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# NET NEUTRALITY WITH COMPETING INTERNET PLATFORMS

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# ABSTRACT

## Net Neutrality with Competing Internet Platforms*

We propose a two-sided model with two competing Internet platforms, and a continuum of Content Providers (CPs). We study the effect of a net neutrality regulation on capacity investments in the market for Internet access, and on innovation in the market for content. Under the alternative discriminatory regime, platforms charge a priority fee to those CPs which are willing to deliver their content on a fast lane. We find that under discrimination investments in broadband capacity and content innovation are both higher than under net neutrality. Total welfare increases, though the discriminatory regime is not always beneficial to the platforms as it can intensify competition for subscribers. As platforms have a unilateral incentive to switch to the discriminatory regime, a prisoner's dilemma can arise. We also consider the possibility of sabotage, and show that it can only emerge, with adverse welfare effects, under discrimination.

JEL Classification: L13, L51, L52 and L96
Keywords: innovation, investment, net neutrality, platform competition and two-sided markets

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# 1 Introduction

Should we continue to treat all types of Internet traffic equally, that is, with no discrimination with respect to the type of content, service or application and the identity of the data transmitter, or should we instead allow Internet platforms (Internet Service Providers, ISPs) to discriminate the traffic they carry? This question over the "net neutrality" has generated hot discussions since the Federal Communications Commission (FCC) changed the classification of Internet transmissions from the category of "telecommunications services" to the category of "information services" in the US in 2005, making ISPs no longer explicitly subject to the principle of net neutrality.

This debate has been exacerbated by the fact that, over the last few years, the volume of Internet traffic has grown up drastically, requiring ISPs to upgrade their network capacity. In 2005, AT&T, later followed by other major telephone and cable operators, proposed to charge content providers (CPs) premium prices for preferential access to broadband transmission services. Comcast, the largest cable operator in the US, was also accused of interfering with users' access to file-sharing services such as BitTorrent. There have been other cases reported in the popular press of ISPs blocking or degrading the quality of content. ISPs argue that these practices are necessary to manage Internet traffic efficiently and ensure a sufficient quality of service, especially for content, services and applications that are very sensitive to delays, such as VoIP services or video conferencing. However, even if this view seems now widely accepted, which traffic management techniques will be allowed is still discussed. In particular, policy-makers argue that it is crucial to prevent ISPs from adopting discriminatory practices for reasons unrelated to traffic management.[1]

The net neutrality issue turns out to be very contested among policy-makers and industry players. Opponents to net neutrality argue that a net neutrality regulation would reduce ISPs' incentives to invest in broadband capacity, and lead to less entry of CPs.[2] Proponents of net neutrality, on the other hand, contend that the Internet has been neutral since its inception, and should be kept free and open to everyone. They further argue that a departure from the net neutrality regime would reduce innovation in Internet services (entry of CPs),[3] and that ISPs will continue to invest in broadband capacities whatever the traffic regime, since this is the only way to

[1] On September 23, 2011, the FCC released an Order on "Preserving the Open Internet" (FCC 10-201, "In the Matter of Preserving the Open Internet, Broadband Industry Practices"), where it adopts three basic protections: transparency, no blocking, and no unreasonable discrimination. This is currently challenged in courts. Some countries have adopted non-binding guidelines on net neutrality, such as Norway and Canada, while Chile was the first country to address directly the principle of net neutrality in its legislation (Holland was the second).

[2] See, for example, Yoo (2005).

[3] See Van Schewick (2006).

keep their demand high. Finally, end users are concerned about the subscription fees that they pay to ISPs, the variety of Internet content, and the quality of their Internet connection. The aim of this paper is to propose a formal analysis of the impact of a transition from the net neutrality regime to a discriminatory regime, in a model with competing ISPs and a continuum of heterogeneous CPs.

It has indeed been argued that spurring competition between ISPs can solve the net neutrality problem, making a discriminatory regime less threatening (in terms of blocking, sabotage, etc.) to the extent that ISPs race against each other.[4] For example, the European Commission (2011) stated that "the significance of the types of problems arising in the net-neutrality debate is correlated to the degree of competition existing in the market."[5] In the US, the FCC exempted mobile networks from most of the net neutrality rules,[6] on the grounds that they face stronger capacity constraints than fixed networks, and that competition warrants net neutrality or at least mitigates the negative effects of a departure from it.[7]

Despite its apparent relevance in the policy context, the competition aspect has been overlooked by the literature, as most papers assume a monopolistic market structure at the ISP level. Though it is always beneficial for a monopolist ISP to depart from the net neutrality regime, since it can extract part of the CPs' revenues by charging them for priority and still serve all end users, it is less clear that a switch to the discriminatory regime would benefit competing ISPs. Moreover, in a monopolistic framework, consumer surplus is not affected by a departure from net neutrality if the ISP can fully extract the surplus from the consumption of content and the consumer market is fully covered. As the ISP additionally extracts part of the CPs' profits under discrimination, a departure from net neutrality then mechanically increases welfare when it is profitable for the ISP, as the ISP internalizes total welfare more. An important question is whether this is still true when there is competition between Internet platforms.

We build a two-sided model where two horizontally-differentiated Internet platforms compete to bring together the two sides of the Internet, the CPs and the end users. We then compare

[4] See, e.g., Becker et al. (2010).

[5] European Commission, 19.4.2011, Communication from the Commission to the European Parliament.

[6] In particular, the rules allow mobile operators to discriminate or to block specific applications. However, mobile networks have the same obligation as fixed networks to publicly disclose their network management practices ("transparency" rule). See Maxwell and Brenner (2012) for a comparison of the net neutrality rules for fixed and mobile networks in the US and in Europe. Choi *et al.* (2013) show that net neutrality rules may be harmful when the network capacity is highly limited (as on mobile broadband networks), because it hinders entry from highly congestion-sensitive CPs.

[7] In its Order, the FCC explains the different rules for fixed and mobile networks by stating in particular that "most consumers have more choices for mobile broadband than for fixed (particularly fixed wireline) broadband" (paragraph 95).

the pricing, investment, and innovation incentives under the net neutrality and the discriminatory regimes. Innovation in services takes place when CPs enter the market and offer advertising-supported content to end users. CPs are heterogeneous with respect to their congestion sensitivity and may single-home, multi-home, or stay out of the market. For the most congestion-sensitive CPs (e.g., those who offer streaming or VoIP applications) delays in data transmissions are harmful, since such delays make end users less likely to click on ads, and hence, reduce advertising revenues. By contrast, the less congestion-sensitive CPs (e.g., those who supply email account services) are hardly affected by congestion. Under net neutrality, CPs that are connected to the same ISP are treated equally, and experience the same level of congestion. Under discrimination, by contrast, ISPs offer two differentiated traffic lanes to CPs, a priority (fast) lane and a non-priority (slow) lane. CPs have to pay a priority fee to their ISP to access the fast lane, while the slow lane remains free-of-charge. Finally, end users – who value the variety of content, but dislike network congestion – choose one ISP to subscribe to.

Our first result is that a switch from the net neutrality regime to the discriminatory regime would be beneficial in terms of investments, innovation, and total welfare. First, when ISPs offer differentiated traffic lanes, investment in broadband capacity increases. This is because the discriminatory regime allows ISPs to extract additional revenues from CPs through the priority fees. Second, innovation in services also increases: some highly congestion-sensitive CPs that were left out of the market under net neutrality enter when a priority lane is proposed. Overall, discrimination always increases total welfare, though the impact of a switch to the discriminatory regime on each type of agent (ISPs, CPs, end users) is generally ambiguous.

Our second result is that ISPs might be trapped in a prisoners' dilemma with regards to the choice of a traffic regime. Indeed, we find that each ISP always has a unilateral incentive to adopt the discriminatory regime, even though the two ISPs' profits might be reduced if they both switch to discrimination.

We extend our baseline model to account for the possibility that ISPs engage in quality degradation or "sabotage" of CPs' traffic. We find that sabotage never arises endogenously under net neutrality. By contrast, under the discriminatory regime, ISPs may have an incentive to sabotage the non-priority lane to make the priority lane more valuable, and hence, to extract higher revenues from the CPs that opt for priority. Any level of sabotage is detrimental for total welfare, and therefore, a switch to the discriminatory regime would still require some regulation of traffic quality. Our qualitative results are robust when we account for the existence of small and large CPs, in which case prioritization is likely to hurt the small CPs more than the large ones. Finally, our qualitative results are also robust when we restrict our attention to one ISP; however, the monopolist is always (at least weakly) better off under discrimination since it can replicate the net neutrality outcome under discrimination.

**Related literature.** While the possibility of a departure from net neutrality has generated rich policy debates, few academic papers have addressed this issue. Choi and Kim (2010) and Cheng *et al.* (2011) study models with a monopolistic ISP and a fixed number of CPs (two) who can access a fast lane by paying a priority fee and the ISP invests in capacity. Krämer and Wiewiorra (2012) extend this framework by considering a continuum of heterogeneous congestion-sensitive CPs.

These contributions concern models of monopoly. In our work we provide a setting with both investment in capacity, innovation by CPs and ISPs' competition, and study whether the policy concerns surrounding the net neutrality debate are alleviated when there is competition between Internet platforms.[8]

A small number of works have considered the question of net neutrality in a model with competing ISPs. Economides and Tåg (2012) propose such a model but in a static framework, which ignores the congestion problem and the investment decisions of the ISPs. Njoroge *et al.* (2012) build up a model with two competing ISPs which can invest in quality, however they do not study analytically the impact of traffic prioritization, which is at the core of the net neutrality debate. Choi *et al.* (2012) analyze a static model with competing and interconnected ISPs and a fixed continuum of heterogeneous CPs. They do not address the investment issue, and focus on the termination fees charged by the ISPs to the CPs and on the interconnection fees charged between ISPs. By contrast, we focus on the impact of the traffic regime (net neutrality vs. discrimination) on investment and innovation incentives, in a setting with competing ISPs.

Our paper is also related to the literature on two-sided markets,[9] and more specifically to the stream of literature that analyzes investment and innovation strategies in two-sided markets (Farhi and Hagiu, 2008). In particular, Belleflamme and Peitz (2010) study the impact of two competing platforms' intermediation mode (for-profit versus free-access) on sellers' investment, in a model where sellers' investment increases the buyers' utility of joining a platform. They show that for-profit intermediation may lead to overinvestment.

[8]Other monopoly models of net neutrality with investments exist, e.g., Economides and Hermalin (2012) and Reggiani and Valletti (2011). See Schuett (2010) for a review of recent literature.

[9]See, for example, Rochet and Tirole (2006) and Armstrong (2006).

Finally, our paper is linked to the literature that analyzes the welfare effects of price discrimination in oligopoly markets. In line with this literature (e.g., Corts, 1998; Armstrong, 2008), in our model discrimination can make competition between Internet platforms either softer or tougher.[10] Alexandrov and Deb (2012) examine the investment incentives and the pricing decisions of the firms when they are allowed (or not) to price discriminate. Price discrimination increases investments in their one-sided model, as it does in our two-sided setting.

The remainder of the paper is as follows. Section 2 sets up the model. Section 3 derives the equilibrium under net neutrality. The equilibrium under discrimination is studied in Section 4. Section 5 compares the two regimes. In Section 6 we extend the model to allow for the possibility of sabotage, while in Section 7 we discuss the case of small and large CPs. Section 8 concludes.

# 2 The Model

Two horizontally-differentiated Internet service providers (ISPs), denoted as $A$ and $B$, bring together two sides of the Internet, respectively content providers (CPs) and end users. CPs provide free content to end users via the broadband networks of the ISPs and derive revenues from advertising,[11] while ISPs sell broadband access to end users. The CPs are global, thus, they are not provided Internet access by ISP $A$ or ISP $B$.[12]

Under net neutrality, ISPs do not charge CPs for access to their broadband network. However, due to capacity constraints, networks can suffer from congestion, which both CPs and end users dislike. We therefore study the effect of an alternative to the net neutrality regime, the discriminatory regime.[13] Under the discriminatory regime, each ISP offers two differentiated traffic lanes to CPs, the priority (fast) and non-priority (slow) lanes. ISPs charge CPs to access their priority lane, whereas they offer free access to the non-priority lane.

[10] See also Liu and Serfes (2013).

[11] This corresponds to the typical business model for CPs on the Internet. Moreover, although some (typically large) CPs charge consumers for content, they often offer a free and ad-supported version of their service as well.

[12] We focus on the "last-mile" market for Internet access, taking as given a competitive backbone that connects global CPs to residential-access ISPs. The debate on net neutrality centers around traffic management at the last-mile level; thus, we take the peering agreements between the networks at the backbone as given.

[13] Note that we first consider each regime separately. In Section 5 we will however discuss an ISP's incentive to switch unilaterally to the discriminatory regime.

## 2.1 Content providers

There is a continuum of non-competing and congestion-sensitive CPs that derive revenues from advertising. At each level of congestion sensitivity $h \in [0, \infty)$, there is a mass 1 of CPs. Each CP may connect to no ISP, to a single ISP, or to both ISPs; that is, we allow CPs to single-home or to multi-home. If it connects to ISP $i$, a CP has access only to the end users connected to that ISP.

CPs receive advertising revenues as follows. When a CP of type $h$ connects to ISP $i$, it receives $\lambda x_i$ visits, where $x_i$ is the number of end users subscribing to ISP $i$ and $\lambda$ is the constant number of visits per user, which is the same for all web sites. Visitors of CP $h$ click on ads with a click-through rate of $(1 - hw_i)$, where $w_i$ denotes the congestion on ISP $i$'s network. The click-through rate represents the proportion of the CP's visitors who actually click on ads. Finally, clicks generate advertising revenues of $a\lambda x_i (1 - hw_i)$ for CP $h$, where $a$ denotes the fixed per-click advertising revenue.

With this formulation, a CP with a high congestion sensitivity (e.g., a CP which offers live streaming) suffers a lot from network congestion, as its click-through rate is sharply reduced. This is because, when there is congestion, end users primarily consume the content, and are less likely to spend enough time on the service to click on ads.[14] By contrast, a CP with a very low congestion sensitivity (e.g., a CP that provides email accounts) is hardly affected by congestion. Since its service requires limited bandwidth, end users can use it with a similar comfort as if there were no congestion, and are therefore almost as likely to click through on ads.

Under net neutrality (N), as no payment is due to the ISPs, the profit of CP $h$ is

$$\Pi_h^N = \begin{cases} a\lambda x_A^N \left(1 - hw_A^N\right) + a\lambda x_B^N \left(1 - hw_B^N\right) & \text{it connects to both ISPs} \\ a\lambda x_i^N \left(1 - hw_i^N\right) & \text{if} \quad \text{it connects only to ISP } i \\ 0 & \text{otherwise.} \end{cases}$$

Under net neutrality, all the CPs that are active at ISP $i$ are treated equally and face the same average level of congestion $w_i^N$. By contrast, under the discriminatory regime, a CP may choose to pay a fixed fee $f_i$ to ISP $i$ to benefit from a priority lane where congestion is lower.[15] The profit of

[14] For example, videos on Youtube come bundled with advertisements that viewers can skip after a few seconds, or view until the end. With a slow connection, it is more likely that these ads will be skipped as the viewer would have to waste quite some time to download and see them in full. In the limit, some applications (e.g., video conferencing) may literally not work with a slow connection, and hence no advertising revenues would be possible at all.

[15] Since each CP receives the same number of visits, having a fixed fee for priority is without loss of generality in our setting, and could be replaced by a variable fee based on data transferred, without affecting our results. If instead CPs generated different amounts of traffic, ISPs could implement non-linear pricing schemes. See Jullien and

CP $h$ under discrimination (D) is then given by

$$\Pi_h^D = \begin{cases} a\lambda x_A^D(1-hw_A^P) - f_A + a\lambda x_B^D(1-hw_B^P) - f_B & \text{priority at both ISPs} \\ a\lambda x_i^D(1-hw_i^P) - f_i + a\lambda x_j^D(1-hw_j^{NP}) & \text{priority only at ISP } i \\ a\lambda x_A^D(1-hw_A^{NP}) + a\lambda x_B^D(1-hw_B^{NP}) & \text{if} \quad \text{non-priority at both ISPs} \\ a\lambda x_i^D(1-hw_i^P) - f_i & \text{priority at ISP } i\text{, no entry at ISP } j \\ a\lambda x_i^D(1-hw_i^{NP}) & \text{non-priority at ISP } i\text{, no entry at ISP } j \\ 0 & \text{otherwise,} \end{cases}$$

where $w_i^P$ and $w_i^{NP}$ denote the congestion at ISP $i$ under priority (P) and non-priority (NP), respectively, with $w_i^P < w_i^N$, as we further detail below.

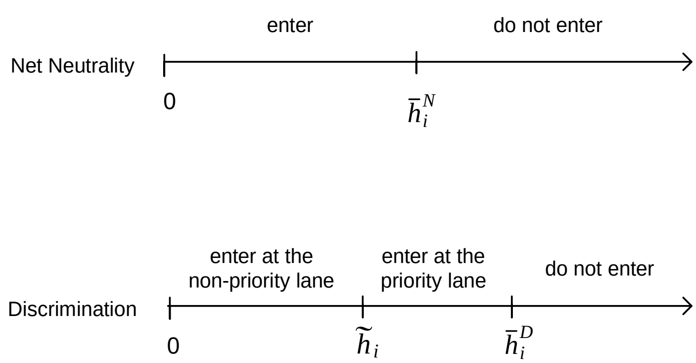


Figure 1: Demand of CPs for ISP $i$

Our model thus intend to capture an elastic supply of CPs. Note that the CPs with a high congestion sensitivity do not enter the market. We denote by $\overline{h}_i^N$ and $\overline{h}_i^D$ the marginal CP which is indifferent between connecting to ISP $i$ and not connecting to it, in the net neutrality and discriminatory regimes, respectively (see an example in Figure 1). Under discrimination, the CPs that enter the market choose either to buy access to the priority lane or to use the non-priority lane for free. We denote by $\widetilde{h}_i$ the CP which is indifferent between the priority lane and the non-priority lane at ISP $i$. In the paper, we refer to the number of CPs that enter the market, $\overline{h}_i^N$ and $\overline{h}_i^D$, as the level of innovation in content and services.[16]

Sand-Zantman (2012) for a monopoly model along these lines.

[16] In the debates around net neutrality, content innovation is often interpreted as the entry of new CPs, which is what we model. Our definition of innovation on the content side ignores some other important dynamic aspects of innovation by content providers, and in particular by incumbent content providers, who could improve the quality of

The connection of an extra end user (keeping the total number of CPs constant) has two opposite effects on CPs' profits. First, there is a demand effect; a larger customer base for ISP $i$ implies larger advertising revenues for the CP. Second, a higher number of consumers for the ISP increases congestion, which decreases the CP's click-through rate and therefore its profit. Overall, the connection of an extra user increases the profit of CP $h$ if and only if[17]

$$h < \frac{\left(\mu_i - \lambda \bar{h}_i x_i\right)^2}{\mu_i},$$

that is, if the CP's congestion sensitivity is not too large.

Two remarks are important about this setting. First, we assume that the ad revenue per click, $a$, is constant. If we endogenize the advertising price (e.g., if $a$ depends on the number of CPs at a given ISP), our results under net neutrality are unchanged. This is because the number of CPs that enter the market does not depend on $a$.[18] Under discrimination, the total number of CPs is also unchanged, while the number of CPs that buy priority increases with the advertising price. To the extent that the advertising price decreases with the number of CPs, this reduces ISPs' investment incentives, compared to our setting with a fixed advertising price. Second, in our model there are no entry costs for the CPs to connect to a platform. It is possible to account for CPs' fixed entry costs. This extension, that we have solved, does not lead to any qualitative change in our main results, and we will comment below only where the analysis is affected.

## 2.2 Internet Service Providers

The two ISPs are located at the extremities of a linear city of length one, with ISP $A$ located at point 0 and ISP $B$ located at point 1.[19] Each ISP $i$ charges a subscription fee $p_i$ to the end users connected to its network, and invests in broadband capacity $\mu_i$. The investment cost $C(\mu_i)$ is increasing and convex in $\mu_i$ (i.e., we have $C' > 0$ and $C'' > 0$).

an existing service and/or introduce additional services.

[17] This condition is the same under both regimes, and we therefore drop the superscripts here for simplicity.

[18] See eq. (9) further below.

[19] Apart from the standard brand differentiation interpretation, horizontal product differentiation may reflect the different types of services offered by the ISPs. For example, one ISP might target "techie" consumers with high computer skills, and offer them flexibility in tuning their Internet connection (e.g., for setting the latency of their broadband connection), while the other ISP might target "non-techie" users with low computer skills, and offer them a broadband service already embedded with the average desirable characteristics of a broadband connection.

Under net neutrality, the profit function of ISP $i$ is

$$\Pi_i^N = p_i^N x_i^N - C(\mu_i^N).$$

Under discrimination, ISP $i$ also charges a fixed fee $f_i$ to the CPs that opt for the priority lane, and makes profit

$$\Pi_i^D = p_i^D x_i^D + (\overline{h}_i^D - \widetilde{h}_i) f_i - C(\mu_i^D),$$

where $\overline{h}_i^D - \widetilde{h}_i$ is the total number of CPs that buy priority at ISP $i$, in the discriminatory regime.

### 2.3 Congestion

Due to capacity constraints, traffic from the content providers to the end users might suffer from congestion. Congestion is measured by the waiting time for end users when they request content from CPs. As it is standard in the literature, we adopt the M/M/1 queuing model to determine the average level of congestion as a function of network capacity and traffic.[20] Under the net neutrality regime, the average level of congestion for ISP $i$ is

$$w_i^N = \frac{1}{\mu_i^N - \overline{h}_i^N \lambda x_i^N}. \tag{1}$$

Note that the level of congestion $w_i^N$ decreases with the level of capacity $\mu_i^N$, while it increases with the number of visits per user $\lambda$, the total number of end users of the ISP $x_i^N$, and the total number of CPs $\overline{h}_i^N$ that connect to ISP $i$. We refer to $\overline{h}_i^N \lambda x_i^N$ as the total traffic of ISP $i$.

Under discrimination, each ISP sorts CPs into two traffic lanes, the priority lane and the non-priority lane. The congestion for the priority lane (P) operated by ISP $i$ is given by

$$w_i^P = \frac{1}{\mu_i^D - \left(\overline{h}_i^D - \widetilde{h}_i\right) \lambda x_i^D}, \tag{2}$$

whereas the congestion for the non-priority lane (NP) is given by

$$w_i^{NP} = \frac{\mu_i^D}{\mu_i^D - \overline{h}_i^D \lambda x_i^D} w_i^P. \tag{3}$$

[20] On the M/M/1 model, see Choi and Kim (2010) and the references cited therein.

Note that the average congestion under discrimination, $w_i^D$, satisfies

$$w_i^D = b_i w_i^P + (1 - b_i) w_i^{NP} = \frac{1}{\mu_i^D - \overline{h}_i^D \lambda x_i^D}, \tag{4}$$

where $b_i = 1 - \widetilde{h}_i / \overline{h}_i^D$ is the share of CPs that buy priority from ISP $i$. If capacities and total traffic volumes are the same under net neutrality and discrimination, the average level of congestion is also the same under both regimes (i.e., we have $w_i^N = w_i^D$), which is a well-known property of the M/M/1 queuing model.

### 2.4 End users

There is a unit mass of users uniformly distributed along the unit interval. Each end user subscribes to only one ISP (i.e., single-homes). Under net neutrality, a user located at $x_j$ on the unit interval and who subscribes to ISP $A$, obtains utility

$$U_j = R + v\overline{h}_A^N + \frac{d}{w_A^N} - p_A^N - tx_j, \tag{5}$$

where $R$ is a fixed utility obtained from Internet access, $v$ represents the consumers' preference for product variety supplied by CPs, $d$ is a parameter which measures the preference for the speed of the connection (as $w_A^N$ is congestion in some time units, $1/w_A^N$ represents the speed of the Internet connection), and finally, $t$ is the standard Hotelling unit transportation cost.

Similarly, under discrimination, the end user located at $x_j$ obtains utility

$$U_j = R + v\overline{h}_A^D + \frac{d}{w_A^D} - p_A^D - tx_j, \tag{6}$$

if she subscribes to ISP $A$. Similar expressions are obtained if the end user subscribes to ISP $B$. We assume that $R$ is sufficiently high so that the market is covered in equilibrium in both regimes.

To see how the connection of an extra CP affects the utility of the end user (keeping the total number of end users at ISP $i$ constant), replace $w_A^N$ from (1) into (5) in the net neutrality regime, and $w_A^D$ from (4) into (6) in the discriminatory regime. In both regimes, the end user's utility can then be rewritten as

$$U_j = R + (v - d\lambda x_i)\,\overline{h}_A + d\mu_i - p_A - tx_j.$$

An extra CP has two effects on the end user's utility: a variety effect and a congestion effect. The net effect is positive (i.e., consumers value the presence of CPs) if the term into brackets is positive, that is, $v - d\lambda x_i > 0$. Although it will not be invoked until we extend the model to account for possible sabotage, we already assume that in the symmetric equilibrium end users value content sufficiently compared to the disutility they suffer from congestion. Therefore, it must be that

$$v > d\lambda/2. \tag{7}$$

In (5) and (6), consumer utility depends only on the average waiting time. With this formulation, we take an "average" approach, which should be viewed as an approximation. As the delay experienced by each CP is the same within a given traffic lane, and consumers care only about total available content and not about specific content or advertising, consumer utility depends only on the average speed of the connection and is independent of the congestion-sensitivity of each specific CP.[21]

# 3 Net Neutrality

In the net neutrality regime, there is a unique lane for Internet transmissions and CPs pay no fee to the ISPs. We study the following two-stage game:[22]

1. The two ISPs choose their capacities, $\mu_A^N$ and $\mu_B^N$, and set the subscription fees to the end users, $p_A^N$ and $p_B^N$.
2. The CPs choose which ISP(s) to connect to (if any), and the end users choose which ISP to subscribe to.

We proceed backwards to solve for the symmetric subgame perfect equilibrium.

## 3.1 Stage 2: Content providers' and end users' decisions

At the second stage, each CP decides whether to multi home, to single home, or to stay out of the market. A CP with congestion sensitivity $h$ connects to ISP $i$ if and only if $\left(1 - hw_i^N\right) \geq 0$, that

[21] See Choi et al. (2013) for an analysis of the differential effect of specific content on consumer utility, within a simplified model with a monopolistic ISP and two types of CPs.

[22] For expositional simplicity, we adopt a timing where capacities and prices are set simultaneously at the first stage of the game. We also solved for the three-stage sequential game, where ISPs first decide on capacity prior to setting their prices, and found similar qualitative results. The proof is available upon request from the authors.

is, if $h \leq \overline{h}_i^N$, where

$$\overline{h}_i^N = \frac{1}{w_i^N}, \text{ for } i = A, B. \tag{8}$$

Replacing for $w_i^N$, as given by (1), into (8) and solving for $\overline{h}_i^N$, we find that the type of the marginal CP is

$$\overline{h}_i^N = \frac{\mu_i^N}{1+\lambda x_i^N}. \tag{9}$$

Given our model assumptions, the number of subscribers affects the number of CPs only through the level of congestion. As a higher number of subscribers implies more congestion on ISP $i$'s network, there is less entry of CPs on that ISP.[23]

Simultaneously, at Stage 2, each consumer chooses whether to subscribe to ISP $A$ or ISP $B$. The indifferent consumer $\widetilde{x}^N$ is given by

$$R + v\overline{h}_A^N + \frac{d}{w_A^N} - p_A^N - t\widetilde{x}^N = R + v\overline{h}_B^N + \frac{d}{w_B^N} - p_B^N - t\left(1 - \widetilde{x}^N\right). \tag{10}$$

Replacing for $\overline{h}_A^N$ and $\overline{h}_B^N$ into (10), we find that the indifferent consumer is defined implicitly from

$$F(\widetilde{x}^N, p_A^N, p_B^N, \mu_A^N, \mu_B^N) \equiv (d+v)\left(\frac{\mu_B^N}{1+\lambda\left(1-\widetilde{x}^N\right)} - \frac{\mu_A^N}{1+\lambda\widetilde{x}^N}\right) - t(1-2\widetilde{x}^N) - (p_B^N - p_A^N) = 0, \tag{11}$$

and, therefore, we have $\widetilde{x}^N = \widetilde{x}^N(p_A^N, p_B^N, \mu_A^N, \mu_B^N)$. The number of end users of ISP $A$ and ISP $B$ are then $x_A^N = \widetilde{x}^N$ and $x_B^N = 1 - \widetilde{x}^N$, respectively.

### 3.2 Stage 1: ISPs' decisions

At the first stage of the game, the two ISPs compete by choosing an investment in capacity, and by setting a subscription fee to the end users. The maximization problem of ISP $i$ can be expressed as follows

$$\max_{p_i^N,\, \mu_i^N} \Pi_i^N = p_i^N x_i^N - C\left(\mu_i^N\right),$$

where $x_i^N = x_i^N\left(p_A^N, p_B^N, \mu_A^N, \mu_B^N\right)$. The two first-order conditions are

$$\frac{\partial \Pi_i^N}{\partial p_i^N} = x_i^N + p_i^N \frac{\partial x_i^N}{\partial p_i^N} = 0, \tag{12}$$

[23] Using (9), we find that an extra end user increases CP $h$'s profit iff $h < \overline{h}_i^N/(1+\lambda x_i^N)$. Since $\overline{h}_i^N/(1+\lambda x_i^N) < \overline{h}_i^N$, the most congestion sensitive CPs would benefit from ISP $i$ serving less end users.

and

$$\frac{\partial \Pi_i^N}{\partial \mu_i^N} = p_i^N \frac{\partial x_i^N}{\partial \mu_i^N} - C'\left(\mu_i^N\right) = 0. \tag{13}$$

We obtain the following result.[24]

**Proposition 1** *Under net neutrality, in the symmetric equilibrium, the capacity level, the subscription fee, the number of CPs and the average level of congestion are given by:*

$$\begin{aligned}
\mu^N &= (C')^{-1}\left(\frac{d+v}{\lambda+2}\right), \\
p^N &= t + \frac{4\lambda\mu^N(d+v)}{(\lambda+2)^2}, \\
\overline{h}^N &= \frac{2\mu^N}{\lambda+2}, \\
w^N &= \frac{\lambda+2}{2\mu^N}.
\end{aligned}$$

**Proof.** Since we do not have an explicit solution for market shares $x_i^N$, we apply the Implicit Function Theorem to equation (11) in order to determine the derivatives $\partial x_i^N/\partial p_i^N$ and $\partial x_i^N/\partial \mu_i^N$, which are then used in the FOCs of Stage 1. Define

$$K^N \equiv \frac{\partial F}{\partial \widetilde{x}^N} = 2t + (d+v)\lambda\left(\frac{\mu_B^N}{\left(1+\lambda x_B^N\right)^2} + \frac{\mu_A^N}{\left(1+\lambda x_A^N\right)^2}\right) > 0.$$

We obtain

$$\frac{\partial x_A^N}{\partial p_A^N} = -\frac{\partial F/\partial p_A^N}{\partial F/\partial \widetilde{x}^N} = -\frac{1}{K^N} < 0 \quad \text{and} \quad \frac{\partial x_A^N}{\partial \mu_A^N} = -\frac{\partial F/\partial \mu_A^N}{\partial F/\partial \widetilde{x}^N} = \frac{d+v}{\left(1+\lambda x_A^N\right)K^N} > 0.$$

Similarly,

$$\frac{\partial x_A^N}{\partial p_B^N} = \frac{1}{K^N} > 0 \quad \text{and} \quad \frac{\partial x_A^N}{\partial \mu_B^N} = -\frac{d+v}{\left(1+\lambda x_B^N\right)K^N} < 0.$$

By replacing for these derivatives in the first-order conditions (12) and (13), and by imposing symmetry, we obtain the symmetric equilibrium levels of investment in capacity and the subscription fees, as reported in the Proposition. We assume that the investment cost function $C(\mu)$ is sufficiently convex so that the candidate equilibrium corresponds to a maximum of the profit function. See Appendix A for the condition on $C''(\cdot)$. ■

[24] With some abuse of notation, in the symmetric equilibrium, we drop the subscripts $i = A, B$ for the two ISPs. For example, we denote by $\mu^N$ the equilibrium level of investment of each ISP. Furthermore, for expositional simplicity, we do not put asterisks to denote the equilibrium values.

In the symmetric equilibrium, the two ISPs share the market equally (i.e., we have $x_A^N = x_B^N = 1/2$). After replacing for the equilibrium values into the profit functions of the ISPs and of the CPs, we obtain the equilibrium profits for each ISP and for each CP,

$$\Pi^N = \frac{t}{2} + \frac{2\lambda\mu^N (d+v)}{(\lambda+2)^2} - C(\mu^N),$$

$$\Pi_h^N = \begin{cases} a\lambda\left(1 - \frac{h(\lambda+2)}{2\mu^N}\right) & \text{if} \quad h \leq \overline{h}^N \\ 0 & \text{if} \quad h > \overline{h}^N \end{cases}.$$

The total profits of CPs are equal to

$$\Sigma\Pi_h^N = \int_0^{\overline{h}^N} \Pi_h^N dh = \frac{a\lambda\mu^N}{\lambda+2}.$$

Finally, we determine consumers' surplus and total welfare in the net neutrality regime.[25] The net utility of end user $j$ located at $x_j \leq 1/2$ is

$$U_j^N = R + \frac{2\mu^N (2-\lambda)(d+v)}{(\lambda+2)^2} - t(1+x_j).$$

By summing up the net surplus of all end users, we obtain the consumers' surplus,

$$CS^N = 2\int_0^{\frac{1}{2}} U_j^N dx_j = R - \frac{5t}{4} + \frac{2\mu^N (2-\lambda)(d+v)}{(\lambda+2)^2}.$$

The total welfare $W^N$ is defined as the sum of ISPs' profits, CPs' profits and consumers' surplus. We find that

$$W^N = 2\Pi^N + \Sigma\Pi_h^N + CS^N = R - \frac{t}{4} + \frac{(a\lambda + 2(d+v))\mu^N}{\lambda+2} - 2C(\mu^N). \tag{14}$$

### 3.3 Equilibrium properties

Under net neutrality, the equilibrium subscription fee is higher than the fee that would prevail in the standard Hotelling setting (i.e., $p = t$). This is due to congestion and to the presence of network

[25] The analysis of consumer surplus in our set-up with competitive ISPs is richer and more relevant compared to the case of a monopolistic ISP, which can fully extract the surplus obtained by consumers from content consumption due to the lack of competition. If we ignore the Hotelling part, consumer surplus would always be zero, with or without neutrality, under a monopolist ISP. This would not be true if either the market of consumers were not fully served, or if consumers were heterogenous with respect to the utility obtained from content.

externalities in our setting. An increase in ISP $i$'s subscription fee decreases directly its demand, but it also leads to a reduction in the congestion on its network, which increases demand. At the same time, less congestion leads to an increase of the number of CPs at the ISP, which in turn affects positively the demand from the end users who benefit from more content. The total effect of a price increase on ISP $i$'s demand is negative, but it is less negative than in a one-sided market, which induces ISPs to set a higher price than in a standard Hotelling model.

The equilibrium converges to a standard Hotelling game in the limiting cases where either there is no traffic ($\lambda \to 0$), or investment in capacity goes to zero ($\mu^N \to 0$). In particular, when $\mu^N \to 0$, the equilibrium subscription fee and the ISPs' equilibrium profits converge to those of the Hotelling model (i.e., $p^N \to t$ and $\Pi^N \to t/2$), whereas the equilibrium congestion goes to infinity (i.e., $w^N \to \infty$) and the number of CPs goes to zero (i.e., $\overline{h}^N \to 0$). However, this degenerate case never arises in equilibrium as the capacity is always positive ($\mu^N > 0$), otherwise there would be no market for Internet access.

Finally, we provide some intuitive comparative statics. We find that when the number of visits per user $\lambda$ increases, the investments in capacity and the number of active CPs decrease, whereas congestion increases. The effect of an increase in $\lambda$ on the subscription fee and the ISP's profit is generally ambiguous and depends on the value of $\lambda$. When $\lambda$ is low enough, congestion is not so important, and hence, an increase in $\lambda$ increases the subscription fees and the ISPs' profits because of the competition-dampening effect from the network externality that we described above. By contrast, when $\lambda$ is high enough, congestion becomes substantial: the prevailing effect comes from a reduction of content, so that prices and ISPs' profits decrease with further increases in $\lambda$.

When the preference for speed $d$ and/or the preference for product variety $v$ increase, ISPs can extract more rents from consumers, which leads to higher subscription fees, and therefore higher investments in capacity, higher entry by the CPs, and lower congestion. The CPs' profits and the total welfare increase too. Finally, the per-click advertising revenue $a$ only enters the CPs' profits, and hence, both the CPs' profits and the total welfare are positively affected by an increase in $a$.

# 4 Discrimination

In the discriminatory regime, each ISP offers a priority lane and a non-priority lane to CPs. The CPs that opt for priority at ISP $i$ pay a fixed fee $f_i$, whereas the non-priority lane is offered for free. We modify our two-stage game accordingly:

1. The two ISPs choose their capacities, $\mu_A^D$ and $\mu_B^D$, set their subscription fees to the end users, $p_A^D$ and $p_B^D$, as well as the fees for their priority lanes, $f_A$ and $f_B$.

2. The CPs choose which ISP(s) to connect to (if any) and whether to pay for priority, and the end users choose which ISP to subscribe to.

### 4.1 Stage 2: Content providers' and end users' decisions

At the second stage, each CP decides whether to multi-home, to single-home or to stay out of the market and, if it enters the market, whether to pay for priority. The CPs which are the most congestion-sensitive opt for the priority lane. A CP of type $h$ connects to the priority lane at ISP $i$ if $h \leq \overline{h}_i^D$, where $\overline{h}_i^D$ solves

$$a\lambda x_i^D(1 - \overline{h}_i^D w_i^P) - f_i = 0. \tag{15}$$

Furthermore, the CP of type $\widetilde{h}_i$ which is indifferent between the priority lane and the non-priority lane at ISP $i$ is defined by

$$a\lambda x_i^D(1 - \widetilde{h}_i w_i^P) - f_i = a\lambda x_i^D(1 - \widetilde{h}_i w_i^{NP}). \tag{16}$$

From (15) and (16), the total number of CPs that pay for priority at ISP $i$ is $\max\{\overline{h}_i^D - \widetilde{h}_i, 0\}$.

Equation (16) implies that

$$f_i = a\lambda x_i^D \widetilde{h}_i \left(w_i^{NP} - w_i^P\right),$$

and replacing for this expression into (15), we obtain

$$1 - \left(\left(\overline{h}_i^D - \widetilde{h}_i\right) w_i^P + \widetilde{h}_i w_i^{NP}\right) = 0.$$

By dividing the latter expression by $\overline{h}_i^D$ and using $w_i^D$ which is defined in (4), we find that the type of the marginal CP that enters at ISP $i$ is $\overline{h}_i^D = 1/w_i^D$, which can be rearranged as

$$\overline{h}_i^D = \frac{\mu_i^D}{1 + \lambda x_i^D}. \tag{17}$$

The type of the marginal CP $\overline{h}_i^D$ is independent of the priority fee and takes an expression similar to the total number of CPs at ISP $i$ in the net neutrality regime (which is given by (9)). Note that two conflicting effects are at play here: a demand effect and a congestion effect. On the one hand, a higher number of subscribers increases CPs' profits, and hence, entry (demand effect). On the other hand, it increases congestion, which reduces entry (congestion effect). We find that the congestion effect always dominates the demand effect, which is why the number of CPs at ISP $i$ decreases with the number of subscribers on this platform. In addition, we have

$$\widetilde{h}_i = \frac{\mu_i^D f_i}{\lambda x_i^D \left(1 + \lambda x_i^D\right) \left(a\lambda x_i^D - f_i\right)} = \frac{f_i}{\lambda x_i^D \left(a\lambda x_i^D - f_i\right)} \overline{h}_i^D. \tag{18}$$

Simultaneously, at Stage 2, each consumer chooses whether to subscribe to ISP $A$ or ISP $B$. The indifferent consumer $\widetilde{x}^D$ is given by

$$R + v\overline{h}_A^D + \frac{d}{w_A^D} - p_A^D - t\widetilde{x}^D = R + v\overline{h}_B^D + \frac{d}{w_B^D} - p_B^D - t\left(1 - \widetilde{x}^D\right). \tag{19}$$

By replacing for $\overline{h}_A^D$ and $\overline{h}_B^D$ into (19), the indifferent consumer satisfies

$$(d + v)\left(\frac{\mu_B^D}{1 + \lambda\left(1 - \widetilde{x}^D\right)} - \frac{\mu_A^D}{1 + \lambda\widetilde{x}^D}\right) - t\left(1 - 2\widetilde{x}^D\right) - \left(p_B^D - p_A^D\right) = 0, \tag{20}$$

and, therefore, we have $\widetilde{x}^D = \widetilde{x}^D(p_A^D, p_B^D, \mu_A^D, \mu_B^D)$. The number of users of ISP $A$ and ISP $B$ are then $x_A^D = \widetilde{x}^D$ and $x_B^D = 1 - \widetilde{x}^D$. Note that equation (20) for the discriminatory regime is similar to equation (11) for the net neutrality regime, and that $\widetilde{x}^D$ is independent of the priority fees.

## 4.2 Stage 1: ISPs' decisions

At the first stage, the two ISPs choose simultaneously their capacities, subscription fees and priority fees. The maximization problem of ISP $i$ can be expressed as follows

$$\max_{p_i^D,\, \mu_i^D,\, f_i} \Pi_i^D = p_i^D x_i^D + \left(\overline{h}_i^D - \widetilde{h}_i\right) f_i - C\left(\mu_i^D\right),$$

where $x_i^D = x_i^D(p_A^D, p_B^D, \mu_A^D, \mu_B^D)$. The corresponding first-order conditions are

$$\frac{\partial \Pi_i^D}{\partial p_i^D} = x_i^D + \left(p_i^D + \frac{\partial((\overline{h}_i^D - \widetilde{h}_i) f_i)}{\partial x_i^D}\right) \frac{\partial x_i^D}{\partial p_i^D} = 0, \tag{21}$$

$$\frac{\partial \Pi_i^D}{\partial \mu_i^D} = \left(p_i^D + \frac{\partial((\overline{h}_i^D - \widetilde{h}_i) f_i)}{\partial x_i^D}\right) \frac{\partial x_i^D}{\partial \mu_i^D} - C'\left(\mu_i^D\right) + \frac{\partial((\overline{h}_i^D - \widetilde{h}_i) f_i)}{\partial \mu_i^D} = 0, \tag{22}$$

$$\frac{\partial \Pi_i^D}{\partial f_i} = \frac{\partial((\overline{h}_i^D - \widetilde{h}_i) f_i)}{\partial f_i} = 0. \tag{23}$$

We obtain the following result.

**Proposition 2** *Under discrimination, in the symmetric equilibrium, the capacity level, the priority fee, the subscription fee, the number of CPs and the levels of congestion are given by:*

$$
\begin{aligned}
\mu^D &= (C')^{-1}\left(\frac{d+v}{\lambda+2}+\frac{a\left(\sqrt{2}\sqrt{\lambda+2}-2\right)^2}{2(\lambda+2)}\right),\\
f &= \frac{a\lambda}{2}\left(1-\frac{\sqrt{2}}{\sqrt{\lambda+2}}\right),\\
p^D &= t+\frac{4\lambda\mu^D(d+v)}{(\lambda+2)^2}-\frac{2\lambda a\mu^D\left(\sqrt{2}\sqrt{\lambda+2}-2\right)}{(\lambda+2)^2},\\
\overline{h}^D &= \frac{2\mu^D}{\lambda+2},\ \widetilde{h}=\left(\frac{\sqrt{2}\sqrt{\lambda+2}-2}{\lambda}\right)\overline{h}^D,\\
w^P &= \frac{\sqrt{2}\sqrt{\lambda+2}}{2\mu^D},\ w^{NP}=\frac{\sqrt{2}(\lambda+2)^{\frac{3}{2}}}{4\mu^D},\ w^D=\frac{\lambda+2}{2\mu^D}.
\end{aligned}
$$

**Proof.** We proceed as in the net neutrality regime, by applying the Implicit Function Theorem to (20) in order to determine the derivatives $\partial x_i^D/\partial p_i^D$ and $\partial x_i^D/\partial \mu_i^D$. We find that

$$
\begin{aligned}
\frac{\partial x_A^D}{\partial p_A^D} &= -\frac{1}{K^D}<0,\ \frac{\partial x_A^D}{\partial p_B^D}=\frac{1}{K^D}>0,\ \frac{\partial x_A^D}{\partial \mu_A^D}=\frac{d+v}{\left(1+\lambda x_A^D\right)K^D}>0,\ \frac{\partial x_A^D}{\partial \mu_B^D}=-\frac{d+v}{\left(1+\lambda\left(1-x_A^D\right)\right)K^D}<0,\\
\frac{\partial x_A^D}{\partial f_A} &= \frac{\partial x_A^D}{\partial f_B}=0,\text{ where } K^D\equiv(d+v)\left(\frac{\lambda\mu_B^D}{\left(1+\lambda\left(1-x_A^D\right)\right)^2}+\frac{\lambda\mu_A^D}{\left(1+\lambda x_A^D\right)^2}\right)+2t>0.
\end{aligned}
$$

By replacing for these derivatives in the three first-order conditions, and by imposing symmetry, we obtain the symmetric equilibrium levels of investment in capacity, the subscription fees and the priority fees, as reported in the Proposition. Provided that the investment cost function is sufficiently convex, the candidate equilibrium corresponds to a maximum of the profit function. See Appendix A for details. ■

In the symmetric equilibrium, the market is equally shared between the two ISPs (i.e., we have $x_A^D=x_B^D=1/2$). The equilibrium profits for an ISP and a CP are

$$
\Pi^D=\frac{t}{2}+\frac{2\lambda\mu^D(d+v)}{(\lambda+2)^2}+\frac{a\mu^D\left(\left(\lambda+2-\sqrt{2}\sqrt{\lambda+2}\right)^2-\lambda\left(\sqrt{2}\sqrt{\lambda+2}-2\right)\right)}{(\lambda+2)^2}-C(\mu^D),
$$

and

$$\Pi_h^D = \begin{cases} \Pi_h^{NP} = a\lambda\left(1 - h\frac{\sqrt{2}(\lambda+2)^{\frac{3}{2}}}{4\mu^D}\right) & \text{if} \quad h \leq \widetilde{h} \\ \Pi_h^P = \frac{\sqrt{2}a\lambda}{\sqrt{\lambda+2}}\left(1 - h\frac{\lambda+2}{2\mu^D}\right) & \text{if} \quad \widetilde{h} < h < \overline{h}^D \\ 0 & \text{if} \quad h \geq \overline{h}^D \end{cases},$$

respectively. The total profits of the CPs are

$$\Sigma\Pi_h^D = \int_0^{\widetilde{h}^D} \Pi_h^{NP} dh + \int_{\widetilde{h}^D}^{\overline{h}^D} \Pi_h^P dh = \frac{2a\mu^D\left(\sqrt{2}\sqrt{\lambda+2} - 2\right)}{\lambda+2}.$$

Finally, the utility of end user $j$ located at $x_j \leq 1/2$ is

$$U_j^D = R + \frac{2\mu^D\left((d+v)(2-\lambda) + a\lambda\left(\sqrt{2}\sqrt{\lambda+2} - 2\right)\right)}{(\lambda+2)^2} - t(1+x_j),$$

which is used to determine consumers' surplus and total welfare,

$$CS^D = 2\int_0^{\frac{1}{2}} U_j^D dx_j = R - \frac{5t}{4} + \frac{2\mu^D\left((d+v)(2-\lambda) + a\lambda\left(\sqrt{2}\sqrt{\lambda+2} - 2\right)\right)}{(\lambda+2)^2},$$

and

$$\begin{aligned} W^D &= 2\Pi^D + \Sigma\Pi_h^D + CS^D \\ &= R - \frac{t}{4} + \frac{2\left((d+v) + a\left(\lambda + 2 - \sqrt{2}\sqrt{\lambda+2}\right)\right)\mu^D}{\lambda+2} - 2C\left(\mu^D\right). \end{aligned} \tag{24}$$

### 4.3 Equilibrium properties

The comparison between the equilibrium subscription fee under discrimination and the fee in the standard Hotelling model (i.e., $t$) depends on the values of the parameters. When $a$ is low enough (i.e., lower than $2(d+v)/\left(\sqrt{2}\sqrt{\lambda+2}-2\right)$), the equilibrium fee for end users in the discriminatory regime is higher than the Hotelling equilibrium price (i.e., $p_i^D > t$). The intuition is as follows. To begin with, if there were no fee for the priority lane, we already know from the analysis under net neutrality that an increase in the subscription fee $p_i^D$ of ISP $i$ would decrease its own demand, but this effect is less severe than in the Hotelling model. Besides, under discrimination, there is an additional effect: revenues from the priority lane are partly passed on to end users, which tend to push the price down. Since more revenues are made from priority fees when CPs earn high advertising revenues, that is, when $a$ is high enough, the second effect can prevail over the former.

Finally, we present some comparative statics. We find that when the number of visits per user $\lambda$ increases, the priority fee increases, since the priority lane is valued more as more advertising revenues are made. However, the effect of an increase in $\lambda$ on all the other equilibrium values is ambiguous and depends on the effect of $\lambda$ on investment in capacity (i.e., on $\partial \mu_i^D / \partial \lambda$). This latter effect is not always negative, as it is the case under net neutrality, since in the discriminatory regime, the ISPs may now have an incentive to increase their capacity when $\lambda$ becomes higher to obtain higher revenues from the CPs that are willing to pay for priority.

An increase in the preference for speed $d$ and an increase in the preference for variety $v$ both affect positively investment in capacity, the total number of CPs, CPs' profits and total welfare. Moreover, congestion decreases with $d$ and $v$. In contrast to the net neutrality regime, an increase in the per-click advertising revenue $a$ affects positively capacity investment, the number of CPs and the pricing decisions of the firms. This is because, under discrimination, ISPs can extract part of the CPs' profits through the priority fees. When $a$ increases, the ISPs charge higher priority fees and increase their investment in broadband capacity. Congestion is reduced and entry of CPs is fostered. Therefore, total welfare increases with $a$.

The comparison between the net neutrality regime and the discriminatory regime is examined in more detail in the next section.

# 5 Net Neutrality vs. Discrimination

We now turn to the main question of this paper. We compare the two alternative regimes, net neutrality and discrimination, to investigate the economic effects of a departure from net neutrality. First, we compare capacity investments and innovation in services in the two regimes. Second, we compare congestion, subscription fees and profits. Finally, we compare end users' utility and total welfare.

## 5.1 Effect on investment and innovation

In this subsection, we compare the investment in capacity and the number of CPs that enter the market, that is, innovation in Internet services, under the net neutrality and the discriminatory regimes. Using Proposition 1 and Proposition 2, we have the following result.

**Proposition 3** *Investment in broadband capacity and innovation in services are higher under the discriminatory regime than under the net neutrality regime, that is,* $\mu^D > \mu^N$ *and* $\overline{h}^D > \overline{h}^N$.

**Proof.** Since $C'' > 0$, $(C')^{-1}$ is an increasing function, and therefore, from Propositions 1 and 2, we have $\mu^D > \mu^N$, as $\lambda + 4 \geq 2\sqrt{2}\sqrt{\lambda+2}$ for all $\lambda \geq 0$. This, in turn, implies that $\overline{h}^D > \overline{h}^N$. ■

An increase in ISP $i$'s capacity increases its demand and its investment cost under both regimes, but in the discriminatory regime it also affects positively the revenues that ISP $i$ can extract from the CPs that opt for priority. Therefore, under discrimination, ISPs have larger investment incentives.

Under net neutrality, ISP $i$'s incentive to invest in capacity is given by the change in its profits due to a marginal increase of the capacity level, that is,

$$\frac{\partial \Pi_i^N}{\partial \mu_i^N} = p_i^N \frac{\partial x_i^N}{\partial \mu_i^N} - C'\left(\mu_i^N\right), \tag{25}$$

where $\partial x_i^N / \partial \mu_i^N > 0$ and $C' > 0$. In the discriminatory regime, we have

$$\frac{\partial \Pi_i^D}{\partial \mu_i^D} = p_i^D \frac{\partial x_i^D}{\partial \mu_i^D} - C'\left(\mu_i^D\right) + \left( \frac{\partial\left(\overline{h}_i^D - \widetilde{h}_i\right)}{\partial \mu_i^D} + \frac{\partial\left(\overline{h}_i^D - \widetilde{h}_i\right)}{\partial x_i^D} \frac{\partial x_i^D}{\partial \mu_i^D} \right) f_i, \tag{26}$$

where $\partial x_i^D / \partial \mu_i^D > 0$. For given levels of subscription fees and capacities, the terms $p_i^N(\partial x_i^N/\partial \mu_i^N) - C'\left(\mu_i^N\right)$ are equal to the terms $p_i^D(\partial x_i^D/\partial \mu_i^D) - C'\left(\mu_i^D\right)$. We further obtain that $\partial(\overline{h}_i^D - \widetilde{h}_i)/\partial \mu_i^D > 0$, $\partial \overline{h}_i^D / \partial x_i^D < 0$ and $\partial \widetilde{h}_i / \partial x_i^D < 0$, but the sign of $\partial(\overline{h}_i^D - \widetilde{h}_i)/\partial x_i^D$ is ambiguous. Nevertheless, we have proved that the parenthesis in (26) is positive, which implies that the marginal revenue of an increase in the capacity level is higher under the discriminatory regime.[26]

Since the ISPs invest more in capacity under discrimination, the total number of CPs that are active under discrimination is also higher than under net neutrality. Innovation in services is increased when there is a fast lane, as congestion-sensitive CPs that could not enter under net neutrality now enter by buying access to the priority lane.

[26] One alternative view of net neutrality would be to state that ISPs cannot prioritize traffic or differentiate the quality of service to CPs, while being able to charge CPs to terminate their traffic. We solved our model in this alternative scenario, where there is a single lane (as in our net neutrality regime), but ISPs can charge (uniform) positive termination fees to CPs. We found that capacity investments under this alternative regime are always (weakly) higher than under our net neutrality regime. Therefore, if one compares our net neutrality regime (a zero price to everybody) with this alternative regime with the same uniform price charged to everybody, our main results still go through. Having an extra "instrument" (a positive termination price) is used by the ISPs to invest more in capacity. However, if the comparison is done between our discriminatory regime and the alternative uniform regime, capacity investments under the alternative regime can be either lower or higher. This is because the comparison is between a scenario with a uniform price to all CPs and a single lane (under the alternative net neutrality regime) and one with a free slow lane and a paid-for fast lane (under the discriminatory regime). In both cases, ISPs have only one price they can charge, though under discrimination the ISPs can offer two different lanes. The computations for the alternative uniform regime are available upon request from the authors.

Note that as the total number of CPs under discrimination is always higher than the total number of CPs under net neutrality, $\overline{h}^D$ is located to right of $\overline{h}^N$. It is also interesting to compare the number of CPs that enter the market under net neutrality, $\overline{h}^N$, to the CP of type $\widetilde{h}$ that is indifferent between buying priority and using the non-priority lane in the discriminatory regime (see Figure 1). We obtain that $\widetilde{h} > \overline{h}^N$ if and only if

$$\frac{\mu^D}{\mu^N} > \frac{\lambda}{\sqrt{2}\sqrt{\lambda+2}-2}. \tag{27}$$

where $\mu^N$ and $\mu^D$ are the equilibrium capacity levels defined in Proposition 1 and 2, respectively. Since $\mu^D$ increases in $a$ while $\mu^N$ is independent of it, for a general functional form $C(\cdot)$ satisfying our assumptions, the ratio $\mu^D/\mu^N$ increases with $a$. Therefore, a sufficient condition for condition (27) to hold is that the per-click advertising revenue is high enough. In this case, innovation in services under discrimination is so important that all CPs that buy priority were not active under net neutrality. A simple revealed preference argument implies then that *all* CPs are better-off in the discriminatory regime, independently from the lane they end up choosing.

When the investment cost is quadratic, that is, $C(\mu) = \mu^2/2$, condition (27) simplifies to

$$\frac{a}{d+v} > \frac{\sqrt{2}\sqrt{\lambda+2}}{\left(\sqrt{2}\sqrt{\lambda+2}-2\right)^2}.$$

Since the right-hand side decreases with $\lambda$, we have $\widetilde{h} > \overline{h}^N$ if $a/(d+v)$ and/or $\lambda$ are sufficiently high.

## 5.2 Effect on network congestion

Discrimination increases capacity compared to net neutrality, but also total traffic grows as more CPs enter the market. In principle, therefore, the effect on average congestion could be ambiguous. However, as the equilibrium number of CPs under both regimes is $\overline{h} = 2\mu/(\lambda+2)$, from the definition of average congestion it then follows that $1/w = \mu - \overline{h}\lambda/2 = 2\mu/(\lambda+2)$. Since $\mu^D > \mu^N$, it is clear that the capacity expansion effect under discrimination prevails. We can thus state immediately the following Proposition.

**Proposition 4** *The average level of congestion is lower under discrimination than under net neutrality, that is,* $w^D < w^N$.

Even if the congestion on the non-priority lane is higher than the congestion in the net neutrality regime, the decrease of congestion on the priority lane is high enough to overcome the increase of congestion on the non-priority lane. In other words, the ISPs manage Internet traffic more efficiently when they can offer multiple lanes, and the more congestion-sensitive CPs can opt and pay for priority.

Since from the properties of the M/M/1 queuing system, we have $w^P < w^D < w^{NP}$, it follows immediately that the level of congestion under net neutrality, $w^N$, is always higher than the level of congestion on the priority lane, $w^P$. After comparing the equilibrium level of congestion on the non-priority lane, $w^{NP}$, to $w^N$, we find that for sufficiently high values of the ratio $\mu^D/\mu^N$ (i.e., higher than $\sqrt{(\lambda+2)/2}$), congestion on the non-priority lane is also lower. Note that $\sqrt{(\lambda+2)/2} < \lambda/(\sqrt{2}\sqrt{\lambda+2}-2)$, hence (27) is sufficient for this to be true.[27] Sufficient conditions are then again that $a$ is sufficiently high in the general case, and that $a/\left(d+v\right)$ and/or $\lambda$ are relatively high with a quadratic cost function.

### 5.3 Effect on subscription fees and profits

We now compare the equilibrium subscription fees in the two regimes. Under net neutrality, the ISPs obtain profits only from the end users, whereas under discrimination, the ISPs can extract additional revenues by charging for access to the priority lane. As we already discussed, the pricing incentives between the two regimes differ, as

$$\frac{\partial \Pi_i^N}{\partial p_i^N} = x_i^N + p_i^N \frac{\partial x_i^N}{\partial p_i^N},$$

whereas,

$$\frac{\partial \Pi_i^D}{\partial p_i^D} = x_i^D + p_i^D \frac{\partial x_i^D}{\partial p_i^D} + \frac{\partial\left(\overline{h}_i^D - \widetilde{h}_i\right)}{\partial x_i^D}\frac{\partial x_i^D}{\partial p_i^D} f_i.$$

An increase in the subscription fee by ISP $i$, decreases the demand that it obtains in both regimes, but it also affects indirectly the total number of CPs that opt for priority in the discriminatory regime (via the term $\partial(\overline{h}_i^D - \widetilde{h}_i)/\partial x_i^D \times \partial x_i^D/\partial p_i^D$). Whenever this latter effect is positive, the incentives of the ISPs to increase the subscription fees under discrimination are higher compared to the net neutrality regime. In this case, competition in subscription fees between the ISPs is relaxed and the end users pay higher prices under discrimination than under net neutrality.

[27] In other words, $\widetilde{h} > \overline{h}^N$ implies that $w^{NP} < w^N$.

Formally, we find that $p^D > p^N$ if and only if

$$\frac{d+v}{a}\left(1-\frac{1}{\mu^D/\mu^N}\right) > \frac{\sqrt{2}\sqrt{\lambda+2}-2}{2}. \tag{28}$$

If this condition holds, subscription fees are higher under discrimination than under net neutrality. The capacity expansion due to the introduction of multiple lanes is relatively high, which leads to a high number of active CPs and thus increases end users' utility. The ISPs extract this increased utility via higher subscription fees. When $a$ goes to zero, the first term in the LHS of (28) goes to infinity, while the second term goes to zero as the ratio $\mu^D/\mu^N$ goes to 1. However, computing the Taylor series of the LHS at $a = 0$, we find that (28) holds at $a = 0$ if

$$\frac{d+v}{\mu^N C''(\mu^N)} > \frac{(\lambda+2)\left(2+\sqrt{2}\sqrt{\lambda+2}\right)}{2\lambda}.$$

If this condition holds, then (28) is satisfied, in the general case, when $a$ is low enough.

Under the quadratic investment cost function example, condition (28) simplifies to

$$\frac{a}{d+v} < \frac{2\left(\sqrt{2}\sqrt{\lambda+2}-2\right)-2}{\left(\sqrt{2}\sqrt{\lambda+2}-2\right)^2}.$$

This latter condition holds if end users value highly the variety and the speed of the network (i.e., $d + v$ is high), if the per-click advertising revenue $a$ is low enough,[28] and/or the number of visits per user $\lambda$ is high enough.[29]

Now, we turn to the profits of the ISPs and of the CPs. The comparison of the ISPs' profits between the two regimes yields that $\Pi^D > \Pi^N$ if and only if

$$\left(p^D - p^N\right)/2 - \left(C\left(\mu^D\right) - C(\mu^N)\right) + \left(\overline{h}_i^D - \widetilde{h}_i\right) f_i > 0.$$

ISP $i$ obtains additional revenues under discrimination through the priority fees, but the comparison depends also on the difference in the subscription fees and on the difference in the costs of capacity. When competition is relaxed under discrimination, the term $\left(p^D - p^N\right)/2$ is positive, and hence, profits tend to be higher under discrimination. Moreover, the difference in the investment

[28] When $a$ increases, it is more likely that the ISPs are willing to reduce their prices under discrimination to obtain a higher demand (the countervailing effect via the increase in congestion is less severe).

[29] The expression $\left(2\left(\sqrt{2}\sqrt{\lambda+2}-2\right)-2\right)/\left(\sqrt{2}\sqrt{\lambda+2}-2\right)^2$ is negative for $\lambda < 2.5$, hence in this range we always have $p^D < p^N$. For higher values of $\lambda$, the expression is non-monotonic: it first increases, reaches a maximum of 1/2 at $\lambda = 6$, and then decreases with $\lambda$.

costs is always positive (since $\mu^D > \mu^N$ and $C' > 0$), which tends to decrease the profits under discrimination compared to the net neutrality regime. The final comparison depends on the levels of capacity and on the parameter values.[30] We can conclude that

**Proposition 5** *A departure from the net neutrality regime is not always beneficial for the ISPs.*

In the case of a monopolistic ISP, a departure from the net neutrality regime is always profitable, since it can extract part of the CPs' profits through the priority fee and still serve the whole mass of end users. However, when there is competition at the ISP level, it is ambiguous whether discrimination will improve or deteriorate the ISPs' profits. Competition for the end users under discrimination might be more severe as the demand of each ISP affects indirectly the profits obtained through the priority lane.

Concerning the CPs, we compare their total profits under the two regimes. We find that $\Sigma\Pi_h^D > \Sigma\Pi_h^N$ if and only if

$$\frac{\mu^D}{\mu^N} > \frac{\lambda}{2\left(\sqrt{2}\sqrt{\lambda+2}-2\right)}. \tag{29}$$

For high values of the ratio $\mu^D/\mu^N$, the total profits of the CPs under discrimination are higher, and hence, on average CPs are better off. Note that this condition is less stringent than (27) that described instead a Pareto improvement for CPs.[31] In the quadratic investment cost example, we have $\Sigma\Pi_h^D > \Sigma\Pi_h^N$ if the ratio $a/(d+v)$ and/or $\lambda$ are sufficiently high.

Since CPs in the non-priority lane only care about their congestion, $w^{NP}$, we obtain from $w^{NP} < w^N$ that they all obtain higher profits compared to the net neutrality regime for high values of $\mu^D/\mu^N$.[32] On the other hand, the CPs in the priority lane benefit from the reduction in the congestion compared to the net neutral regime ($w^P < w^N$), but pay priority fees. Since this fee is fixed and each CP in the priority lane faces the same level of congestion, we conclude that the highly congestion-sensitive CPs benefit more from priority compared to the less congestion-sensitive CPs. Still, the CPs in the priority lane earn higher profits compared to the net neutral regime for high values of the ratio $\mu^D/\mu^N$, but this threshold is lower for the more congestion-sensitive CPs.

[30] We discuss the quadratic case below in Figure 2.

[31] The right-hand side of (29) is just half the right-hand side of (27).

[32] The condition for $\Pi_h^{NP} > \Pi_h^N > 0$ is again $\mu^D/\mu^N > \sqrt{(\lambda+2)/2}$.

### 5.4 Effect on end users' utility and total welfare

Now, we proceed with the comparison of the end users' utility and the total welfare in the discriminatory and net neutrality regimes. For the consumers' surplus, we have $CS^D > CS^N$ if

$$\frac{a}{d+v}\frac{\mu^D/\mu^N}{(\mu^D/\mu^N)-1} > \frac{\lambda-2}{\lambda\left(\sqrt{2}\sqrt{\lambda+2}-2\right)}. \tag{30}$$

On the one hand, discrimination affects positively the end users' utility, since it increases innovation in services and reduces the average level of congestion in the network. On the other hand, discrimination may increase the subscription fees that the end users have to pay for Internet access. For sure, (30) is satisfied in the general case when $a$ is high enough, as the first term on the LHS increases linearly with $a$, while the second term decreases with $a$ but is bounded by 1 from below. It is also always true for low enough values of $\lambda$. We also note from (28) that when $p^D < p^N$, then $CS^D > CS^N$ always holds.[33] Therefore, when discrimination leads to more competitive pressure at the ISP level with respect to the subscription fees, the end users are better off and the ISPs tend to be worse off. When $\mu^D/\mu^N$ increases, it is less likely that the end users will pay lower subscription fees under discrimination, but it is more likely that the profits of the ISPs will be higher.[34]

In the quadratic investment cost example, condition (30) becomes

$$\frac{a}{d+v} > \frac{(\lambda-2)\left(\sqrt{2}\sqrt{\lambda+2}-2\right)-2\lambda}{\lambda\left(\sqrt{2}\sqrt{\lambda+2}-2\right)^2}.$$

Since the right-hand side decreases down to zero when $\lambda$ gets large, this condition holds if $a/(d+v)$ and/or $\lambda$ are sufficiently high.[35]

We finally turn to the question of which regime is to be preferred according to a welfare criterion.

**Proposition 6** *Total welfare under discrimination is higher than total welfare under net neutrality, that is, $W^D > W^N$.*

**Proof.** Let

$$\Delta(\mu) = \frac{2\left(a\left(\lambda+2-\sqrt{2}\sqrt{\lambda+2}\right)+d+v\right)\mu}{\lambda+2} - \frac{(a\lambda+2(d+v))\mu^N}{\lambda+2} - 2\left(C(\mu)-C(\mu^N)\right).$$

[33] From (28) we obtain that $p^D < p^N$ if and only if $\frac{a}{d+v}\frac{\mu^D/\mu^N}{\left(\mu^D/\mu^N\right)-1} > \frac{2}{\sqrt{2}\sqrt{\lambda+2}-2} > \frac{\lambda-2}{\lambda\left(\sqrt{2}\sqrt{\lambda+2}-2\right)}$.

[34] Such an analysis is irrelevant in the monopolistic ISP set-up, since the monopolistic ISP charges the monopoly price in both regimes to extract the entire consumers' surplus (except for the Hotelling part). Thus, consumers are indifferent between the two regimes under monopoly.

[35] The condition additionally holds if the right-hand side is negative, which happens for $\lambda < 5+\sqrt{13} \approx 8.61$.

The difference between the total welfare under discrimination and net neutrality is $W^D - W^N = \Delta\left(\mu^D\right)$. We show that $\Delta\left(\mu^D\right) > 0$. To see that, first note that $\Delta\left(\mu^N\right) > 0$ as $2(a(\lambda + 2 - \sqrt{2}\sqrt{\lambda+2}) + d + v) > (a\lambda + 2(d+v)) > 0$. Second, we have $\mu^D > \mu^N$, and $\Delta'(\mu) > 0$ for $\mu \in \left[\mu^N, \mu^D\right]$ since the level of capacity that maximizes $\Delta(\mu)$ is higher than the equilibrium level of capacity $\mu^D$ and $\Delta(\cdot)$ is concave. Therefore, $\Delta\left(\mu^D\right) > \Delta\left(\mu^N\right) > 0$. ■

Total welfare is the sum of firms' profits and end users' utility. While the impact of discrimination on each agent is generally ambiguous, the overall effect on the aggregate economy is always positive: prioritization leads to more efficient allocations.

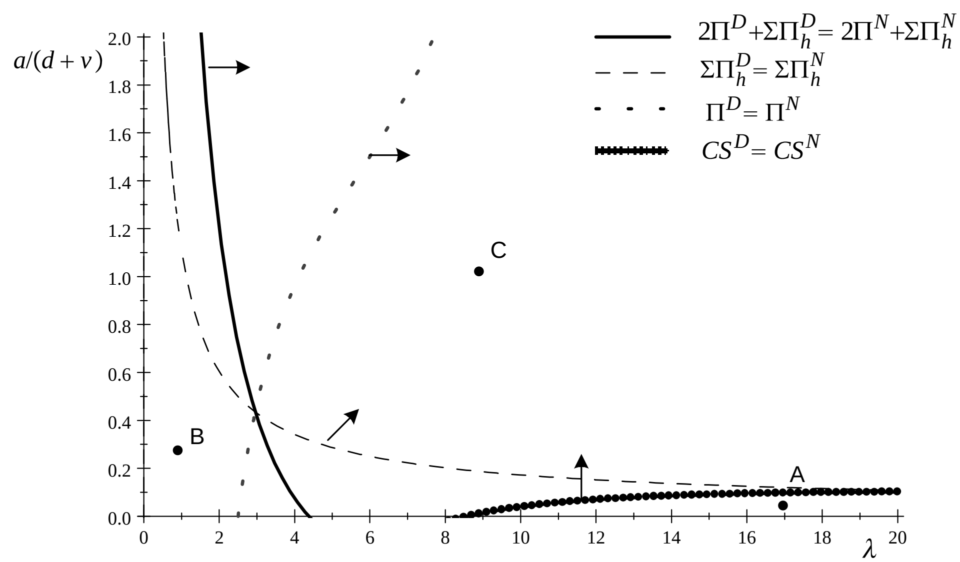


Figure 2: Discrimination vs. Neutrality when $C(\mu) = \mu^2/2$

Figure 2 shows the comparison between the ISPs' profits, the CPs' profits, the total industry profits and the end users' utility in the discriminatory and the net neutrality regimes, when the investment cost function takes the quadratic form $C(\mu) = \mu^2/2$. The horizontal axis represents the number of visits per user $\lambda$, while the vertical axis represents the ratio $a/(d+v)$. The lines represent the locus of points where there is no difference between the regimes. The arrows indicate in which direction, in the $(\lambda, a/(d+v))$ space, the profits or the end users' utility are higher under discrimination than under net neutrality.

Three cases emerge. First, when there is a switch from net neutrality to the discriminatory regime, the market profits may increase more than the reduction in the end users' utility. This arises in the bottom-right part of the Figure (e.g., point A). Second, the end users' utility may increase more than the reduction in the market profits. This arises in the left part of the Figure (e.g., point B). Third, both market profits and the end users' utility may increase under discrimination. This is the case in the central, and in the top-right part of the Figure (e.g., point C).

### 5.5 Incentives to switch to the discriminatory regime

So far, we have considered that the traffic regime (either net neutrality or discrimination) was given exogenously, and hence, a departure from net neutrality meant that both ISPs adopted the discriminatory regime. An interesting question is however whether the ISPs would endogenously decide to remain under net neutrality, or rather to implement the discriminatory regime. To analyze this question, we study an ISP's unilateral incentives to depart from the net neutrality regime, at the first stage of the game. We obtain the following result:

**Lemma 1** *Each ISP has a unilateral incentive to adopt the discriminatory regime.*

**Proof.** Whenever the priority fees are equal to zero, the discriminatory regime coincides with the net neutrality regime, since all CPs connect to the priority lane. Therefore, ISP $i$ has a unilateral incentive to discriminate if its profit increases with the priority fee at $f_i = 0$. By replacing (17) and (18) into $\Pi_i^D$, we find that, irrespective of $f_j$,

$$\left.\frac{\partial \Pi_i^D}{\partial f_i}\right|_{f_i=0} = \left.\frac{\mu_i^D \left(\lambda x_i^D \left(a\lambda x_i^D - f_i\right)^2 - f_i \left(a\lambda x_i^D - f_i\right) - a\lambda x_i^D f_i\right)}{\lambda x_i^D \left(1+\lambda x_i^D\right)\left(a\lambda x_i^D - f_i\right)^2}\right|_{f_i=0} = \frac{\mu_i^D}{1+\lambda x_i^D} > 0.$$

■

This Lemma shows that each ISP has an incentive to switch from the net neutrality to the discriminatory regime, unilaterally and independently of the rival ISP, in an effort to extract part of CPs' profits, and whatever the rival does. With Proposition 5, we have shown that ISPs' profits under discrimination can be lower than their profits under net neutrality, as a result of more intense competition. We therefore obtain the following result.

**Proposition 7** *ISPs can be trapped in a prisoner's dilemma, with respect to the choice of the traffic regime.*

In such a case, both ISPs would prefer to remain under net neutrality to achieve higher profits,[36] but each of them has a unilateral incentive to switch to the discriminatory regime.[37] In Figure 2, the prisoner's dilemma arises, for example, at point B.

All in all, in this section we have shown that a departure from the net neutrality regime increases total welfare in the market for Internet access. However, as we argue in the next section, policy-makers should be aware of other practices that ISPs could adopt in order to manipulate the traffic in their networks and increase their profits, for example, sabotage.

# 6 Sabotage

Up to now, we have examined the effect of a departure from the net neutrality regime by introducing a discriminatory regime where both ISPs offer a paid-for priority lane and a free (best-effort) non-priority lane. The debates around net neutrality however also stress that ISPs could be tempted to adopt strategies to manipulate the traffic in their networks. One such practice could be to degrade the quality of the CPs that do not pay for priority. As shown by Deneckere and McAfee (1996), damaging some of their goods may help firms to price discriminate. In our setting, such a strategy could work especially in the discriminatory regime to make the priority lane more valuable relative to the best-effort lane. By doing so, ISPs may appropriate a higher share of the CPs' surplus via the priority fee.

In this section, we study the case where the ISPs can endogenously decide on a level of sabotage, which reduces the click-through rate of the CPs and thus their revenues. In what follows, we begin by studying the incentives of the ISPs to do sabotage in the net neutrality regime, and then we analyze the incentives for sabotage in the discriminatory regime.

[36] As a consequence, ISPs would have an incentive to lobby jointly for net neutrality. However, since each ISP has a unitaleral incentive to adopt the discriminatory regime, each ISP would also have an incentive to deviate from the lobbying agreement, making such joint lobbying difficult to implement.

[37] Note that this prisoner's dilemma appears only in a setting with ISP competition. With a monopoly at the ISP level, there is no strategic interaction, and the monopolistic ISP prefers (at least weakly) the discriminatory regime that always increases its profit compared to the net neutrality regime.

### 6.1 Sabotage in the net neutrality regime

We extend the baseline analysis of the net neutrality regime, and suppose now that ISPs may sabotage CPs at no cost. The profit of CP $h$ then becomes

$$\Pi_h^N = \begin{cases} a\lambda x_A^N \left(1 - \left(1 + s_A^N\right) h w_A^N\right) + a\lambda x_B^N \left(1 - \left(1 + s_B^N\right) h w_B^N\right) & \text{it connects to both ISPs} \\ a\lambda x_i^N \left(1 - \left(1 + s_i^N\right) h w_i^N\right) & \text{if} \quad \text{it connects only to ISP } i \\ 0 & \text{otherwise,} \end{cases}$$

where $s_i^N \geq 0$ is the level of sabotage imposed by ISP $i$ in the net neutrality regime, with $i = A, B$. The expression of the CP's profit is the same as in our baseline model of Section 2, except that the CP's congestion sensitivity is increased by the level of sabotage.

The timing of the game is modified as follows. At the first stage, ISPs decide on capacity levels, subscription fees, and sabotage levels simultaneously and non-cooperatively. At the second stage of the game, CPs decide which ISP(s) to connect to and end users choose an ISP.

The analysis is similar to the analysis of the baseline model in Section 2. We obtain the following result.

**Proposition 8** *In the net neutrality regime, ISPs never sabotage the CPs, that is,* $s_i^N = 0$*, for* $i = A, B$*.*

**Proof.** Solving backwards for the symmetric equilibrium, and following the same procedure as in the baseline model, we find that the profit functions of the ISPs are decreasing with respect to the level of sabotage, that is,

$$\frac{\partial \Pi_i^N}{\partial s_i^N} = p \frac{\partial x_i}{\partial s_i^N} = -\frac{(2v - d\lambda)\,\mu p}{t\,(2s + \lambda + 2)^2 + 4\lambda\mu\,(d + v + ds)} < 0,$$

where $p_A^N = p_B^N = p$, $\mu_A^N = \mu_B^N = \mu$ and $s_A^N = s_B^N = s$. Note that we invoke (7) here, so that $(2v - d\lambda) > 0$. Therefore, in equilibrium, ISPs set a zero level of sabotage. ■

Even if we allow the level of sabotage to be endogenous, the ISPs do not have any incentive to sabotage the CPs in the net neutrality regime. Indeed, there is a unique lane to transfer the data. Any positive level of sabotage would just reduce the revenues of the CPs, and subsequently the total number of active CPs. ISPs would then have to lower the subscription fees to the end users, since innovation in services would be lower, which would result in lower profits for the ISPs. Therefore, sabotage in the net neutrality regime is not an equilibrium outcome.

### 6.2 Sabotage in the discriminatory regime

It is interesting to study the incentives of the ISPs to sabotage the different lanes in the discriminatory regime. We allow the model to be flexible, and assume that there could in principle be two different sabotage rates that the ISPs can set at no cost, one for the priority lane, denoted by $s_i^P \geq 0$, and one for the non-priority lane, denoted by $s_i^{NP} \geq 0$, with $i = A, B$.[38] Sabotage levels are chosen at the first period of the game, at the same time as capacity levels and subscription fees. The analysis is then similar to the analysis of the baseline model in Section 3, except that the profits of the CPs are now given by

$$\Pi_h^D = \begin{cases} a\lambda x_A^D(1-\left(1+s_A^P\right)hw_A^P) - f_A + a\lambda x_B^D(1-\left(1+s_B^P\right)hw_B^P) - f_B & \text{priority at both ISPs} \\ a\lambda x_i^D(1-\left(1+s_i^P\right)hw_i^P) - f_i + a\lambda x_j^D(1-\left(1+s_j^{NP}\right)hw_j^{NP}) & \text{priority only at ISP } i \\ a\lambda x_A^D(1-\left(1+s_A^{NP}\right)hw_A^{NP}) + a\lambda x_B^D(1-\left(1+s_B^{NP}\right)hw_B^{NP}) \quad \text{if} & \text{non-priority at both ISPs} \\ a\lambda x_i^D(1-\left(1+s_i^P\right)hw_i^P) - f_i & \text{priority at } i\text{, no access at } j \\ a\lambda x_i^D(1-\left(1+s_i^{NP}\right)hw_i^{NP}) & \text{non-priority at } i\text{, no access at } j \\ 0 & \text{otherwise.} \end{cases}$$

We examine the local incentives of the ISPs to implement sabotage. In other words, we evaluate the ISPs' incentives to decide on some positive level of sabotage in the symmetric case, starting from a baseline case with no sabotage. We find the following result.[39]

**Proposition 9** *Under discrimination, ISPs have no incentive to sabotage their priority lanes, that is, $s_i^P = 0$. By contrast, ISPs may have incentives to sabotage the non-priority lane if the advertising rate is sufficiently high.*

**Proof.** By solving backwards and by the first-order conditions of the ISPs' profits with respect to the sabotage rate in the priority and non-priority lanes, evaluated at zero, under symmetry, we have

$$\left.\frac{\partial \Pi_i^D}{\partial s_i^P}\right|_{s_i^P = s_i^{NP} = 0} = -\frac{\mu N\left(2v - d\lambda\right)}{\lambda\left(\lambda+2\right)^{\frac{5}{2}}} < 0,$$

[38] Since ISPs can damage their fast and slow lanes independently, it may happen that an ISP damages one lane, but not the other. For this reason, the sabotage decision here is not equivalent to the choice of a lower capacity, which would degrade both lanes in a similar way.

[39] Note that all our results are robust to the introduction of some "sabotage cost function," as long as the marginal cost of sabotage at a zero level of sabotage is zero.

where

$$N = \left(\sqrt{2}\,(\lambda+2) - 2\sqrt{\lambda+2}\right) + a\left(\sqrt{2}\sqrt{\lambda+2} - 2\right)\left(\sqrt{\lambda+2}\,(\lambda^2+2\lambda+4) - 2\sqrt{2}\,(\lambda+2)\right) > 0,$$

and

$$\left.\frac{\partial \Pi_i^D}{\partial s_i^{NP}}\right|_{s_i^P=s_i^{NP}=0} = \frac{\mu\left(a\left(2\sqrt{2}\,(\lambda+4) - 8\sqrt{\lambda+2}\right) - \left(\sqrt{\lambda+2}-\sqrt{2}\right)(2v-d\lambda)\right)}{\lambda\,(\lambda+2)^{\frac{3}{2}}},$$

where $\mu_A^D = \mu_B^D = \mu$, with $\left.\frac{\partial \Pi_i^D}{\partial s_i^{NP}}\right|_{s_i^P=s_i^{NP}=0} > 0$ if $a > (2v-d\lambda)/2(\sqrt{2}\sqrt{\lambda+2}-2) > 0$, implying $s_i^{NP} > 0$. Note that we also invoke (7) here, so that $(2v - d\lambda) > 0$. ∎

This Proposition shows that a zero sabotage rate is still a candidate equilibrium for the priority lane, since the ISPs' profits, at that point, are decreasing with respect to the level of sabotage. However, for some parameter values, ISPs have now an incentive to sabotage the non-priority lane. Note that we only study the local incentives of the ISPs to sabotage, without fully characterizing the equilibrium sabotage rates, as we just want to highlight a possibility result.[40]

It is not profitable for the ISPs to degrade the quality of the priority lane, since this would reduce its attractiveness and lower the profits obtained by the ISPs through the priority fees. By contrast, we have established that sabotage can emerge endogenously for the best-effort non-priority lane. In particular, for sufficiently high values of the advertising revenue $a$ or sufficiently low values of the preference of the end users for innovation $v$, the ISPs find it profitable to sabotage the non-priority lane. Degrading the quality of the non-priority lane makes the priority lane more attractive, and hence, the ISPs can extract higher profits from CPs.[41] The total number of CPs decreases with sabotage at the non-priority lane, but the total number of CPs that opt for priority increases. Since innovation in services is reduced, the ISPs have to charge less for access to the end users. But when the preference for innovation $v$ is low relative to the advertising revenue $a$, the revenue loss on the end users' side is more than compensated by the gains on the CPs' side.

It is important to examine now the effect of sabotage on welfare. Let us consider a symmetric equilibrium where the ISPs impose small but positive sabotage rates on the non-priority lane, that is, $s_A^{NP} = s_B^{NP} = s_i^{NP} > 0$. Consequently, total welfare is a function of these rates, $W^D\left(s_A^{NP}, s_B^{NP}\right)$.

[40] Also, sabotage arises because there is still a "missing" (zero) price for the non-priority lane. If the ISP could charge for it, a price instrument will always do better than a non-price instrument such as sabotage. Nevertheless, the zero price for best-effort traffic is a requirement of every legislation we are aware of, thus making sabotage a real possibility.

[41] Our finding is somewhat reminiscent of the result obtained by Choi and Kim (2010) that an ISP might have incentives to limit capacity expansion because expanding capacity makes paying for priority less desirable.

By calculating the local effect of an increase of the sabotage rate on the non-priority lane on total welfare, we obtain

$$\left.\frac{\partial W^D}{\partial s_i^{NP}}\right|_{s_i^P=s_i^{NP}=0} = -\frac{2\mu\left(a\left((\lambda+4)(\lambda+2)-2\sqrt{2}(\lambda+2)^{\frac{3}{2}}\right)+\left(\lambda+2-\sqrt{2}\sqrt{\lambda+2}\right)(2v-d\lambda)\right)}{\lambda(\lambda+2)^2} < 0,$$

where $\mu_A^D = \mu_B^D = \mu$.

An increase of the sabotage rates on the non-priority lane from zero to a positive level always decreases total welfare. The CPs on the non-priority lane and the end users are worse off: the CPs that do not opt for priority obtain lower advertising revenues due to sabotage, and the end users face less variety in the market. However, the ISPs benefit from sabotage (for the range of the parameter values discussed above).

To sum up, while in the baseline model the introduction of the priority lanes and fees is always welfare-enhancing due to the more efficient traffic management and the associated higher incentives to invest, policy-makers should be aware of the additional practices that the ISPs may adopt under discrimination. The implementation of sabotage by the ISPs gives them an additional instrument to extract more profits, which could potentially decrease social welfare. Such a practice may reduce innovation in services, and thus exclude some CPs from the Internet market. Therefore, the competitive pressure at the ISP level is not sufficient to eliminate the probability of sabotage.

# 7 Small and large CPs

In the baseline model, we assumed that the advertising rate was identical across CPs. However, some (small) CPs may earn lower advertising rates than other (large) CPs. One concern expressed by the proponents of net neutrality is that a departure from the neutral regime could hurt these small CPs, and even drive them out of the market. To study this issue, we consider that, for each level of congestion sensitivity $h$, a proportion $\gamma$ of the CPs has a low advertising rate $a_L$, while a proportion $1-\gamma$ has a high advertising rate $a_H$, with $a_H > a_L$ and $\gamma \in (0,1)$. The former are considered to be "small" due to lower advertising revenues, and the latter to be "large". We assume that $\gamma a_L + (1-\gamma) a_H = a$, which means that the average advertising rate is the same as in our baseline model. We keep assuming that each ISP charges a fixed fee for the priority lane, that is, does not seek to price discriminate between small and large CPs.

The equilibrium outcome under net neutrality for this extended setting is the same as the one described in Proposition 1.[42] When there is a unique traffic lane, advertising rates do not affect the equilibrium level of capacity investment, innovation in services, the subscription fees and network congestion.[43] The only difference is that small CPs obtain lower profits than large CPs. However, total welfare remains unchanged.

Under discrimination, we denote by $\overline{h}_{k,i}$ the total number of CPs entering ISP $i$ when they earn advertising rate $a_k$, and by $\widetilde{h}_{k,i}$ the CP which is indifferent between the priority lane and the best-effort lane at ISP $i$, with $k = L, H$, and $i = A, B$. We solve the game in a similar way as for our baseline model, and obtain the same qualitative results. In particular, a switch from the net neutrality regime to the discriminatory regime remains beneficial in terms of investments, innovation and total welfare.

However, a departure from the net neutrality regime hurts the small CPs more often than the large CPs. In particular, there might be cases where large CPs benefit from a switch to the discriminatory regime, while small CPs are hurt.[44] This is due to the fact that large CPs earn higher advertising revenues, and therefore, there is more entry from large CPs than from small CPs, using the priority lane. Finally, for some parameter values, for example, when the difference $a_H - a_L$ is large enough, all small CPs are excluded from the priority lane, though they still can use the free-of-charge non-priority lane.

To sum up, in this extension, a departure from the net neutrality regime is still positive in terms of total welfare, but with a caveat, as small CPs get hurt more than large CPs.

# 8 Conclusion

We propose a model with two competing Internet platforms (ISPs) that bring together Internet users and a continuum of congestion-sensitive advertiser-supported content providers. The CPs deliver content to the end users via the ISPs' broadband networks. Under the net neutrality regime, CPs pay no fees to the ISPs for network access, whereas under the alternative discriminatory regime,

[42] See Appendix B for the detailed analysis.

[43] The equilibrium is slightly affected by the introduction of a fixed cost for the CPs who connect to an ISP. We find that the equilibrium level of entry by CPs increases with the advertising rate. As a consequence, the entry of CPs with high advertising rates is higher compared to the entry of CPs with low advertising rates. Nevertheless, in this extension, we still obtain that entry under discrimination is higher compared to entry under net neutrality (due to higher capacity investments under discrimination). The proof is available upon request from the authors.

[44] Recall that this result is obtained under the assumption that ISPs cannot price discriminate between small and large CPs. If the ISPs had the ability to price discriminate between small and large CPs for access to the priority lane, the effect of a departure from net neutrality on small CPs could be different (e.g., it could be less negative if the small CPs were offered a lower price).

the CPs who opt for an ISP's fast lane have to pay a priority fee to that ISP, while the other CPs can use a best-effort slow lane at no charge.

We find that in the discriminatory regime, where the two ISPs offer prioritized lanes, Internet traffic is managed more efficiently than in the net neutrality regime. Consequently, the average level of congestion experienced by end users is lower under discrimination than under net neutrality. Moreover, ISPs invest more in network capacity, since they can be partly compensated for their investments by the additional revenues that they can extract from the CPs through the priority fees. Innovation in services is also higher in the discriminatory regime compared to the net neutrality regime. As traffic is managed more efficiently, some highly congestion-sensitive CPs are able to enter the market when a prioritized lane is available, while they choose to remain out of the market when there is only one best-effort lane for all CPs.

In this duopoly framework, ISPs do not always benefit from a departure from the net neutrality regime, as the introduction of multiple lanes can actually intensify competition between Internet platforms. However, ISPs always have a unilateral incentive to adopt the discriminatory regime, when they are allowed to. In such a case, the two competing ISPs might be trapped in a prisoner's dilemma, switching to the discriminatory regime, even though it makes them worse-off. Finally, while the effect of a departure from the net neutrality regime on the CPs' profits and the end users' utility is generally ambiguous, total welfare always increases when there is a switch from the net neutrality to the discriminatory regime.

Our findings in a setting with competing platforms are useful to support and qualify some policy statements. For example, the FCC exempted cellular operators from most of the net neutrality rules on the grounds in particular that the cellular industry is typically more competitive than the fixed-line industry, suggesting that competition might itself bring net neutrality, without mandating it. Our results support the idea that lifting net neutrality regulation on competing platforms is welfare-increasing. However, this is not because competition reduces the ISPs' incentives to discriminate. In fact, each operator has a unilateral incentive to introduce a priority lane, no matter what its rival does.

Though welfare-enhancing, the discriminatory regime has some undesirable effects. When we distinguish between small and large CPs, it turns out that a switch to the discriminatory regime hurts more the small ones than the large ones. Besides, and perhaps more importantly, the discriminatory regime might bring forth a risk of sabotage by ISPs of content providers' traffic. Whereas this risk is absent under net neutrality – sabotage is never an optimal strategy for the ISPs under this regime – under the discriminatory regime, if the advertising revenue is sufficiently high, each ISP benefits from degrading the quality of the non-priority lane in order to extract higher profits from the priority lane.

If regulation of traffic quality is too complex and/or costly, keeping the current net neutrality regime might be a solution to avoid sabotage of CPs' traffic. Otherwise, our analysis suggests that a switch to the discriminatory regime would be welfare-improving, while still requiring some monitoring of traffic quality.

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## Appendix A: Second-order conditions

**Net neutrality.** The candidate equilibrium in Proposition 1 corresponds to a maximum of the profit function if the Hessian matrix is negative definite, which is the case if

$$C''(\mu) > \frac{4(d+v)^2}{(\lambda+2)^2\left(t(\lambda+2)^2 + 4\lambda\mu(d+v)\right)}.$$

**Discrimination.** The candidate equilibrium in Proposition 2 corresponds to a maximum of the profit function if the Hessian matrix is negative definite. The Hessian matrix is

$$H = \begin{bmatrix} \frac{\partial^2\Pi_i}{\partial p_i^2} & \frac{\partial^2\Pi_i}{\partial p_i\partial\mu_i} & \frac{\partial^2\Pi_i}{\partial p_i\partial f_i} \\ \frac{\partial^2\Pi_i}{\partial\mu_i\partial p_i} & \frac{\partial^2\Pi_i}{\partial\mu_i^2} & \frac{\partial^2\Pi_i}{\partial\mu_i\partial f_i} \\ \frac{\partial^2\Pi_i}{\partial f_i\partial p_i} & \frac{\partial^2\Pi_i}{\partial f_i\partial\mu_i} & \frac{\partial^2\Pi_i}{\partial f_i^2} \end{bmatrix}.$$

In the symmetric equilibrium under discrimination, we have

$$\frac{\partial^2\Pi_i}{\partial p_i^2} = -\frac{\sqrt{2}\sqrt{\lambda+2}\left(\sqrt{2}\sqrt{\lambda+2}t(\lambda+2)^3+2\mu_i\left(a\left((\lambda+2)\left(16\lambda+8\lambda^2+\lambda^3+16\right)-\sqrt{2}\sqrt{\lambda+2}\left(\lambda^3+10\lambda^2+20\lambda+16\right)\right)+2\sqrt{2}\lambda(\lambda+2)^{\frac{3}{2}}(d+v)\right)\right)}{2\left(t(\lambda+2)^2+4\lambda\mu_i(d+v)\right)^2} < 0,$$

$$\begin{aligned} \frac{\partial^2\Pi_i}{\partial p_i\partial\mu_i} &= \frac{\partial^2\Pi_i}{\partial\mu_i\partial p_i} \\ &= \frac{\sqrt{2}\left(t(\lambda+2)^2\left(a\left(\sqrt{2}\lambda(\lambda+2)^2-\lambda(\lambda+2)^{\frac{5}{2}}\right)+\sqrt{2}(\lambda+1)(\lambda+2)^2(d+v)\right)\right)}{(\lambda+2)^2\left(t(\lambda+2)^2+4\lambda\mu_i(d+v)\right)^2} + \\ &\quad \frac{\sqrt{2}\left(4\mu_i(d+v)\left(\sqrt{2}\lambda(\lambda+1)(\lambda+2)^2(d+v)-\frac{1}{2}a\left(\sqrt{2}(\lambda+2)^4(\lambda+4)-(\lambda+2)^{\frac{7}{2}}\left(\lambda^2+4\lambda+8\right)\right)\right)\right)}{(\lambda+2)^2\left(t(\lambda+2)^2+4\lambda\mu_i(d+v)\right)^2}, \end{aligned}$$

$$\frac{\partial^2\Pi_i}{\partial p_i\partial f_i} = \frac{\partial^2\Pi_i}{\partial f_i\partial p_i} = -\frac{2\mu_i(\lambda+2)\left(\sqrt{2}(\lambda+2)^{\frac{3}{2}}-(\lambda+4)\right)}{t\lambda(\lambda+2)^2+4\lambda^2\mu_i(d+v)} < 0,$$

$$\begin{aligned} \frac{\partial^2\Pi_i}{\partial\mu_i^2} &= -C''(\mu_i) \\ &\quad -\frac{2\sqrt{2}(d+v)\left(2t\left(a\left(\sqrt{2}\lambda(\lambda+2)^2-\lambda(\lambda+2)^{\frac{5}{2}}\right)+\frac{1}{2}\sqrt{2}\lambda(\lambda+2)^2(d+v)\right)\right)}{(\lambda+2)\left(t(\lambda+2)^2+4\lambda\mu_i(d+v)\right)^2} \\ &\quad -\frac{2\sqrt{2}(d+v)\left(2\mu_i(d+v)\left(a\left(\sqrt{\lambda+2}\left(\lambda^3+4\lambda^2+16\lambda+16\right)-\sqrt{2}\left(20\lambda+6\lambda^2+\lambda^3+16\right)\right)+2\sqrt{2}\lambda^2(d+v)\right)\right)}{(\lambda+2)\left(t(\lambda+2)^2+4\lambda\mu_i(d+v)\right)^2}, \end{aligned}$$

$$\frac{\partial^2 \Pi_i}{\partial \mu_i \partial f_i} = \frac{\partial^2 \Pi_i}{\partial f_i \partial \mu_i} = \frac{4\mu_i (d+v)\left(\sqrt{2}(\lambda+2)^{\frac{3}{2}} - (\lambda+4)\right)}{t\lambda(\lambda+2)^2 + 4\lambda^2 \mu_i (d+v)} > 0,$$

and

$$\frac{\partial^2 \Pi_i}{\partial f_i^2} = -\frac{4\sqrt{2}\sqrt{\lambda+2}\mu_i}{a\lambda^2} < 0.$$

The Hessian matrix is negative definite if $\partial^2\Pi_i/\partial p_i^2 < 0$, $\partial^2\Pi_i/\partial \mu_i^2 < 0$, $\partial^2\Pi_i/\partial f_i^2 < 0$, $\left(\partial^2\Pi_i/\partial p_i^2\right)\left(\partial^2\Pi_i/\partial \mu_i^2\right) - \left(\partial^2\Pi_i/\partial p_i \partial \mu_i\right)^2 > 0$, and if the determinant of the Hessian matrix is negative. The first and the third inequalities are always true, and the rest holds if $C(\cdot)$ is sufficiently convex. This always holds when transportation costs are high enough.

## Appendix B: Small and large CPs

**Net neutrality.** The equilibrium outcome under net neutrality with small and large CPs is the same as the equilibrium described in Proposition 1, with the total number of CPs now being equal to $\gamma \overline{h}_L^N + (1-\gamma)\overline{h}_H^N = \overline{h}^N$. In equilibrium, the ISPs' profits, the consumers' surplus and total welfare remain unchanged, whereas the CPs' profits are now given by

$$\Pi_{h_L}^N = \begin{cases} a_L\lambda\left(1 - \frac{h_L(\lambda+2)}{2\mu^N}\right) & \text{if} \quad h_L \leq \overline{h}_L^N \\ 0 & \text{if} \quad h_L > \overline{h}_L^N \end{cases} \quad \text{and} \quad \Pi_{h_H}^N = \begin{cases} a_H\lambda\left(1 - \frac{h_H(\lambda+2)}{2\mu^N}\right) & \text{if} \quad h_H \leq \overline{h}_H^N \\ 0 & \text{if} \quad h_H > \overline{h}_H^N \end{cases}.$$

**Discrimination.** At the second stage, a CP of type $h_k$, with $k = L, H$, connects to the priority lane at ISP $i$ if $h_k \leq \overline{h}_{k,i}^D$, where $\overline{h}_{k,i}^D$ solves $a_k\lambda x_i^D(1 - \overline{h}_{k,i}^D w_i^P) - f_i = 0$, while the CP of type $\widetilde{h}_{k,i}$, which is indifferent between the priority and non-priority lanes at ISP $i$, is defined by $a_k\lambda x_i^D(1 - \widetilde{h}_{k,i}w_i^P) - f_i = a_k\lambda x_i^D(1 - \widetilde{h}_{k,i}w_i^{NP})$, where

$$\begin{aligned} w_i^P &= \frac{1}{\mu_i - \left(\gamma\left(\overline{h}_{L,i}^D - \widetilde{h}_{L,i}\right) + (1-\gamma)\left(\overline{h}_{H,i}^D - \widetilde{h}_{H,i}\right)\right)\lambda x_i}, \\ w_i^{NP} &= \frac{\mu_i}{\mu_i - \left(\gamma\overline{h}_{L,i}^D + (1-\gamma)\overline{h}_{H,i}^D\right)\lambda x_i} w_i^P. \end{aligned}$$

Similar to our baseline model, from these expressions we obtain that

$$\begin{aligned} \overline{h}_{L,i}^D &= \frac{\mu_i a_H (a_L\lambda x_i - f_i)}{(1+\lambda x_i)(\lambda a_H a_L x_i - (a_L + \gamma(a_H - a_L)) f_i)}, \widetilde{h}_{L,i} = \frac{\mu_i a_H f_i}{\lambda x_i (1+\lambda x_i)(\lambda a_H a_L x_i - (a_L + \gamma(a_H - a_L)) f_i)}, \\ \overline{h}_{H,i}^D &= \frac{\mu_i a_L (a_H\lambda x_i - f_i)}{(1+\lambda x_i)(\lambda a_H a_L x_i - (a_L + \gamma(a_H - a_L)) f_i)}, \widetilde{h}_{H,i} = \frac{\mu_i a_L f_i}{\lambda x_i (1+\lambda x_i)(\lambda a_H a_L x_i - (a_L + \gamma(a_H - a_L)) f_i)}. \end{aligned}$$

Simultaneously, at stage 2, each consumer chooses whether to subscribe to ISP $A$ or ISP $B$. The indifferent consumer $\widetilde{x}^D$ is given by

$$R+v\left(\gamma\overline{h}_{L,A}^D+(1-\gamma)\,\overline{h}_{H,A}^D\right)+\frac{d}{w_A^D}-p_A^D-t\widetilde{x}^D=R+v\left(\gamma\overline{h}_{L,B}^D+(1-\gamma)\,\overline{h}_{H,B}^D\right)+\frac{d}{w_B^D}-p_B^D-t\left(1-\widetilde{x}^D\right),$$

where $w_i^D=1/\left(\mu_i-(\gamma\overline{h}_{L,i}^D+(1-\gamma)\,\overline{h}_{H,i}^D)\lambda x_i\right)$. By replacing for $\overline{h}_{k,i}^D$ into the expression for the indifferent consumer, we find that $\widetilde{x}^D$ satisfies equation (20) as in the baseline model.

At the first stage, the two ISPs choose simultaneously their capacities, subscription fees and priority fees. The maximization problem of ISP $i$ can be expressed as follows

$$\max_{p_i^D,\,\mu_i^D,\,f_i}\Pi_i^D=p_i^D x_i^D+\gamma\left(\overline{h}_{L,i}^D-\widetilde{h}_{L,i}\right)+(1-\gamma)\left(\overline{h}_{H,i}^D-\widetilde{h}_{H,i}\right)-C\left(\mu_i^D\right),$$

where $x_i^D=x_i^D(p_A^D,p_B^D,\mu_A^D,\mu_B^D)$. Solving for the first-order conditions $\partial\Pi_i^D/\partial p_i^D=0$, $\partial\Pi_i^D/\partial\mu_i^D=0$, $\partial\Pi_i^D/\partial f_i=0$, we obtain the capacity level, the priority fee, the subscription fee, the number of CPs and the levels of congestion in the symmetric equilibrium:

$$\begin{aligned}
\mu^D &= (C')^{-1}\left(\frac{d+v}{\lambda+2}+\frac{a_H a_L\left(\sqrt{2}\sqrt{\lambda+2}-2\right)^2}{2\,(\lambda+2)\,(a_L+\gamma\,(a_H-a_L))}\right),\\
f &= \frac{\lambda a_H a_L}{2\,(a_L+\gamma\,(a_H-a_L))}\left(1-\frac{\sqrt{2}}{\sqrt{\lambda+2}}\right),\\
p^D &= t+\frac{4\lambda\mu^D\,(d+v)}{(\lambda+2)^2}-\frac{2\lambda a_H a_L\mu^D\left(\sqrt{2}\sqrt{\lambda+2}-2\right)}{(\lambda+2)^2\,(a_L+\gamma\,(a_H-a_L))},\\
\overline{h}_L^D &= \frac{\left(2a_H-(1-\gamma)\,(a_H-a_L)\,\sqrt{2}\sqrt{\lambda+2}\right)\mu^D}{(\lambda+2)\,(a_L+\gamma\,(a_H-a_L))},\ \widetilde{h}_L=\frac{2a_H\left(\sqrt{2}\sqrt{\lambda+2}-2\right)\mu^D}{\lambda\,(\lambda+2)\,(a_L+\gamma\,(a_H-a_L))},\\
\overline{h}_H^D &= \frac{\left(2a_L+\gamma\,(a_H-a_L)\,\sqrt{2}\sqrt{\lambda+2}\right)\mu^D}{(\lambda+2)\,(a_L+\gamma\,(a_H-a_L))},\ \widetilde{h}_H=\frac{2a_L\left(\sqrt{2}\sqrt{\lambda+2}-2\right)\mu^D}{\lambda\,(\lambda+2)\,(a_L+\gamma\,(a_H-a_L))},\\
w^P &= \frac{\sqrt{2}\sqrt{\lambda+2}}{2\mu^D},\ w^{NP}=\frac{\sqrt{2}\,(\lambda+2)^{3/2}}{4\mu^D},\ w^D=\frac{\lambda+2}{2\mu^D}.
\end{aligned}$$

The proof is similar to the one provided in the main text for Proposition 2. The resulting equilibrium profits, consumers' surplus and total welfare are

$$
\begin{aligned}
\Pi^D &= \frac{t}{2}+\frac{2\lambda\mu^D(d+v)}{(\lambda+2)^2}+\frac{\mu^D a_H a_L\left(\left(\lambda+2-\sqrt{2}\sqrt{\lambda+2}\right)^2-\lambda\left(\sqrt{2}\sqrt{\lambda+2}-2\right)\right)}{(\lambda+2)^2\left(a_L+\gamma\left(a_H-a_L\right)\right)}-C\left(\mu^D\right),\\
\Pi^D_{h_L} &= \begin{cases} \Pi^{NP}_{h_L}=a_L\lambda(1-h_L\frac{\sqrt{2}(\lambda+2)^{3/2}}{4\mu^D}) & \text{if} \quad h_L\leq\widetilde{h}_L \\ \Pi^P_{h_L}=\frac{\sqrt{2}a_L\lambda}{\sqrt{\lambda+2}}\left(\frac{2a_H-(1-\gamma)(a_H-a_L)\sqrt{2}\sqrt{\lambda+2}}{2(a_L+\gamma(a_H-a_L))}-h_L\frac{(\lambda+2)}{2\mu^D}\right) & \text{if} \quad \widetilde{h}_L<h_L<\overline{h}^D_L \\ 0 & \text{if} \quad h_L\geq\overline{h}^D_L \end{cases},\\
\Pi^D_{h_H} &= \begin{cases} \Pi^{NP}_{h_H}=a_H\lambda(1-h_H\frac{\sqrt{2}(\lambda+2)^{3/2}}{4\mu^D}) & \text{if} \quad h_H\leq\widetilde{h}_H \\ \Pi^P_{h_H}=\frac{\sqrt{2}a_H\lambda}{\sqrt{\lambda+2}}\left(\frac{2a_L+\sqrt{2}\sqrt{\lambda+2}\gamma(a_H-a_L)}{2(a_L+\gamma(a_H-a_L))}-h_H\frac{\lambda+2}{2\mu^D}\right) & \text{if} \quad \widetilde{h}_H<h_H<\overline{h}^D_H \\ 0 & \text{if} \quad h_H\geq\overline{h}^D_H \end{cases},\\
CS^D &= R-\frac{5t}{4}+\frac{2\mu^D}{(\lambda+2)^2}\left((d+v)(2-\lambda)+\frac{a_H a_L\lambda\left(\sqrt{2}\sqrt{\lambda+2}-2\right)}{a_L+\gamma\left(a_H-a_L\right)}\right),\\
W^D &= R-\frac{t}{4}+\mu^D\left(\frac{2(d+v)}{\lambda+2}+\frac{\sqrt{2}\sqrt{\lambda+2}\left(\lambda\gamma(1-\gamma)\left(a_H-a_L\right)^2-4a_H a_L\right)+4(\lambda+2)a_H a_L}{2(\lambda+2)\left(a_L+\gamma\left(a_H-a_L\right)\right)}\right)\\
&\quad -2C\left(\mu^D\right).
\end{aligned}
$$

**Comparisons.** Direct comparisons of the equilibrium levels of investment, innovation and total welfare in the net neutrality and discriminatory regimes yield that $\mu^D>\mu^N$, $\gamma\overline{h}^D_L+(1-\gamma)\overline{h}^D_H>\gamma\overline{h}^N_L+(1-\gamma)\overline{h}^N_H$ and $W^D>W^N$. Moreover, there are parameter values such that $\Sigma\Pi^D_{h_H}>\Sigma\Pi^N_{h_H}$ while $\Sigma\Pi^D_{h_L}<\Sigma\Pi^N_{h_L}$. The set of parameter values where all CPs are hurt by prioritization is smaller than the set of parameters where only the small CPs are hurt.

Finally, the previous analysis is valid for the parameter values such that $\overline{h}^D_L-\widetilde{h}_L>0$, i.e., when there exists some small CPs that opt for priority. However, when the difference $a_H-a_L$ is large enough, all small CPs are excluded from the priority lane, though they still can use the free-of-charge non-priority lane.