality regime through comparing its profit derived in both regimes. And, we have found that it derives more profit through deviation. Then, we evaluate the welfare implication of such a deviation. Our findings suggest that while the ISP, EUs and quality-sensitive CAPs benefit from network management regime, regular CAPs are hurt. In the extended version of the model with the duopoly competition, although we have ambiguous result for the incentive of the ISPs, the rest of the findings address similar results.

There is a tiny but growing economic literature on the network neutrality debate. However related works to our scope can be examined in three

categories:

The first category can be represented by Hermalin and Katz [5], which emphasizes on content providers with differentiated products. In their model, content providers differ in their attractiveness of their content. And, they are free to choose their connection quality to the network. However, under neutrality regime ISP(s) is restricted to offer a single connection quality. Although the impact on total surplus is ambiguous, negative effects are observed through exclusion of certain types of content providers. Although our model specification is different, we have observed similar implications as Hermalin and Katz [5].

The second category emphasizes on congestion issue on the Internet around the neutrality debate [2], [3], [6]. These works examine both short-run and long-run effects of deviation from neutrality. These works differ from ours in two points: First, we do not explicitly employ the congestion issue, but we wanted to assign a similar effect through specifying different CAPs for their quality of connection needs. Second, we concentrate on the short-run effects of deviation from neutrality by imposing fixed network capacity.

The third category is represented by Economides and Tåg [4], which examine the network neutrality debate from a two-sided market perspective through emphasizing on externalities specific to two-sided markets. We used similar specifications with the authors for the EUs on one side, and CAPs on the other side of the market. In addition, as the authors did, we extended our model with duopoly competition. However, Economides and Tåg [4] do not consider a network management regime in the sense that certain CAPs are treated with different quality-connection than the others.

The rest of the paper is organized as follows: The second section introduces the main model with a monopolist ISP. In this section, first we model the Internet as a two-sided market. Then, we examine welfare implications through switching to network management regime. In the third section, we extend the main model introducing duopoly competition, and examine the effects of competition on welfare. In the fourth section, we will conclude with some remarks.

## 2 The Model

### 2.1 Modeling the Internet as a two-sided market

In our two-sided market model, EUs reside on one side and CAPs reside on the other side of the market. Between these two sides, an integrated ISP operates as a platform.

**The ISP** controls the two-sided market as a monopolist. Under a network neutrality regime, it offers linear pricing contract to EUs for subscription, but it is not allowed to charge any CAPs. We assume that the ISP has a single cost per EU ( $c$ ) to transmit data from CAPs to EUs. And, it serves with an identical connection quality for each CAPs,  $z$ . This identical connection quality level can also be considered as *best-effort* level. On the other hand, under network management regime, the ISP is allowed to discriminate between CAPs. More specifically, the ISP can charge certain CAPs for an additional QoS ( $z$ ). We assume that we are in short-run, and we eliminate any expansion or upgrade in network capacity. So the additional connection quality appears as prioritization, and this does not create any additional cost for the ISP. However, as the capacity of the network does not change, the prioritization for certain CAPs results a reduction of the initial connection quality level for the rest of the CAPs. Then, the ISP's general profit function can be formulated as

$$\Pi = n(p - c) + N_Q P \quad (1)$$

where  $n$  denotes the number EUs connected to the internet and  $p$  represent the linear price charged for the connection. On the other hand, under network management regime  $N_Q$  indicates the number CAPs which provides quality-sensitive contents or applications which gives a fee ( $P$ ) for the provision of additional connection quality.

**CAPs** consist of variety of content or application providers. They are not substitutes and they do not compete with each other. Their sole revenue source is advertising revenue, which is a function of both number of viewers and the connection quality. Their fixed set-up cost ( $T$ ) are different from each other. We assume that they are uniformly distributed in a interval,  $[0, 1]$  according to their fixed set-up costs.

Furthermore, in order to differentiate the services of CAPs, we made a distinction according to their quality-sensitiveness for their products. We assume that while some of the CAPs provide regular services which need less

connection quality, other CAPs provide contents or applications which need more connection quality. These differences in needs of different connection quality can also be observed in their revenue measure on advertisement. We assume that quality-sensitive CAPs' (CAPs<sub>Q</sub>) revenue measure is greater than the regular CAPs'(CAPs<sub>R</sub>), which is expressed by  $\Omega_Q > \Omega_R$ .

While under neutrality regime the ISP is not allowed to exploit this difference, under network management regime it is allowed to do it. More specifically, the ISP allowed to charge CAPs<sub>Q</sub> with a fee  $P$ , for an additional connection quality,  $z$ . Thus, profit function of marginal CAPs with the locations  $y$  and  $j$  for CAPs<sub>R</sub> and for CAPs<sub>Q</sub> are

$$U_R = \Omega_R(\underline{z} - z)n - T_y, \quad (2)$$

$$U_Q = \Omega_Q(\underline{z} + z)n - P - T_j \quad (3)$$

where we assume the additional connection quality level is smaller than the initial level ( $\underline{z} > z$ ).

**EUs** consist of variety of internet consumers. Their valuation of being connected to the internet is different from each other because of variety of reasons. We assume that they are uniformly distributed according to their preferences of valuation from higher to lower on an interval,  $[0,1]$ . And, they face a unit cost ( $t$ ) to be connected to the ISP. This cost is also interpreted as a differentiation parameter for EUs.

EUs gain positive utility to be able to visit different kinds of CAPs. On the other hand, their utility is sensitive for connection quality. Hence, EUs' utility is an increasing function of both for the number of CAPs connected to the platform and their connection quality. However, we assume that EUs' marginal value for additional CAPs and for their connection quality differs according to type of contents or applications. In other words, EUs give more value on quality-sensitive services such as games, voice or video telephony, etc. than the regular services;  $\omega_Q > \omega_R$ . Therefore, the utility of a marginal EU located at  $x$  can be written as

$$u = v + \omega_R(\underline{z} - z)N_R + \omega_Q(\underline{z} + z)N_Q - p - tx \quad (4)$$

where  $v$  is the intrinsic value of EU gains from to be connected to the ISP,  $N_R$  and  $N_Q$  are the number of CAP<sub>R</sub> and CAP<sub>Q</sub>, and  $p$  is fee charged by the ISP. <sup>1</sup>

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<sup>1</sup>We assume that  $v > c$ .

## 2.2 Under network neutrality regime

Under network neutrality regime, we assume that the ISP is not allowed to differentiate its service among the CAPs ( $z = 0$ ). Hence, the ISP offer a fixed connection quality at  $\underline{z}$  for both types of CAPs.

### 2.2.1 Demand for the ISP

Demand for the ISP requires to find the demand from both side of the market which can be represented by market participation of EUs, and both types of CAPs. From equation 4, expected market participation of the EUs is

$$n = \frac{v + \underline{z} (N_Q^e \omega_Q + N_R^e \omega_R) - p}{t} \quad (5)$$

where  $N_Q^e$  and  $N_R^e$  represent the expected market participation for CAPs<sub>Q</sub> and CAPs<sub>R</sub>, respectively.

The expected demand for the other side of the market can be calculated from equations 2 and 3:

$$N_R = \frac{n^e \Omega_R \underline{z}}{T} \quad (6)$$

and

$$N_Q = \frac{n^e \Omega_Q \underline{z}}{T} \quad (7)$$

where  $n^e$  represents the EUs' expected market participation.

At fulfilled expectations, where  $n^e = n$ ,  $N_Q^e = N_Q$ , and  $N_R^e = N_R$ , throughout simultaneous solution of equations 5, 6, and 7, we arrive to demand from each side of the market as functions of linear fee charged by the monopoly ISP:

$$n(p) = \frac{T(v - p)}{tT - \underline{z}^2 (\omega_Q \Omega_Q + \omega_R \Omega_R)}, \quad (8)$$

$$N_R(p) = \frac{(v - p) \Omega_R \underline{z}}{tT - \underline{z}^2 (\omega_Q \Omega_Q + \omega_R \Omega_R)}, \quad (9)$$

and

$$N_Q(p) = \frac{(v - p) \Omega_Q \underline{z}}{tT - \underline{z}^2 (\omega_Q \Omega_Q + \omega_R \Omega_R)}. \quad (10)$$



### 2.2.2 The monopoly ISP

Considering the demand from both side of the market, the ISP's problem is to set optimal price that maximize

$$\Pi(p) = n(p - c). \quad (11)$$

First order condition ( $\frac{d\Pi}{dp} = 0$ ) gives us the optimal price for the ISP under network neutrality regime:<sup>2</sup>

$$p^{NN} = \frac{c + v}{2}. \quad (12)$$

For this optimal price market participation of the sides can be re-written as

$$n^{NN} = \frac{T(v - c)}{2(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))}, \quad (13)$$

$$N_R^{NN} = \frac{(v - c)\Omega_R\underline{z}}{2(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))}, \quad (14)$$

and

$$N_Q^{NN} = \frac{(v - c)\Omega_Q\underline{z}}{2(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))}. \quad (15)$$

Considering the market participation of the two sides, the monopolist ISP's profit is

$$\Pi^{NN} = \frac{T(v - c)^2}{4(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))} \quad (16)$$

which is positive satisfied from the second-order conditions.

### 2.3 Network Management Regime

Now we suppose that the ISP is allowed to manage its network through differentiating its service in terms of its quality. In fact, under network management regime the ISP has an opportunity to charge  $CAP_Q$  for an increase connection quality to  $\underline{z} + z$ . However, as mentioned earlier, since there is not any capacity expansion in the network, the connection quality level ready for  $CAP_R$  decreases to  $\underline{z} - z$ .

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<sup>2</sup>The second order conditions require  $tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R) > 0$ .

### 2.3.1 Demand for the ISP

Following the same steps as in the previous subsection, one can find the demand for the ISP at fulfilling expectations. However, now the market participation of the units is not only a function of  $p$ , but also a function of charge for  $CAP_Q$  ( $P$ ) for the additional connection quality:

$$n(p, P) = \frac{T(v - p) - P\omega_Q(z + \underline{z})}{tT - \omega_R\Omega_R(z - \underline{z})^2 - \omega_Q\Omega_Q(z + \underline{z})^2}, \quad (17)$$

$$N_R(p, P) = \frac{\Omega_R(z - \underline{z})(T(p - v) + P\omega_Q(z + \underline{z}))}{T(tT - \omega_R\Omega_R(z - \underline{z})^2 - \omega_Q\Omega_Q(z + \underline{z})^2)}, \quad (18)$$

and

$$N_Q(p, P) = \frac{T(v - p)\Omega_Q(z + \underline{z}) - P(tT - \omega_R\Omega_R(z - \underline{z})^2)}{T(tT - \omega_R\Omega_R(z - \underline{z})^2 - \omega_Q\Omega_Q(z + \underline{z})^2)}. \quad (19)$$

### 2.3.2 The monopoly ISP in deviation

Considering the demand from both side of the market, the ISP's problem now is to set optimal prices  $p$  and  $P$ , that maximize its profit, which was given in equation 1. First order conditions ( $\frac{\partial \Pi}{\partial p} = 0$  and  $\frac{\partial \Pi}{\partial P} = 0$ ) gives us the optimal price for the ISP under network management regime:<sup>3</sup>

$$p^{NM} = \frac{2(c + v)(tT - \omega_R\Omega_R(z - \underline{z})^2) - c\omega_Q^2(z + \underline{z})^2 - (c + v)\omega_Q\Omega_Q(z + \underline{z})^2 - v\Omega_Q^2(z + \underline{z})^2}{4(tT - \omega_R\Omega_R(z - \underline{z})^2) - (z + \underline{z})^2(\omega_Q + \Omega_Q)^2}, \quad (20)$$

and

$$P^{NM} = \frac{T(v - c)(\Omega_Q - \omega_Q)(z + \underline{z})}{4(tT - \omega_R\Omega_R(z - \underline{z})^2) - (z + \underline{z})^2(\omega_Q + \Omega_Q)^2} \quad (21)$$

For these optimal prices market participation of the sides can be re-written:

$$n^{NM} = \frac{2T(v - c)}{4(tT - \omega_R\Omega_R(z - \underline{z})^2) - (z + \underline{z})^2(\omega_Q + \Omega_Q)^2}, \quad (22)$$

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<sup>3</sup>The second order conditions require  $tT - \omega_R\Omega_R(z - \underline{z})^2 - \omega_Q\Omega_Q(z + \underline{z})^2 > 0$ .

$$N_R^{NM} = \frac{2(v-c)\Omega_R(\underline{z}-z)}{4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (z+\underline{z})^2(\omega_Q + \Omega_Q)^2}, \quad (23)$$

and

$$N_Q^{NM} = \frac{(v-c)(\omega_Q + \Omega_Q)(z+\underline{z})}{4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (z+\underline{z})^2(\omega_Q + \Omega_Q)^2}. \quad (24)$$

Considering those market participation the ISP's profit is

$$\Pi^{NM} = \frac{T(c-v)^2}{4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (z+\underline{z})^2(\omega_Q + \Omega_Q)^2} \quad (25)$$

which is positive satisfied from the second-order conditions.

## 2.4 Incentive of the ISP to differentiate

After obtaining the profits under network neutrality and network management regime, now we can examine incentive of the ISP to differentiate its service. In doing so, we compare the profits obtained in each regime, and observe the change in. Since we are interested in observing the incentive to deviate from neutrality, if there exist any, we look at change in profit through deviation:  $\Delta\Pi = \Pi^{NM} - \Pi^{NN}$ . This is

$$\Delta\Pi = \frac{T(c-v)^2}{4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (z+\underline{z})^2(\omega_Q + \Omega_Q)^2} - \frac{T(v-c)^2}{4(tT - \omega_Q\Omega_Q\underline{z}^2 - \omega_R\Omega_R\underline{z}^2)} > 0 \quad (26)$$

which is positive if  $(\omega_Q + \Omega_Q)^2 > 4\omega_R\Omega_R$ . This condition implies sufficient differentiation between regular and quality sensitive services, in terms of their marginal values for EUs and marginal revenues for CAPs.

## 2.5 Welfare Implications

### 2.5.1 Welfare under neutrality regime

Considering our model in neutrality regime, we have four different parties in the market, EUs,  $CAP_{RS}$ ,  $CAP_{QS}$ , and the the monopolist ISP. Then, the welfare in this market consists of surpluses of the indicated parties:

$$\underbrace{\text{TotalSurplus}}_{\text{TS}} = \underbrace{\text{End-userSurplus}}_{\text{EUS}} + \underbrace{\text{RegularCAPSurplus}}_{\text{CAP}_{RS}} + \underbrace{\text{QualityCAPSurplus}}_{\text{CAP}_{QS}} + \underbrace{\text{ISP'sProfit}}_{\text{PS}}. \quad (27)$$

The components of the above expression are determined throughout the equilibrium market participation and profit maximizing price of the ISP. The components of 27 are

$$\text{EUS}^{\text{NN}} = \int_0^{n^{\text{NN}}} u_i di = \frac{tT^2(v-c)^2}{8(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2}, \quad (28)$$

$$\text{CAPS}_R^{\text{NN}} = \int_0^{N_R^{\text{NN}}} U_y dy = \frac{T(v-c)^2\Omega_R^2\underline{z}^2}{8(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2}, \quad (29)$$

$$\text{CAPS}_Q^{\text{NN}} = \int_0^{N_Q^{\text{NN}}} U_j dj = \frac{T(v-c)^2\Omega_Q^2\underline{z}^2}{8(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2}, \quad (30)$$

and

$$\text{PS}^{\text{NN}} = \Pi^{\text{NN}} = \frac{T(v-c)^2}{4(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))}. \quad (31)$$

Then, the total surplus under neutrality regime is

$$\text{TS}^{\text{NN}} = \frac{T(c-v)^2(3tT - \underline{z}^2(2\omega_Q\Omega_Q - \Omega_Q^2 + 2\omega_R\Omega_R - \Omega_R^2))}{8(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2}. \quad (32)$$

which is positive satisfied from the second-order conditions.

### 2.5.2 Welfare under network management regime

Considering the market participation in both side of the market under network management regime the components of the total surplus are

$$\text{EUS}^{\text{NM}} = \int_0^{n^{\text{QoS}}} u_i di = \frac{2tT^2(c-v)^2}{(4(tT - \omega_R\Omega_R(z - \underline{z})^2) - (z + \underline{z})^2(\omega_Q + \Omega_Q)^2)^2}, \quad (33)$$

$$\text{CAPS}_R^{\text{NM}} = \int_0^{N_Q^{\text{QoS}}} U_y dy = \frac{2T(v-c)^2 \Omega_R^2 (z-z)^2}{(4(tT - \omega_R \Omega_R (z-z)^2) - (z+z)^2 (\omega_Q + \Omega_Q)^2)^2}, \quad (34)$$

$$\text{CAPS}_Q^{\text{NM}} = \int_0^{N_Q^{\text{NN}}} U_j dj = \frac{T(v-c)^2 (\omega_Q + \Omega_Q)^2 (z+z)^2}{2(4(tT - \omega_R \Omega_R (z-z)^2) - (z+z)^2 (\omega_Q + \Omega_Q)^2)^2}, \quad (35)$$

and

$$\text{PS}^{\text{NM}} = \pi^{\text{QoS}} = \frac{T(c-v)^2}{4(tT - \omega_R \Omega_R (z-z)^2) - (z+z)^2 (\omega_Q + \Omega_Q)^2}, \quad (36)$$

Then, the total surplus under network management regime is

$$\begin{aligned} \text{TS}^{\text{NM}} &= \frac{T(c-v)^2 (4tT + 4\Omega_R^2 (z-z)^2 + (\omega_Q + \Omega_Q)^2 (z+z)^2)}{2(-4(tT - \omega_R \Omega_R (z-z)^2) + (\omega_Q + \Omega_Q)^2 (z+z)^2)^2} \\ &+ \frac{T(c-v)^2 (2(4(tT - \omega_R \Omega_R (z-z)^2) - (\omega_Q + \Omega_Q)^2 (z+z)^2))}{2(-4(tT - \omega_R \Omega_R (z-z)^2) + (\omega_Q + \Omega_Q)^2 (z+z)^2)^2} \end{aligned} \quad (37)$$

which is positive considering the previously imposed conditions.

### 2.5.3 Assessments

This subsection investigates welfare effects throughout comparing surpluses under network management regime with under neutrality regime. Since we are interested in observing the implications of deviation from neutrality, we look at change in surplus through deviation:  $\Delta \text{Surplus} = \text{Surplus}^{\text{NM}} - \text{Surplus}^{\text{NN}}$ .

The change in EU Surplus is calculated through the equations 28 and 33:

$$\begin{aligned} \Delta \text{EUS} &= \frac{1}{8} t T^2 (c-v)^2 \left( \frac{16}{(4(tT - \omega_R \Omega_R (z-z)^2) - (\omega_Q + \Omega_Q)^2 (z+z)^2)^2} \right) \\ &- \frac{1}{8} t T^2 (c-v)^2 \left( \frac{1}{(tT - z^2 (\omega_Q \Omega_Q + \omega_R \Omega_R))^2} \right) > 0 \end{aligned} \quad (38)$$

which is positive for sufficiently larger  $t$  and  $T$  parameters, and the condition required for the incentive to deviate for the ISP;  $(\omega_Q + \Omega_Q)^2 > 4\omega_R\Omega_R$ .

The change in surplus of regular CAPs surplus is calculated through the equations 29 and 34:

$$\begin{aligned} \Delta\text{CAP}_R S &= \frac{1}{8}T(c-v)^2\Omega_R^2 \left( \frac{16(z-\underline{z})^2}{(4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (\omega_Q + \Omega_Q)^2(z+\underline{z})^2)^2} \right) \\ &\quad - \frac{1}{8}T(c-v)^2\Omega_R^2 \left( \frac{\underline{z}^2}{(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2} \right) < 0 \end{aligned} \quad (39)$$

which is negative for sufficiently larger  $t$  and  $T$  parameters.

The change in quality sensitive CAPs surplus is calculated through the equations 30 and 35:

$$\begin{aligned} \Delta\text{CAP}_Q S &= \frac{1}{8}T(c-v)^2 \left( \frac{4(\omega_Q + \Omega_Q)^2(z+\underline{z})^2}{(4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (\omega_Q + \Omega_Q)^2(z+\underline{z})^2)^2} \right) \\ &\quad - \frac{1}{8}T(c-v)^2 \left( \frac{\Omega_Q^2\underline{z}^2}{(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2} \right) > 0 \end{aligned} \quad (40)$$

which is positive for sufficiently larger increase in additional connection quality ( $\omega_Q(z+\underline{z}) - \Omega_Q(\underline{z}-z) > 0$ ).

Hence, the difference in total surplus is:

$$\begin{aligned} \Delta\text{TS} &= \frac{1}{8}T(c-v)^2 \left( \frac{4((4tT + 4\Omega_R^2(z-\underline{z})^2 + (\omega_Q + \Omega_Q)^2(z+\underline{z})^2))}{(4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (\omega_Q + \Omega_Q)^2(z+\underline{z})^2)^2} \right) \\ &\quad + \frac{1}{8}T(c-v)^2 \left( \frac{4((2(4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (\omega_Q + \Omega_Q)^2(z+\underline{z})^2))}{(4(tT - \omega_R\Omega_R(z-\underline{z})^2) - (\omega_Q + \Omega_Q)^2(z+\underline{z})^2)^2} \right) \\ &\quad - \frac{1}{8}T(c-v)^2 \left( \frac{3tT - 2\omega_Q\Omega_Q\underline{z}^2 + \Omega_Q^2\underline{z}^2 - 2\omega_R\Omega_R\underline{z}^2 + \Omega_R^2\underline{z}^2}{(tT - \underline{z}^2(\omega_Q\Omega_Q + \omega_R\Omega_R))^2} \right) \end{aligned} \quad (41)$$

which is undetermined. But considering the increases in EUS, CAP<sub>Q</sub>S, and the ISP's profit, one can argue that change in total surplus in the market may be positive, if the decrease in CAP<sub>R</sub>S is offset.

### 3 An Extension: Duopoly Competition

This section extends the previous model through introducing an additional platform. In other words, in this section we have duopoly platform competition between two identical ISPs. During this section we assume that each EU is connected to the internet through a sole ISP, and CAPs serve through both ISPs.

#### 3.1 Duopoly competition in two sided-market

Now there are **two competing ISPs** that control the two-sided market,  $ISP_i$  where  $i \in \{1, 2\}$ . As in the monopoly model, under the network neutrality regime, they offer linear pricing contract to EUs for subscription, but they are not allowed to charge any CAPs. And, they give identical service for each CAPs, which has the same connection quality,  $\underline{z}$ . And similarly, under network management regime, the ISPs are allowed to discriminate between CAPs. We assume the ISPs are identical for their quality of transmission and for their costs. Then, the  $i^{th}$  ISP's profit function is

$$\Pi_i = (p_i - c) n_i + P_i N_{Qi}. \quad (42)$$

**CAPs** are defined as in the monopoly model above. Thus, profit function of marginal CAPs in both type, which serve through the  $ISP_i$ , are

$$U_{Ri} = \Omega_R (\underline{z} - z) n_i - Ty, \quad (43)$$

and

$$U_{Qi} = \Omega_Q (\underline{z} + z) n_i - P_i - Tj. \quad (44)$$

**EUs** are assumed to be uniformly distributed over an interval  $[0, 1]$ , as in the monopoly model. However, here we assume that two ISPs are located at the edges of this interval. More specifically, while  $ISP_1$  resides at 0,  $ISP_2$  resides at 1. Thus, for a marginal EU who resides at  $x$ , the cost to connect to  $ISP_1$  and  $ISP_2$  can be cited as  $tx$  and  $(1 - x)t$ , respectively. Then, the utility of a marginal consumer for each ISPs are <sup>4</sup>

$$u_1 = v + \omega_R (\underline{z} - z) N_{R1} + \omega_Q (\underline{z} + z) N_{Q1} - p_1 - tx, \quad (45)$$

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<sup>4</sup>Here we assume a full market coverage for the EUs to simplify our calculation.

and

$$u_2 = v + \omega_R (\underline{z} - z) N_{R2} + \omega_Q (\underline{z} + z) N_{Q2} - p_2 - (1 - x)t. \quad (46)$$

### 3.2 Under network neutrality regime

Under the neutrality regime, one can follow the same steps as in the monopoly model, and find the the the market participation of the EUs and the CAPs at the fulfilling expectations. Then, the profit the profit maximizing ISPs take into account the demand from both side of the market and solve their problem of setting the profit maximizing prices. The first order condition ( $\frac{d\Pi_i}{dp_i}$ ) gives <sup>5</sup>

$$p_i^{\text{NN}} = \frac{T(c + t) - (\omega_Q \Omega_Q + \omega_R \Omega_R) \underline{z}^2}{T}. \quad (47)$$

Considering the profit maximizing prices of each ISPs, the market participation is

$$n_i^{\text{NN}} = \frac{1}{2}, \quad (48)$$

$$N_{Ri}^{\text{NN}} = \frac{\Omega_R \underline{z}}{2T}, \quad (49)$$

and

$$N_{Qi}^{\text{NN}} = \frac{\Omega_Q \underline{z}}{2T}. \quad (50)$$

Then considering the above mentioned market participation from both sides, the ISP<sub>*i*</sub>'s profit is

$$\Pi_i^{\text{NN}} = \frac{Tt - (\omega_Q \Omega_Q + \omega_R \Omega_R) \underline{z}^2}{2T} \quad (51)$$

which is positive satisfied by the second order conditions.

### 3.3 Under network management regime

Now we assume the ISPs are allowed to differentiate their services throughout charging certain CAPs for additional connection quality as in the monopoly model. Again, one can follow the same steps as in the monopoly model, and

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<sup>5</sup>The second order conditions require  $tT - (\omega_Q \Omega_Q + \omega_R \Omega_R) \underline{z}^2 > 0$



find the the market participation of the EUs and the CAPs at the fulfilling expectations. Then, the profit the profit maximizing ISPs take into account the demand from both side of the market and solve their problem of setting the profit maximizing prices. However, now the ISPs' problem includes to find optimal prices charged for the quality sensitive CAPs. Hence the first order conditions ( $\frac{\partial \Pi_i}{\partial p_i}$  and  $\frac{\partial \Pi_i}{\partial P_i}$ ) give <sup>6</sup>

$$p_i^{\text{NM}} = (c + t) - \frac{4\omega_R\Omega_R(z - \underline{z})^2 + (z + \underline{z})^2(3\omega_Q\Omega_Q + \Omega_Q^2)}{4T}, \quad (52)$$

and

$$P_i^{\text{NM}} = \frac{1}{4}(\Omega_Q - \omega_Q)(z + \underline{z}). \quad (53)$$

Considering the profit maximizing prices of each ISPs, the market participation is

$$n_i^{\text{NM}} = \frac{1}{2}, \quad (54)$$

$$N_{\text{Ri}}^{\text{QoS}} = \frac{\Omega_R(z - z)}{2T}, \quad (55)$$

and

$$N_{\text{Qi}}^{\text{NM}} \rightarrow \frac{(\omega_Q + \Omega_Q)(z + \underline{z})}{4T}. \quad (56)$$

Then considering the above mentioned market participation from both sides, the ISP<sub>*i*</sub>'s profit is

$$\Pi_i^{\text{NM}} = \frac{8(tT - \omega_R\Omega_R(z - \underline{z})^2) - (z + \underline{z})^2(\omega_Q^2 + 6\omega_Q\Omega_Q + \Omega_Q^2)}{16T}. \quad (57)$$

which is positive for sufficiently larger  $t$  and  $T$  parameters.

### 3.4 Incentive of the duopoly ISPs to differentiate

After obtaining the profits under network neutrality and network management regime, now we can examine incentive of duopoly ISPs to differentiate its service. As in the previous model, we compare the profits obtained in each regime, and observe the change in. And, since we are interested in observing

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<sup>6</sup>The second order conditions require  $tT - \omega_R\Omega_R(z - \underline{z})^2 - \omega_Q\Omega_Q(z + \underline{z})^2 > 0$

the incentive to deviate from neutrality, we look at change in profit through deviation:  $\Delta\Pi_i = \Pi_i^{NM} - \Pi_i^{NN}$ . This is

$$\Delta\Pi_i = \frac{8z\omega_R\Omega_R(2\underline{z} - z) - \omega_Q^2(z + \underline{z})^2 - \Omega_Q^2(z + \underline{z})^2 - 2\omega_Q\Omega_Q(3z^2 + 6z\underline{z} - \underline{z}^2)}{16T} \quad (58)$$

which gives us an ambiguous result about incentive of duopoly ISPs to differentiate its service. This result may be interpreted as a weak evidence obtained by introducing competition.

### 3.5 Welfare Implications in duopoly model

Under neutrality regime with duopoly platforms surplus of the parties can be calculated through their equilibrium market participation and profit maximizing prices of the ISPs, as in the monopoly model:

$$EUS_i^{NN} = \frac{T(4(v - c) - 5t) + 6(\omega_Q\Omega_Q + \omega_R\Omega_R)\underline{z}^2}{8T}, \quad (59)$$

$$CAPS_{Ri}^{NN} = \frac{\Omega_R^2\underline{z}^2}{8T}, \quad (60)$$

and

$$CAPS_{Qi}^{NN} = \frac{\Omega_Q^2\underline{z}^2}{8T}. \quad (61)$$

Then, taking into account the ISPs' profits in equation 51 one can find the total welfare in the market:

$$TS_i^{NN} = \frac{T(4(v - c) - t) + (2\omega_Q\Omega_Q + \Omega_Q^2 + \Omega_R(2\omega_R + \Omega_R))\underline{z}^2}{8T}. \quad (62)$$

On the other hand, the components of the total surplus under network management regime can also be calculated through similar steps:

$$EUS_i^{NM} = \frac{T(4(v - c) - 5t) + 6\omega_R\Omega_R(z - \underline{z})^2 + (z + \underline{z})^2(\omega_Q^2 + 4\omega_Q\Omega_Q + \Omega_Q^2)}{8T}, \quad (63)$$

$$\text{CAPS}_{\text{Ri}}^{\text{NM}} \longrightarrow \frac{\Omega_R^2 (z - \underline{z})^2}{8T}, \quad (64)$$

and

$$\text{CAPS}_{\text{Qi}}^{\text{NM}} \longrightarrow \frac{(\omega_Q + \Omega_Q)^2 (z + \underline{z})^2}{32T}. \quad (65)$$

Then, taking into account the ISPs' profits in equation 57 one can find the total welfare in the market:

$$\text{TS}_i^{\text{NM}} = \frac{(4(v - c) - t)}{8} + \frac{4\Omega_R (2\omega_R + \Omega_R) (z - \underline{z})^2 + (z + \underline{z})^2 (3\omega_Q^2 + 6\omega_Q\Omega_Q + 3\Omega_Q^2)}{32T}. \quad (66)$$

In order to find the welfare implications we should find the changes in surpluses as in the monopoly model:  $\Delta\text{Surplus}_i = \text{Surplus}_i^{\text{NM}} - \text{Surplus}_i^{\text{NN}}$ .

The change in EU surplus can be calculated through the equations 59 and 63:

$$\Delta\text{EUS}_i = \frac{(z + \underline{z})^2 (\omega_Q^2 + \Omega_Q^2) + 2\omega_Q\Omega_Q (2z^2 + 4z\underline{z} - \underline{z}^2) - 6z\omega_R\Omega_R (2\underline{z} - z)}{8T} > 0 \quad (67)$$

which is positive for sufficiently larger values of additional connection quality level,  $z$ .

The change in regular CAPs surplus can be calculated through the equations 60 and 64:

$$\Delta\text{CAPS}_{\text{Ri}} = \frac{z\Omega_R^2 (z - 2\underline{z})}{8T} < 0 \quad (68)$$

which is negative without imposing any requirement.

The change in quality sensitive CAPs surplus can be calculated through the equations 61 and 65:

$$\Delta\text{CAPS}_{\text{Qi}} = \frac{(\omega_Q + \Omega_Q)^2 (z + \underline{z})^2 - 4\Omega_Q^2 \underline{z}^2}{32T} > 0 \quad (69)$$

which is positive for sufficiently larger increase in additional connection quality level and tolerable difference between  $\Omega_Q$  and  $\omega_Q$ , which comes from the requirement  $(\Omega_Q (z - \underline{z}) + \omega_Q (z + \underline{z})) > 0$ .

Although the difference in total surplus can be calculated, it can not be interpreted, since the profit of the duopoly ISPs is undetermined.

## 4 Concluding remarks

Our analysis which investigates the welfare implications of switching from a neutrality regime to a network management regime suggests some interesting results that may contribute to the debate. The primary insight from this study may refer the potential gains that can be captured through network management regime. More specifically, switching from *a-bit-is-a-bit* principle may create social benefits at least more than one parties in the market. Both in monopoly and duopoly models we have observed that EUs and quality-sensitive CAPs benefit from network management regime in case of enough increase in quality of connection offered by ISP(s).

On the other hand, it has to be kept in mind that network management regime primarily requires ISP(s) action. Thus, ISP(s) incentive to switch network management regime is crucial. Our findings in the main model with a monopolist ISP suggest that in case of higher valuation from the EU side for the quality-sensitive content or applications, and higher revenue parameter from its providers is a necessary condition for ISP(s) to differentiate its service in terms of quality connection. However, in the extended version of the model (duopoly competition) we have not arrived a definite conclusion about these incentives. One can interpret this finding as a an impact of competition between ISPs. But, we have not enough evidence to support this argument.

The overall effect of deviation from neutrality regime on total surplus may not defined clearly in both models. In the main model, with a monopolist ISP, although we have found that only the regular CAPs suffer, we can not arrive a definite conclusion for the total welfare. In the extended model with duopoly competition, regular CAPs still suffer, additionally we faces ambiguous result for the incentive of the ISPs. And, this make the total surplus undetermined once more.

Before concluding, it has to be emphasized that the main mechanism which makes the quality-sensitive CAPs and EUs better-off results from devoting the available network resources more to quality-sensitive CAPs. In contrast with this situation, regular CAPs suffer, since the quality of the connection available for them is less than the neutrality regime. However, the interesting thing here is, revealing the potential gains through considering the economic values of data packets with the network management regime.

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