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Prioritization vs zero-rating: Discrimination on the internet*

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Abstract

This paper analyzes two business practices on the mobile internet market, paid prioritization and zero-rating. Both violate the principle of net neutrality by allowing the internet service provider to discriminate different content types. In recent years these practices have attracted considerable media attention and regulatory interest. The EU, and until recently the US have banned paid prioritization but tolerated zero-rating under conditions. With prioritization, the ISP delivers content at different speeds and it is equivalent to a discrimination in terms of quality. With zero-rating, the ISP charges different prices for content and it is equivalent to a discrimination in terms of prices. We first show that neither of these practices lead to the exclusion of a content provider, a serious concern of net neutrality advocates. The ISP chooses prioritization when traffic is highly valuable for content providers and congestion is severe, and zero-rating in all other cases. Furthermore, investment in network capacity is suboptimal in the case of prioritization and socially optimal under zero-rating.

JEL Classification: D21; L12; L51; L96

Keywords: Net Neutrality; Paid Prioritization; Zero-rating; Sponsored Data; Data Cap; Congestion

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1 Introduction

Net neutrality is the principle of equal treatment of all data packages sent over the internet, irrespectively of their content, origin, destination and type of equipment used to access it. This regulatory principle prohibits discrimination on the internet and mandates Internet Service Providers (ISPs) to treat all data packets equally. In recent years, two business practices, prioritization and zero-rating, have been widely discussed and debated both in policy circles and the media. These practices violate the net neutrality principle and allow the ISP to discriminate between content in terms of **quality** for prioritization and in terms of **price** for zero-rating. Thus they allow the ISP to add an additional layer of differentiation between content providers beyond their intrinsic differentiation. Our objective in this paper is to build a model that evaluates the costs and benefits of such an empowerment of the ISP and to contrast and compare the two practices.

The practice of **prioritization** consists in creating a fast lane on the internet where privileged content circulates in case of congestion. In a context of data congestion, the prioritized content has a better quality –faster delivery– while the non-prioritized content types experience congestion in the form of throttling, jitters and/or delays. Giving priority to one content over the others is a way for the ISP to differentiate further the different content providers (CPs) by adding another dimension of differentiation, the delivery speed. Prioritization is thus equivalent to quality differentiation. The **zero-rating** practice consists in creating financial differentiation between content providers. In this case, the ISP makes the consumption of some data packets more expensive than others. A typical example of financial discrimination is mobile data plans with zero-rated content. With such a contract, users subscribe for a package with a monthly data cap but the usage of some content (e.g. Facebook or Netflix) does not count against this data cap, i.e., the ISP charges different marginal rates for different types of content. Zero-rating is thus equivalent to price discrimination. With prioritization and zero-rating, the ISP directly influences the competition between content providers and, as this can provide an advantage to the privileged content or, alternatively, a disadvantage to the non-privileged ones, the content providers may be ready to compensate the ISP for having priority or being zero-rated.

Due to the indisputable importance of the internet, its regulation is a highly contentious issue (see for instance the detailed discussion in Greenstein et al. (2016)) and net neutrality is the only regulation that is specific to the internet. Different countries adopt widely different regulatory approaches and even within one jurisdiction, net neutrality regulations tend to be the subject of frequent changes. Moreover, regulators often have a contrasted attitude towards prioritization and zero-rating. For example, in the US, the need to regulate zero-rating arose in 2011 after a complaint about MetroPCS exempting Youtube from its customers' data cap. The first set of net neutrality rules adopted after this case was the 2015 Open Internet Order. It explicitly mandated a case-by-case treatment of zero-rating, i.e., zero-rating was tolerated, in contrast with paid prioritization which was prohibited by a bright line rule. The FCC, the US telecommunications regulatory body, investigated the four zero-rating offers in place in 2016 and expressed concern over two them (Verizon's FreeBee Data and AT&T's Sponsored Data programs) likely harming consumers[1]. These two programs have in common that the ISP zero-rated exclusively its affiliated video service subsidiary while the other programs for instance Binge On by T-Mobile where non-exclusive. However, this investigation did not have any legal effect as the FCC's composition changed under the Trump administration, and all further investigation was stopped. Moreover, the new FCC voted a repeal of the 2015 rules and abolishing net neutrality protections in December 2017. The repeal has resulted in both business practices being currently permitted in the US.

In 2015, the EU decided to adopt rules similar to the US regulation that were in place between 2015 and 2017. BEREC (Body of European Regulator for Economic Communications) published Guidelines for net neutrality (BEREC, 2016) mandating a case-by-case treatment of zero-rating offers by national regulatory authorities, while explicitly banning paid prioritization. The Guidelines explicitly prohibit zero-rating of content in case the data cap is reached and all other content is throttled or blocked. In practice, according to this principle, some specific zero-rating offerings were banned by NRAs (see e.g. the case of Telenor in Hungary and Telia in Sweden). In contrast, other offerings were found legal (Proximus in Belgium and T-Mobile in Germany). A court case in the Netherlands lifted the regulator's ban on T-Mobile's zero-rating offer in the country, establishing that the BEREC Guidelines must take precedent over national net neutrality law. A report by the European Commission (2017) describes most of these cases in detail. While Canada also decided not to ban zero-rating ex-ante, in practice CRTC, its regulatory authority took a very strict approach toward it, de facto prohibiting both zero-rating and paid prioritization[2]. For a detailed summary of the history of zero-rating regulation up to the end of 2016, see Yoo (2016).

The objective of this paper is to compare the two types of business practices within the same model, thus evaluating the often differentiated policy towards them. Our comparison will focus on the ability of the ISP to differentiate content and the impact this empowerment has on prices, consumer surplus and profits. In our model, discrimination has no value as

[1] https://apps.fcc.gov/edocs_public/attachmatch/DOC-342982A1.pdf

[2] https://arstechnica.com/tech-policy/2017/04/as-us-prepares-to-gut-net-neutrality-rules-canada-strengthens-th

such, instead it is considered as a tool for the ISP to alter competition on the content market. We investigate whether allowing the ISP to do so could be considered as efficient.[3] More specifically, we construct a model to compare three regimes that could be observed in the mobile internet market: prioritization (P), zero-rating (ZR) and net neutrality (NN). In our model, there are two competing content providers. The CPs are financed by advertising and they compete to attract internet users. They offer differentiated content, we use the Hotelling model to represent horizontal differentiation of content types. Importantly, we suppose asymmetric content providers with one CP (the weak CP) being located at the extreme of the Hotelling segment, while the other (the strong CP) being located in the interior, close to the other extreme but benefiting from a larger home market. To access content, users must subscribe to an internet service provider (ISP), that we suppose to be in a monopolistic position. The ISP faces a capacity constraint and thus may not be able to deliver the best available quality to all users. The comparison of the three regulatory regimes is meaningful only under the risk of congestion, exactly when the discriminatory programs are likely to be offered. Therefore our analysis mainly applies to the mobile internet market where limited transmission capacity is still an important constraint for ISPs.

Under prioritization, the ISP discriminates between content providers and gives the content supplied by CP_i priority access over the content supplied by CP_j. This means that if there is congestion on the internet, the download quality is not identical for the two types of content. The priority content provider CP_i may or may not compensate the ISP for getting priority. Importantly, consumers pay the same price to the ISP for accessing both types of content.[4] Under zero-rating, consumers are not charged the same price by the ISP when they access content of CP_i as when they access content of CP_j. In other words, the ISP financially discriminates the two content providers but they remain identical in terms of download quality. The zero-rated content provider CP_i may or may not compensate the ISP for this service.[5] Under net neutrality, the ISP cannot discriminate between content providers, so this regime can serve as a natural benchmark. In particular, net neutrality prohibits quality

[3] There are other costs and benefits associated with the two practices that are not considered in our model. For instance, prioritization is considered to be an efficient tool to manage congested data traffic when content have different sensitivity to delay (Peitz and Schuett (2016)).

[4] We use the term "prioritization" instead of "paid prioritization" (the standard way to refer to this type of quality differentiation) because we allow the ISP to prioritize a CP even in the absence of transfers between the ISP and the CP.

[5] Some use the term "sponsored data" to describe this business practice. However, "sponsored" implies a transfer from the CP to the ISP which does not necessarily occur in our model, nor in real life. In the US, most mobile carriers zero-rate some video content. The Binge On program of T-Mobile is a free zero-rating program and all the content providers that meet some technical requirements can apply freely. On the contrary, to be admitted in the zero-rating plan of AT&T (called Sponsored Data), content providers have to compensate the ISP.

differentiation like prioritized content and financial discrimination like applying a lower rate for some types of content. A consequence is the absence of financial transfers between the ISP and the CPs under net neutrality.

In our model, the price charged by the ISP to users, the market shares of CPs and the download qualities are all endogenous. Under NN, there is no additional differentiation of content providers beside their intrinsic differences captured by different locations on the Hotelling line. Furthermore, the ISP cannot make the internet connection's price dependent on which content is consumed. In this context, both P and ZR constitute a way to differentiate content further for the users by adding another layer of differentiation, in quality or in price, respectively.

Solving the model, we show first that both under zero-rating and prioritization, the ISP will privilege the weak content provider. For financial discrimination, this is obvious as it means that the ISP charges a higher price for the content that the consumers like more. For prioritization, the intuition is similar. Given that the ISP charges the same price for accessing both content, it will prioritize the weak content to mitigate the initial asymmetry between CPs, thereby increasing the subscription price paid by consumers. Furthermore, we show that under prioritization, de facto exclusion of the non-priority content is not a concern and that prioritization does not lead to market tipping, a serious concern in the net neutrality discussions.

Second, we show that the ISP will choose prioritization only when traffic is highly valuable for CPs and congestion is severe. In all other cases; low congestion and/or low value of traffic, the ISP chooses to price discriminate between content types. The intuition is the following. Without side payments, the ISP prefers to discriminate in price rather than in quality, i.e. it prefers zero-rating to prioritization. Then, the ISP will choose prioritization only if it receives a large payment from the prioritized content provider. This will be the case when traffic has a lot of value for content providers *and* prioritization is associated with large benefits on the market for content, which is the case when congestion is severe. In all other cases, the ISP will choose zero-rating. Third, we show that when prioritization is implemented, it can benefit both the ISP and the consumers. To understand this result, it is important to notice that the price is linear in capacity under zero-rating but concave under prioritization. This reflects the fact that an increase in bandwidth benefits all consumers equally in the zero-rating regime, as quality is uniform; while it benefits only the consumers of the slow-lane content under prioritization. In other words, the individual benefit of capacity extension is linked to the market share of the non-prioritized content. Thus for severe congestion, the price paid by consumers under prioritization will be low, while the contribution of the CPs will be high and there is a form of 'cross-subsidization' of consumers by the CPs. Hence, consumers might be better-off under prioritization than under zero-rating and, eventually, than under net neutrality. The interests of the consumers and the ISP could converge on prioritization while we show that it is never the case for zero-rating.

Finally, we consider four extensions of the model. First, we consider the possibility for the ISP to combine zero-rating and prioritization. In this case, priority will be, as in the baseline model, given to the weak CP but it will be zero-rated in addition only if congestion is limited. We show that combining price and quality discrimination is not profitable without side payments from the CPs and it will be implemented only when CPs derive a large value from traffic. In the second extension, we consider the incentives of the ISP to invest in network improvements and we show that, under prioritization, incentives to invest are suboptimal. The intuition is that the more severe congestion is, the more impact prioritization has on the market for content and hence, the more surplus the ISP can extract from content providers. For this reason, incentives to invest in capacity extension are limited. On the contrary, we find that under zero-rating the ISP's investment incentives are socially optimal. Third, we consider the case of vertical integration between the ISP and one CP. We show that privileging the weak CP remains the preferred policy choice even if the ISP is integrated with the strong content provider, i.e. its rival. Last, we consider the case when the value of traffic is different for the two CPs and we show that our main results continue to hold true even if the strong CP has a higher ability to monetize traffic than the weak CP, provided that this advantage is not too important.

1.1 Related literature

Our research project is closely related to the rich body of literature in theoretical industrial organization about net neutrality. This literature has focused on three practices that are violations of the net neutrality principle: exclusion of lawful content (Broos and Gautier (2017)), throttling and paid prioritization. In the context of congested networks, a two-tiered internet service with a fast lane for prioritized content is considered as a more efficient tool for traffic management than a strict net neutrality rule, see the contribution of Hermalin and Katz (2007), Choi and Kim (2010), Economides and Hermalin (2012), Peitz and Schuett (2016), Reggiani and Valletti (2016) and, for recent surveys, Greenstein et al. (2016) or Krämer et al. (2013). However, departing from a neutral internet and pricing congestion changes the incentives of the ISP to invest in network capacity (Choi and Kim (2010), Reggiani and

Valletti (2016)), to enter the market, or to improve their content provision (Reggiani and Valletti (2016), Bourreau, Kourandi, and Valletti (2015), Choi, Jeon, and Kim (2018)).

To date there have been few formal economic studies modeling zero-rating. Jullien and Sand-Zantman (2018) model zero-rating as a coupon from content providers to end users, a potential way to overcome the misallocation problem stemming from the free content business model. Somogyi (2018) investigates the trade-off between congestion and increased utility from consumption by modeling data caps explicitly, distinguishing the two types of zero-rating programs (open and exclusionary) currently in use. Jeitschko et al. (2017) focus on vertical integration between a content provider and the internet service provider in a zero-rating regime. Finally, Hoernig and Monteiro (2018) analyze zero-rating when payments from content providers to the ISP are banned and the profitability of zero-rating arises solely from network effects. In a recent report, Krämer and Peitz (2018) highlight the prevalence of throttling of zero-rated content. Our model is well suited to analyze this case, as throttling of a content provider can be seen as prioritizing its rivals. Beside this small literature, the analysis of zero-rating has mostly been relegated to the realms of legal science and descriptive studies. For two summaries providing an overview of zero-rating programs, see Marsden (2016) and Yoo (2016).

The fact that congestion is still a salient feature of the internet today has recently been documented by the thorough empirical studies of Nevo, Turner, and Williams (2016) and Malone, Nevo, and Williams (2017). In particular, by analyzing fixed residential broadband data they estimate a large willingness-to-pay to avoid congestion. Several factors, including hard technological constraints make mobile internet even more susceptible to congestion, including the scarcity of spectrum and limits on cell size reduction (see e.g. Clarke (2014)). Indeed, Heikkinen and Berger (2012) find that in most countries packet loss, a standard measure of congestion, is higher on the mobile internet.

Finally, our model is also related to the literature of simultaneous horizontal and vertical product differentiation. The two seminal articles in the literature; Economides (1989), and Neven and Thisse (1989) show that firms choose maximal differentiation in one dimension and minimal differentiation in the other dimension. More recent research assuming multidimensionally heterogeneous consumers include Ellison (2005) and Shi, Liu, and Petruzzi (2013).

2 A model of zero-rating and prioritization

There are three categories of players in the model: competing content providers (CP), a monopolistic internet service provider (ISP) and consumers.

2.1 Content providers

There are two contents providers and we use a Hotelling line of length 1 to model horizontal differentiation between content types. CPs are asymmetric, CP_S is located at point $a \geq 0$ on the unit interval and CP_W is located at point 1. CP_S, hereafter the strong content, is in a privileged position with a larger natural market than its rival CP_W, hereafter the weak content. In the sequel, we will assume that $a < \frac{1}{7}$, i.e. the initial asymmetry between CPs is small.[6,7]

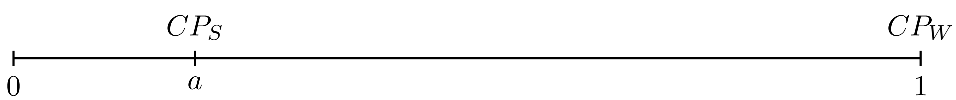

Figure 1: Content providers on the Hotelling line

Consumers who are connected to the internet single-home, that is they choose to consume the content of either CP_S or CP_W. Content is offered for free by the CPs and the content provision service is financed by advertising revenues. We suppose that the CPs collect an exogenous advertising revenue ρ per viewer. Content providers operating costs are normalized to zero. If we denote the total mass of viewers of content $i \in \{S, W\}$ by n_i, the profits of the content providers are $\pi_{CP_i} = \rho n_i$.

2.2 Internet service provider

There is a single ISP. Consumers need to be connected to the ISP to access the content offered by the CPs. Each connected consumer will consume one unit of content either at CP_S or at CP_W and the total demand of the ISP is $n_S + n_W$.

The ISP has a transmission capacity of κ. Limited capacity may lead to congestion if the

[6]The strong CP can create such an asymmetry in a number of ways, including a larger installed base thanks to a first-mover advantage, or simply providing more attractive content.

[7]From the formulation of $U(x)$ below, it is clear that this setting is equivalent to a model of vertical differentiation where both firms are located at the extremities and all consumers have a valuation $v_S = v + a\tau$ for the strong content and $v_W = v$ for the weak content.

bandwidth is insufficient to carry all the traffic. The consumption of time-sensitive content will be altered in case of congestion and consumers will experience jitters, delays, interruptions or a degradation of the content quality (throttling). We represent the surfing experience quality by a parameter q, that can be interpreted as the probability of on-time delivery (Peitz and Schuett, 2016). This probability is equal to the ratio of the bandwidth to the traffic: $q = \min[1, \frac{\kappa}{n_S+n_W}]$. If $n_S + n_W < \kappa$, there is no congestion on the internet and all content can be delivered on time: $q = 1$. If $n_S + n_W > \kappa$, the internet is congested and the ISP can no longer deliver the quality $q = 1$ to all users. If there is no discrimination between content providers, the probability of on-time delivery is the same for all users and all content and equals $q = \frac{\kappa}{n_S+n_W} < 1$.

In the prioritization regime, the ISP will give priority to content i over content j and the probability of on-time delivery will be higher for content i than for content j: $q_i \geq q_j$. If $n_i < \kappa$, part of the bandwidth will be used for the prioritized content that will be delivered on time: $q_i = 1$ while the remaining bandwidth $(\kappa - n_i)$ will be used for the non-priority content that will experience delays: $q_j = \frac{\kappa-n_i}{n_j} < 1$. If $n_i > \kappa$, it is not possible to deliver even the priority content on time and the probabilities are $q_i = \frac{\kappa}{n_i} > 0$ and $q_j = 0$. In both cases, the quality differential decreases in capacity κ:[8] $\frac{\partial(q_i-q_j)}{\partial\kappa} \leq 0$.

Consumers pay the ISP for accessing the internet. Mobile internet subscription are usually defined as a three-part tariff with a monthly fee ϕ, a data cap $\tilde{\theta}$ and an overage fee (i.e., a price for additional data) $\tilde{\phi}$. Therefore a consumer with a consumption equal to θ pays a total amount of $\phi + \max[0, \theta - \tilde{\theta}]\tilde{\phi}$. In the case of zero-rating, the price of additional data is different for CP_S $(\tilde{\phi}_S)$ and CP_W $(\tilde{\phi}_W)$, with one of these two prices equal to zero. If content i is zero-rated $(\tilde{\phi}_i = 0)$ then the total payment for a consumer choosing to consume from CP_i is equal to ϕ, while if he chooses CP_j, it is equal to $\phi + (\theta - \tilde{\theta})\tilde{\phi}_j$. In our model, consumers have a fixed demand equal to one $(\theta = 1)$. With a uniform marginal price (in the case of net neutrality and prioritization), we will use a single price p as a reduced form to represent the mobile subscription paid to the ISP, with $p = \phi + (1 - \tilde{\theta})\tilde{\phi}$. In the zero-rating case, we will represent the subscription fee by a base price $p = \phi$ and an additional premium $d = (1 - \tilde{\theta})\tilde{\phi}_j$ for consuming the non zero-rated content.

[8] This important property is also present in the M/M/1 queuing system used by Choi and Kim (2010), Cheng et al. (2011) and Choi et al. (2018).

2.3 Consumers

The utility of a consumer when he chooses content i depends on (1) the price paid to the ISP for accessing the internet, (2) his preference for content i over content j, this horizontal differentiation is captured by his position on the Hotelling line, and (3) the download quality of the content, q_i.

There is a mass one of consumers uniformly located on the Hotelling line. If we denote by x the location of the consumer on the line, by τ the unit transportation cost and by p_i the price paid to the ISP for accessing content i, the utility of consumer x is defined as:

$$U(x) = \begin{cases} v + q_S - \tau|x - a| - p_S & \text{if he chooses } CP_S \\ v + q_W - \tau(1 - x) - p_W & \text{if he chooses } CP_W \end{cases}$$

In the basic framework with a mass one of consumers we will suppose that (1) the market is fully covered at equilibrium: $n_S + n_W = 1$, a sufficient condition for that is a sufficiently large value for v, (2) download capacity is scarce: $\kappa < 1$, and (3) consumers have a reservation utility of zero.

2.4 Regulatory regime

The ISP can practice two types of discrimination between content types: quality discrimination and financial discrimination. Quality discrimination consists in differentiating content by having a different probability of on-time delivery ($q_S \neq q_W$). Financial discrimination consists in charging a higher price for the consumption of a particular content ($p_S \neq p_W$).

We will consider two different regulatory regimes: the net neutrality and the laissez-faire. Under Net Neutrality (NN), both types of discrimination are prohibited (by law). In a neutral internet, we have $q_S = q_W = q$ and $p_S = p_W = p$. In the laissez-faire regime, the ISP can discriminate in price or in quality between different types of content.[9] There are thus two different regimes in a laissez-faire economy: Prioritization (P) and Zero-rating (ZR). Under prioritization, the ISP gives priority to CP_i over CP_j and creates vertical differentiation between the two content $q_i \geq q_j$. In this regime, the price paid by the consumers to the ISP is the same: $p_S = p_W = p$. Under zero-rating, there is no vertical differentiation between content: $q_S = q_W = q$ but the ISP financially discriminates between the zero-rated content i and the non zero-rated content j. Access to content i is sold at $p_i = p$, access to content j

[9] We consider the possibility to discriminate at the same time in price and in quality as an extension in Section 6.1.

is sold at $p_j = p + d$. Under P and ZR, the CPs compete for being privileged by offering a compensation to the ISP.

2.5 Timing of the events and equilibrium concept

The timing of the events is the following:

1. In the laissez-faire regime, the ISP decides to implement P, ZR or nothing (which is equivalent to NN).
2. Under P or ZR, the content providers compete for priority.
3. The ISP sets the connection prices p_S and p_W.
4. Consumers simultaneously decide which CP to buy from, correctly anticipating the decision of other consumers.

We will refer to stages 3 and 4 of the full game as the *pricing subgame*. There are five different pricing subgames corresponding to the following regimes: net neutrality, prioritization giving priority to either the strong or the weak firm and zero-rating the content of either the strong or the weak firm. In this model, the eventual compensation paid by the CP to the ISP for being privileged is a pure transfer between the ISP and the CP and does not influence the pricing subgame.

Under NN and ZR, the quality of content the consumers face is independent of the action of other consumers. However, under P, the utility of accessing prioritized content decreases in the mass of other consumers subscribing to the priority content. Indeed, in the extreme case of everyone subscribing to the prioritized content, the quality they enjoy is the same as under the other regimes, i.e. all advantage of buying prioritized content disappears. Therefore, when making their decision in stage 4 of the game, consumers are part of a game involving all other consumers. We apply the concept of rational expectations equilibrium to solve this subgame, i.e. we assume that consumers can correctly anticipate the decision of other consumers. From a technical viewpoint, this means that we will find the location of indifferent consumers as fixed points of the demand functions. Note that this assumption is common in the literature (see e.g. Choi and Kim, 2010). As usual, we will solve the full game by backwards induction using the solution concept of subgame-perfect Nash equilibrium.

3 Pricing subgames

In this section we will derive equilibria of the pricing subgames that consist of the ISP's pricing decision followed by the consumers' choice of content. We will find equilibria under the five possible subgames.

3.1 Net neutrality

Under net neutrality there is a unique price p to access both CPs' content and their quality q are identical. The indifferent consumer between CP_S and CP_W is characterized by:

$$v + q - p - \tau(x - a) = v + q - p - \tau(1 - x) \quad \Leftrightarrow \quad x = \frac{a+1}{2}.$$

Using $q = \kappa$, the ISP maximizes its profit by extracting all the surplus from the indifferent consumer and chooses a price

$$p^{NN} = \pi^{NN}_{ISP} = v + \kappa - \frac{\tau}{2} + \frac{a\tau}{2}.$$

Given $a \leq 1/7$, the consumer located at 0 is willing to buy at that price and the market is fully covered. The profits of the ISP and the CPs are equal to $\pi^{NN}_{ISP} = p^{NN}$, $\pi^{NN}_{CP_S} = \rho\frac{a+1}{2}$ and $\pi^{NN}_{CP_W} = \rho\frac{1-a}{2}$.

3.2 Zero-rating

Under ZR, the two content providers have the same download quality $q = \kappa$ but they are financially differentiated. Accessing the zero-rated content costs p while accessing the other costs $p + d$. The ISP has the choice between zero-rating the strong or the weak content, and we show below that the latter option is always strictly preferred.

When CP_W is zero-rated, the location of the indifferent consumer x is given by:

$$v + \kappa - p - d - \tau(x - a) = v + \kappa - p - \tau(1 - x) \quad \Leftrightarrow \quad x = \frac{1+a}{2} - \frac{d}{2\tau}.$$

The ISP's maximization problem is the following:

$$\max_{p,d} \quad p + xd = p + \frac{1+a}{2}d - \frac{d^2}{2\tau} \qquad \text{s.t.} \qquad p \leq v + \kappa - \tau(1 - x).$$

The optimal solution is $p^{ZR} = v + \kappa - \frac{\tau}{2} + \frac{a\tau}{4}$ and $d = \frac{a\tau}{2} > 0$. At this price, the market is covered as $a \leq 1/7$. Notice that the price charged for zero-rated content is lower than the uniform price under net neutrality, whereas the non-zero-rated content is more expensive: $p^{ZR} < p^{NN} < p^{ZR} + d$. These prices lead to the indifferent consumer being located at $x = \frac{1}{2} + \frac{a}{4}$. The average price $\tilde{p}^{ZR}$, i.e. the ISP's profit is:

$$\tilde{p}^{ZR} = \pi_{ISP}^{ZR} = p^{ZR} + xd = v + \kappa - \frac{\tau}{2} + \frac{a\tau}{2} + \frac{a^2\tau}{8} = \pi^{NN} + \frac{a^2\tau}{8}.$$

Zero-rating the weak firm is more profitable for the ISP then the neutral regime whenever $a > 0$ and it is easy to check that zero-rating the strong firm results in lower profits. The profits of the CPs are: $\pi_{CP_S}^{ZR} = \rho\frac{2+a}{4}$ and $\pi_{CP_W}^{ZR} = \rho\frac{2-a}{4}$.

Remark: Although in the rest of the paper we assume that content providers follow an advertising-based business model, our qualitative results also hold in a subscription-based business model where CPs charge consumers access fees. To see this, consider an additional first stage in the model where CPs simultaneously choose the level of subscription fees.[10] In the Appendix we show that despite the strong CP's ability to directly benefit from its advantageous position (by charging a higher fee to consumers than its rival), the ISP still has room to create additional profitable differentiation by zero-rating the weak CP. Therefore, the logic of the advertising business model described above still applies to the subscription-based business model.

3.3 Prioritization

With prioritization, the two content providers offer different qualities. If content i has the priority, the qualities are $(q_i, q_j) = (1, \frac{\kappa - n_i}{n_j})$ if $n_i \leq \kappa$ and $(q_i, q_j) = (\kappa/n_i, 0)$ otherwise. Qualities depend on market shares and according to the rational expectations equilibrium concept we assume that in equilibrium consumers correctly anticipate the qualities.

There are three possible equilibrium configurations of the pricing subgame. When content i has priority, we call

1. an *interior equilibrium* when $n_i, n_j > 0$ and $(q_i, q_j) = (1, \frac{\kappa - n_i}{n_j})$,
2. a *semi-corner equilibrium* when $n_i, n_j > 0$ and $(q_i, q_j) = (\kappa/n_i, 0)$, and
3. a *corner equilibrium* when $n_j = 0$ and $(q_i, q_j) = (\kappa, 0)$.

[10] For a justification of this timing, see Jeitschko et al. (2018).

In a corner equilibrium, the market tips in the sense that all consumers choose the prioritized firm. Such an equilibrium arises typically when the transportation cost τ is very low. In a semi-corner equilibrium, some consumers choose the non-prioritized firm even though it has the lowest quality (recall that we assume a large valuation v for internet connection that is irrespective of the quality of the CPs). Such an equilibrium arises typically when congestion is very severe, i.e. the capacity κ is small. Finally, there is an interior equilibrium where both market shares and qualities are positive. We will focus our attention on interior equilibria, as it is standard in models of two-sided platforms in general (see Armstrong (2006), and Armstrong and Wright (2007)) and models of net neutrality in particular (see Choi and Kim (2010) and Cheng et al. (2011)). Firstly, we derive conditions of existence of such equilibria both for the case when the weak and the strong CP is prioritized. Secondly, we show that the interior equilibria when the weak firm is prioritized is the unique equilibrium of the subgames involving prioritization whenever such an equilibrium exists.

3.3.1 Priority to the weak CP

If the ISP gives priority to the weaker firm's content, in an interior equilibrium the indifferent consumer's location x is given by

$$v + q_S - p - \tau(x - a) = v + 1 - p - \tau(1 - x),$$

where the quality of the stronger CP's content is $q_S = \frac{\kappa-(1-x)}{x} = 1 - \frac{1-\kappa}{x}$, given that x is indeed an interior solution, i.e. $1 - x < \kappa$. This leads to two potential interior solutions for x:

$$x_1 = \frac{1+a}{4} - \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}} \quad \text{and} \quad x_2 = \frac{1+a}{4} + \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}},$$

which in turn lead to two different prices:

$$p_1 = v+1-\tau\left(\frac{3-a}{4} + \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}\right) < p_2 = v+1-\tau\left(\frac{3-a}{4} - \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}\right).$$

Given that $x_1 < x_2$, it is straightforward that the latter leads to a higher price. Moreover, whenever $1 - x_1 < \kappa$, the condition for the first solution being interior is satisfied, $1 - x_2 < \kappa$ also holds, i.e. the second solution is also interior. Therefore, whenever the first solution is potentially an interior equilibrium, the second solution is also potentially an interior equilibrium and it leads to a higher price for the ISP. Hence the first solution is always dominated by the second and will never constitute an equilibrium of the pricing subgame. The following Lemma establishes the conditions for the existence of an interior equilibrium when the weak firm is prioritized.

Lemma 1 *An interior solution for the pricing subgame exists under the regime when the weaker CP has priority whenever* $\kappa \geq \kappa^* \equiv \frac{1+\tau-a\tau}{2\tau}$. *It consists of the ISP choosing a price equal to* $p_W^{INT} = v + 1 - \tau\left(\frac{3-a}{4} - \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}\right)$, *with the indifferent consumer located at* $x_W^{INT} = \frac{1+a}{4} + \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}$.

Note that the condition for the consumer sitting at 0 buying from CP_S is $x_W^{INT} \geq 2a$ which is satisfied for $a \leq 1/7$. According to Lemma 1 an interior equilibrium exists if the capacity is sufficiently large and the two CPs are sufficiently differentiated horizontally. Intuitively, a large capacity is needed for the firm to be able to (profitably) serve every consumer and thus avoid a semi-corner solution. Notice that $\kappa^* < 1$ implies $\tau(1+a) > 1$. Intuitively, products must be sufficiently different from each other to avoid market tipping, a corner solution in which the prioritized firm serves all consumers. Throughout the paper we will assume these properties, as it is standard in the literature (see e.g. Choi and Kim (2010, p. 454), and Cheng et al. (2011, p. 65)).

Assumption 1: $\kappa \geq \kappa^* \equiv \frac{1+\tau-a\tau}{2\tau}$.

Therefore, we restrict our attention to situations where congestion is not too severe and products are sufficiently differentiated horizontally.

3.3.2 Priority to the strong CP

If the ISP gives priority to the stronger firm's content, in any interior solution the indifferent consumer's location x is given by

$$v + 1 - p - \tau(x - a) = v + q_W - p - \tau(1 - x) \quad \Leftrightarrow \quad x = \frac{1+a}{2} + \frac{1-q_W}{2\tau},$$

where the quality of the weaker CP's content is $q_W = \frac{\kappa - x}{1-x}$. As in the previous case, there are two potential interior solutions for x:

$$x_1' = \frac{3+a}{4} - \sqrt{\frac{(1-a)^2}{16} - \frac{1-\kappa}{2\tau}} \quad \text{and} \quad x_2' = \frac{3+a}{4} + \sqrt{\frac{(1-a)^2}{16} - \frac{1-\kappa}{2\tau}},$$

which in turn lead to two different prices for the ISP:

$$p_1' = v+1-\tau\left(\frac{3(1-a)}{4} - \sqrt{\frac{(1-a)^2}{16} - \frac{1-\kappa}{2\tau}}\right) > p_2' = v+1-\tau\left(\frac{3(1-a)}{4} + \sqrt{\frac{(1-a)^2}{16} - \frac{1-\kappa}{2\tau}}\right).$$

Analogously to the previous case, it can be shown that one of the solutions leads to a strictly higher price while being always an interior solution whenever the other solution is interior. Therefore, the solution x_2' is dominated, and the condition for the existence of an interior solution is $x_1' < \kappa$ which translates to $\kappa \geq \frac{1+\tau+a\tau}{2\tau}$. In the following, we will use the following notations to stress that the values belong to the strong CP: $x_S^P = x_1'$ and $p_S^P = p_1'$.

3.3.3 Comparison of equilibria under prioritization

Next, we establish a clear relationship between all the equilibria of the subgames in which the ISP opts for P. In particular, we show in the Appendix that whenever an interior equilibrium in the subgame prioritizing the strong CP exists, an interior equilibrium in the subgame prioritizing the weak CP also exists. Moreover, this latter always results in a higher price for the ISP, therefore the former equilibrium can never be a subgame-perfect equilibrium of the full game. The next Proposition establishes an even stronger claim: The interior equilibrium when the weak CP is prioritized dominates all other potential equilibria when P is chosen in the first stage, i.e. it dominates all the potential corner and semi-corner equilibria as well.

Proposition 1 *The interior solution of the pricing subgame with the weaker CP having priority leads to a higher price than all other potential equilibria of the subgames involving prioritization under Assumption 1, i.e. whenever such an equilibrium exists.*

The proof, relegated to the Appendix, compares the price p_W^{INT} to all other equilibria involving prioritization, including semi-corner and corner equilibria, both when the weak and the strong firm is prioritized, and shows that it is the highest (whenever its existence condition is satisfied). Consequently, the equilibrium price under P and the ISP's profit are:

$$p^P = \pi_{ISP}^P = v + 1 - \tau\left(\frac{3-a}{4} - \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}\right).$$

At this equilibrium, the indifferent consumer is located at $x_2 = x_W^P = \frac{1+a}{4} + \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}$ and the CPs' profits are: $\pi_{CP_S}^P = \rho(1 - x_W^P)$ and $\pi_{CP_W}^P = \rho x_W^P$.

According to Proposition 1, given Assumption 1, it is sufficient to compare p^P to the equilibrium profits arising from ZR and NN to find the equilibrium of the full game.

Corollary 1 *It is not in the ISP's interest to exclude any of the content providers from the market.*

In our model, a corner solution corresponds to the ISP creating an extreme quality difference that results in the de facto exclusion of one of the CPs. Indeed, such an exclusion of non-prioritized content is one of the main concerns of net neutrality advocates, both relating to prioritization and to zero-rating (see Marsden (2010) and Van Schewick (2016)). Recall that Proposition 1 ensures the optimality of an interior solution with positive market shares for both CPs and a limited quality differential. Solutions with extreme quality differential (semi-corner equilibria) or market tipping (corner equilibria) are suboptimal.

4 Comparisons of regimes without side payments

In this section, we compare the equilibria in the three different regimes. In these subgames, the ISP has one or two instruments. The first, which is the base price charged to be connected to the internet, is used to transfer the surplus of the indifferent consumer to the ISP. The second, which is the price or quality differential, is used to change the market shares of the content providers (under ZR and P, respectively). We discuss the role of these two instruments in turn.

4.1 Market shares

For the consumers, the ISP is a bottleneck access to the content providers. In a neutral internet, the ISP cannot discriminate between content: they are offered by the ISP at the same price and at the same download quality. Competition between content to attract audience is not altered by the ISP. When we depart from neutrality, the ISP has the possibility to influence the market for content by creating additional differentiation between content, either in price or in quality.

The price difference under zero-rating is represented by the surcharge d applied to the non-prioritized content. The quality difference between the prioritized and the non-prioritized content is equal to $\Delta q = 1 - q_S$ in the interior equilibrium with priority to the weak. For $d > 0$

and $\Delta q > 0$, the privileged content has an extra audience compared to the neutral regime and, as we will discuss in Section 5, the ISP can extract part of this benefit in a previous stage of the game.

In our model, the quality differential Δq, which is a form of vertical differentiation between content, and the price differential d can be easily compared. The indifferent consumers under ZR and P are located at:

$$x^{ZR} = \frac{1+a}{2} - \frac{d}{2\tau}, \quad x^P = \frac{1+a}{2} - \frac{\Delta q}{2\tau}.$$

Comparing the indifferent consumers x^{ZR} and x^P which define the market shares of each CP, it is clear that a price differential d has the same impact as an equivalent quality differential Δq. In this sense, price differential d can be interpreted as creating vertical differentiation between content types, facilitating the comparisons between price and quality differentiation. The ISP creates more "distortion" on the market for content with quality differentiation than with price differentiation if $\Delta q \geq d$ as in this case $x^P \leq x^{ZR}$ i.e. the extra audience gained by the privileged content is larger.

The logic of price discrimination is to charge a higher price for the content that consumers like the most. In our model, this is captured by the "home market" of the strong content. A higher parameter a (more consumers preferring the strong content), translates into a higher surcharge $d = a\tau/2$. This logic applies independently of the network congestion, as the ISP offers the same download quality. Therefore the optimal surcharge d does not depend on the bandwidth capacity κ.

On the contrary, the possibility to differentiate content with respect to download quality depends on the bandwidth capacity κ.[11] With a large bandwidth (κ close to 1), the differentiation between content is limited, while for more severe congestion, differentiation Δq will be larger. In other words, the quality differential Δq is decreasing in κ. Furthermore, we show that:

Lemma 2 *There exists* $\kappa_1 = 1 - \frac{a\tau(2+a)}{8}$ *such that for* $\kappa = \kappa_1$, $\Delta q = \frac{a\tau}{2} = d$.

A direct consequence of this result is that $x^P < x^{ZR}$ for $\kappa < \kappa_1$ i.e. prioritization has a greater impact on the market for content than zero-rating when congestion is relatively severe. Conversely, $x^P > x^{ZR}$ holds for $\kappa > \kappa_1$, i.e. for more limited congestion.

[11] Assuming that the ISP will not deliberately slow down content when there is capacity available.

4.2 Prices and profits

We now look at the impact of these distortions on the ISP and the consumers. The prices p^{ZR} and p^{NN} are both linearly increasing in κ with a slope equal to 1. This means that, the benefit of increasing the bandwidth and therefore the quality delivered to consumers can be fully captured by the ISP in a neutral or a zero-rating regime. And, as we have shown earlier, the profit of the ISP is larger under zero-rating than under net neutrality as $\tilde{p}^{ZR} > p^{NN}$. Hence, it always pays for the ISP to zero-rate the weak content.

On the other hand, the price p^P is not linear but strictly concave in κ. With prioritization, quality is not uniform across consumers and content; it is equal to 1 on the fast lane and to q_i on the slow lane. Therefore, should the ISP increase the bandwidth, it will only benefit those who are on the slow lane, i.e. consumers of the non-prioritized content. Furthermore, the benefit of a larger bandwidth for consumers on the slow lane is larger when this extra capacity is shared between few of them i.e. when the non-prioritized content has a lower market share. Since this market share x^P increases in κ, the benefit of increasing capacity is increasing but concave in κ. As the price charged by the ISP reflects the benefit of the marginal consumer, the price is concave too. We will show (Lemma 4) that for exactly the same reason, the consumer surplus is convex in κ.

Comparing the prices $\tilde{p}^{ZR}$ and p^P, we show that the average price is always higher under ZR than under P except for $\kappa = \kappa_1$ where they are equal. Comparing the prices under NN and P, we find that p^P is larger than p^{NN} if $\kappa \geq \kappa_2 = 1 - \frac{a\tau}{2}$, with $\kappa_2 < \kappa_1$. We summarize our findings in the following lemma:

Lemma 3 *(1) If $\kappa_2 \geq \kappa^*$, then $\tilde{p}^{ZR} \geq p^P \geq p^{NN}$ for all $\kappa \in [\kappa_2, 1]$ and $\tilde{p}^{ZR} \geq p^{NN} \geq p^P$ for all $\kappa \in [\kappa^*, \kappa_2]$. (2) If $\kappa_2 \leq \kappa^*$, then $\tilde{p}^{ZR} \geq p^P \geq p^{NN}$ for all $\kappa \in [\kappa^*, 1]$.*

The results of Lemma 3 are represented on Figure 2. Lemma 3 shows that without side payment from the content providers, the ISP will always implement a zero-rating policy with the weak content being privileged.

4.3 Consumer surplus

We now turn to the comparison of the consumer surplus. To understand our comparison, it is important to recall three important features of the model. First, the average quality is the same in all the configurations we considered (and equal to κ), and in particular, there is no

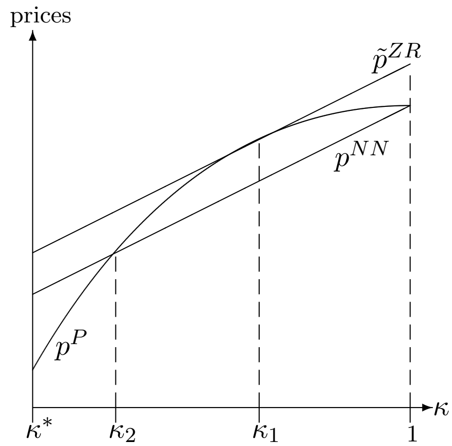

Figure 2: Prices under NN, ZR and P for $\kappa_2 > \kappa^*$.

improvement of the average quality under prioritization. Second, under NN and ZR, prices are linear in κ so any quality increase is fully captured by the ISP. Last, transportation costs are minimized if there is no discrimination between content types i.e. they are the lowest under net neutrality. These observations lead to the immediate conclusion that the consumer surplus is higher under NN than under ZR.[12] In both cases, the surplus is independent of κ and equal to :

$$CS^{NN} = v + \kappa - p^{NN} - \int_0^a \tau(a-t)\mathrm{d}t - \int_a^{x^{NN}} \tau(t-a)\mathrm{d}t - \int_{x^{NN}}^1 \tau(1-t)\mathrm{d}t = \tau\left(\frac{1}{4} - \frac{3}{4}a^2\right),$$

$$CS^{ZR} = v + \kappa - p^{ZR} - \int_0^a d + \tau(a-t)\mathrm{d}t - \int_a^{x^{ZR}} d + \tau(t-a)\mathrm{d}t - \int_{x^{ZR}}^1 \tau(1-t)\mathrm{d}t,$$

which simplifies to

$$CS^{ZR} = \tau\left(\frac{1}{4} - \frac{15}{16}a^2\right) = CS^{NN} - \tau\frac{3}{16}a^2.$$

We now integrate the prioritization case in our comparisons. The surplus is equal to:

$$CS^P = v - p^P + \int_0^a q_S - \tau(a-t)\mathrm{d}t + \int_a^{x^P} q_S - \tau(t-a)\mathrm{d}t + \int_{x^P}^1 1 - \tau(1-t)\mathrm{d}t,$$

[12] Remember that our model is a fixed demand model and that zero-rating does not lead to an increased global consumption of content. If it were the case, there would be two additional effect at play. First, consumption increases which benefits the consumers and to a certain extent the ISP that can then charge higher prices to capture the additional consumers' benefit. Second, congestion increases which would undoubtedly hurt consumers. For these reasons, it is not clear at all that zero-rating would harm or benefit consumers in a context of variable demand (Somogyi (2018) discusses this point in detail.)

which simplifies to

$$CS^P = v + \kappa - p^P - \int_0^a \tau(a-t)\mathrm{d}t - \int_a^{x^P} \tau(t-a)\mathrm{d}t - \int_{x^P}^1 \tau(1-t)\mathrm{d}t.$$

Contrary to the other cases, the surplus is not constant in κ, as x^P is concave in κ.

Lemma 4 *The consumer surplus under P is convex in κ with $CS^P = CS^{NN}$ for $\kappa = 1$ and $\frac{\partial CS^P}{\partial \kappa} = 0$ for $\kappa = \kappa_2$.*

Comparing the surplus under NN and P, it is clear that for all $\kappa_2 \leq \kappa < 1$, $CS^{NN} > CS^P$ as the price and the transportation cost are both higher under P. For lower values of κ, prioritization leads to a lower price but still a higher transportation cost. We can show that:

Lemma 5 *There exists $\kappa_3 = 1 - a\tau + \alpha^2\tau < \kappa_2$ such that (1) If $\kappa_3 \leq \kappa^*$, the consumer surplus is the highest under net neutrality for all $\kappa \in [\kappa^*, 1]$. (2) If $\kappa_3 \geq \kappa^*$, $CS^P \geq CS^{NN}$ for $\kappa \in [\kappa^*, \kappa_3]$ and $CS^P \leq CS^{NN}$ for $\kappa \in [\kappa_3, 1]$.*

The consumer surplus under P, ZR and NN is represented on Figure 3. From Lemma 2 and 3, it follows that for κ_1, the surplus is the same under P and ZR. Formally the comparison between the two cases can be summarized as follows:

$$CS^{ZR} \geq CS^P \text{ if } \kappa \in [\kappa_4 = \frac{8 - 6a\tau + 3a^2\tau}{8}, \kappa_1 = \frac{8 - 2a\tau - a^2\tau}{8}].$$

4.4 Welfare

The total welfare is defined as the sum of $CS + \pi^{ISP} + \sum_{i=S,W} \pi^{CP_i}$. In our model with unit consumption and covered market, the profits of the CPs are constant and the price paid from consumers to the ISP are pure transfers. Therefore, the welfare is equal to $v+\kappa-T+\rho$, where T is the total transportation cost supported by consumers. Therefore, welfare is highest in the regime where the transportation costs are lowest. Transportation costs are minimized when $x = \frac{1+a}{2}$ and this solution is implemented under net neutrality. This implies that discrimination of content by the ISP - either in price or in quality- is never welfare-improving. This result does not come as a surprise as in our model, discrimination is only a tool for the ISP to alter competition on the market for content and does not have added value. Comparing P and ZR, the solution leading to higher welfare is the one where the market share of CP_W is the smaller (see Lemma 2 for details).

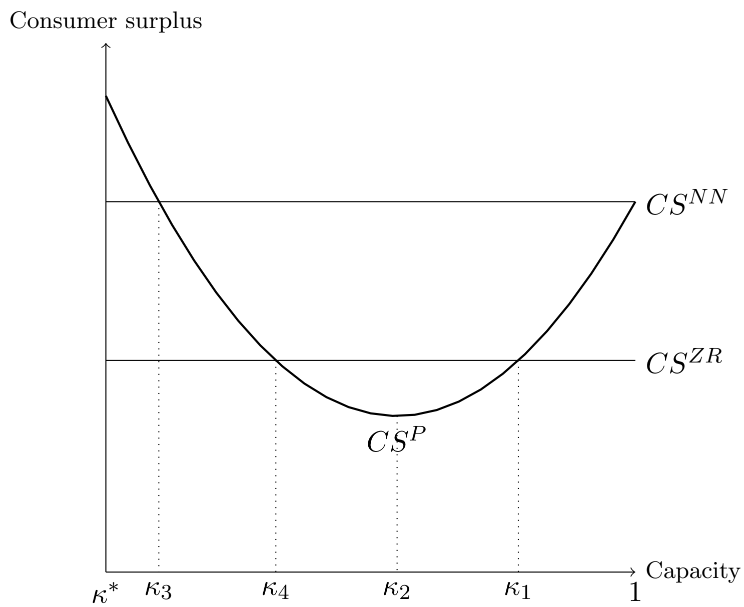

Figure 3: Consumer surplus under NN, ZR and P for $\kappa_3 \geq \kappa^*$.

5 Potential transfers from the CPs to the ISP

In the previous section we search for the preferred policy for the ISP, ignoring that CPs can compensate the ISP for having a privileged treatment. In this section, we solve the full game and investigate how the ISP's ability to extract money from the CPs alters market outcomes.

Importantly, we assume that in the beginning of the game the ISP credibly commits itself to offering only one type of preferential treatment: either paid prioritization or zero-rating (or nothing), and this becomes common knowledge among all players. Therefore, after committing to paid prioritization, it cannot threaten a CP to approach its competitor with a zero-rating offer and vice versa. In other words, we restrict the ISP's possible threats in the bargaining stage, simplifying the analysis considerably. Given the regime chosen at stage 1, CPs are competing for preferential treatment. CPs simultaneously submit offers to the ISP who then either accepts one of the offers or rejects both. In the latter case the neutral regime applies. Finally, an offer consists in a transfer from the CP to the ISP and does not include a commitment to the price charged to consumers. In other words, the ISP subsequently plays one of the price subgames described in Section 3.

5.1 Zero-rating offers

In this subsection we investigate the outcome of a subgame in which the ISP is restricted to zero-rating offers.

In the previous analysis we established that in the absence of transfers from CPs to the ISP, the optimal zero-rating policy of the ISP is zero-rating the weak CP, corresponding to the case described above with $d > 0$. It also clearly follows that the ISP will never benefit from zero-rating the strong CP. So, in the case where the game ends with zero-rating the strong content (corresponding to $d < 0$), in the subsequent price subgame, the ISP will choose a value for the discount d as close as possible to zero. This means that zero-rating the strong content is equivalent to the NN situation.

Therefore the credible threat point of the ISP in case its offer is refused by the weak CP is the NN situation. If implemented, the weaker CP loses the market share of $(1 - x^{ZR}) - (1 - x^{NN})$, thus its maximal willingness to pay for the preferential treatment is $\rho(x^{NN} - x^{ZR}) > 0$. The strong CP's maximal bid is the same amount, as it knows that it is never in the ISP's interest to zero-rate its content. Its loss of revenue from its competitor being zero-rated instead of the NN situation is exactly $\rho(x^{NN} - x^{ZR})$. Given that if the ISP accepts the offer of the strong firm, it looses revenue from the consumers as $p^{NN} < \tilde{p}^{ZR}$, the outcome will be to zero-rate the weak firm.

It remains to determine the optimal bid. There are two cases depending on the size of the CPs' advertising revenue, ρ. First, if it is sufficiently large that the maximal bid of the strong CP compensates the ISP for the loss of revenue, i.e., if

$$\rho(x^{NN} - x^{ZR}) + p^{NN} > \tilde{p}^{ZR} \quad \Leftrightarrow \quad \rho > \frac{\tilde{p}^{ZR} - p^{NN}}{x^{NN} - x^{ZR}} \equiv \rho^{ZR} = \frac{a\tau}{2} \tag{1}$$

then the weaker firm must bid a positive amount to get the zero-rating agreement. In particular, in equilibrium the weak CP's bid equals

$$\rho(x^{NN} - x^{ZR}) + p^{NN} - \tilde{p}^{ZR} > 0$$

which is positive given $\rho > \rho^{ZR}$ and smaller as its maximal willingness to bid as $\tilde{p}^{ZR} > p^{NN}$.

Second, if advertising revenues are relatively small, $\rho \leq \rho^{ZR}$, then (1) is not satisfied, thus the stronger CP's maximal bid is insufficient to compensate for the ISP's loss of profits, therefore the weak firm gets zero-rated for free, and its optimal bid is 0.

Generally, the weak CP bids $\max\{0;\ \rho(x^{NN}-x^{ZR})+p^{NN}-\tilde{p}^{ZR}\}$ and wins the zero-rating contract. The ISP's overall profit is given by $\max\{\tilde{p}^{ZR};\ \rho(x^{NN}-x^{ZR})+p^{NN}\}$.

5.2 Paid prioritization offers

In this subsection we investigate the outcome of a subgame after the ISP chooses the paid prioritization regime in the previous stage.

Although from the previous section we know that under $\kappa \geq \kappa^*$ prioritizing the weak CP is the best prioritizing option for the ISP, the payment the ISP can extract from the CPs depend on the exact value of its profit when prioritizing the strong CP. The next Lemma identifies a necessary and sufficient condition for the interior solution to be optimal for the ISP in case it offers priority to the strong CP, analogously to Lemma 1 and Proposition 1.

Lemma 6 *The interior solution of the pricing subgame with the* stronger *CP having priority leads to a higher price than all other potential equilibria of the subgames involving prioritizing the strong CP whenever such an equilibrium exists, i.e. for* $\kappa \geq \frac{1+\tau+a\tau}{2\tau}$. *The ISP's profit is then given by* p_S^P.

Notice that the condition of Lemma 6 is stronger than the condition of Proposition 1, but they are qualitatively similar: they both require a relatively high level of capacity and horizontal differentiation. For the subsequent analysis, we will assume that this condition holds but as we discuss below, our results do not qualitatively depend on this parameter restriction.

Two cases have to be distinguished according to the severity of congestion, which determines the relative ranking of optimal prices.

Case 1: $\boldsymbol{\kappa > \kappa_2}$**.** In this case $p^{NN} < p^P$. This means that, first, the ISP is better-off prioritizing the weak CP compared to the neutral situation, and second, that the weak CP is better-off being prioritized. Consequently, a neutral regime is never implemented, at worst the weak CP offers 0 and the ISP accepts this bid.

Following the logic laid out above in the zero-rating case, we first determine the strong firm's maximal bid. Its maximal bid equals $\rho(x_S^P - x_W^P)$. The weak CP must then bid

$$\max\{0;\ \rho(x_S^P - x_W^P) + p_S^P - p^P\}$$

to win the contract, and the ISP's profit is given by $\max\{p^P;\ \rho(x_S^P - x_W^P) + p_S^P\}$.

Case 2: $\kappa \leq \kappa_2$**.** If the level of capacity is below κ_2 then $p^P < p^{NN}$ and in the absence of a sufficiently large payment from one of the CPs, the ISP prefers neutrality. Consequently, in order to be prioritized, the weak CP must overturn both neutrality and priority to the strong CP.

Let b^S denote the maximal willingness to pay of the strong CP to overturn net neutrality, $\rho(x_S^P - x^{NN})$. Let b^W be the corresponding value of the weak CP, $\rho(x^{NN} - x_W^P)$. If $b^W < p^{NN} - p^P$ and $b^S < p^{NN} - p_S^P$ are jointly satisfied then none of the CPs find it profitable to compensate the ISP's loss from prioritization, therefore net neutrality arises as an equilibrium outcome.

If ρ is large enough that at least one of these inequalities is not satisfied, then net neutrality will surely be overturned by a large enough bid. Therefore the maximal bid of the strong firm is $\rho(x_S^P - x_W^P)$, as before. Following similar steps to above, in equilibrium the weak firm secures the paid priority contract by bidding $\max\{p^{NN} - p^P;\ \rho(x_S^P - x_W^P) + p_S^P - p^P\}$ and the ISP's profit is $\max\{p^{NN};\ \rho(x_S^P - x_W^P) + p_S^P\}$.

5.3 ISP's choice between paid prioritization and zero-rating

Next we investigate the ISP's decision in a regulatory environment where the ISP is free to choose either prioritization or zero-rating.

The level of CPs' advertising revenues is a key factor in the ISP's choice. From the previous results it clearly follows that for low advertising revenues the ISP prefers zero-rating as $\tilde{p}^{ZR} > p^P$. Intuitively, with low advertising revenues, the CPs cannot afford to compensate the ISP for switching to the other regime, as it would result in relatively large losses on the consumer side.

Conversely, with high advertising revenues the large payments from CPs to the ISP can dwarf the eventual loss of ISP profit from the consumer side when it changes to paid priority programs. Under certain conditions, prioritization creates a larger divide in market shares than zero-rating programs, making them more attractive for the ISP when advertising revenues are high. The next Proposition formalizes these findings.

Proposition 2 *There exist $\kappa' \in (\kappa_1, 1)$ and $\overline{\rho}(\kappa) > 0$ such that prioritization is the equilibrium choice of the ISP for $\kappa < \kappa'$ and $\rho \geq \overline{\rho}(\kappa)$. Otherwise the ISP chooses zero-rating in equilibrium.*

Intuitively, to overturn the zero-rating regime, prioritization must create a larger distortion in market shares than zero-rating. For that, the quality differential between the prioritized and the non-prioritized content should be large enough, which corresponds to a relatively low value of capacity. In addition, traffic should be sufficiently valuable for CPs, as captured by the level of advertising revenues.[13]

Proposition 2 describes the optimal policy choice of the ISP in a laissez-faire regime. The consequences of this choice on consumers can be easily inferred from Figure 3. We observe that, when congestion is limited, zero-rating is always harmful to consumers independently of ρ. Note that for large ρ, zero-rating is implemented precisely when congestion is limited. Hence, for $\rho \geq \overline{\rho}$, when zero-rating is chosen, it is the worst outcome for consumers (as $\kappa' \geq \kappa_1$). Next, when prioritization is implemented, it benefits consumers only if congestion is severe ($\kappa \leq \kappa_4$). In those cases, the price charged to consumers is low and the ISP creates a large distortion on the content market. Hence, it manages to extract a large payment from the prioritized CP. The lower revenues on the consumer side are more than compensated by higher transfers on the CP side. In that sense, the CP 'subsidizes' the consumers who thus benefit from this policy. We summarize this discussion in the following corollary.

Corollary 2 *Regarding the choice between zero-rating and prioritization, for low congestion levels ($\kappa \geq \kappa'$), the interests of the ISP and the consumers are opposed; for severe congestion ($\kappa \leq \kappa_4$), the interests of the ISP and the consumers are congruent if ρ is large.*

6 Extensions

6.1 Prioritization and zero-rating

In our baseline model, we give to the ISP the choice between two forms of discrimination in price or in quality. In this section, we consider the situation in which the ISP can discriminate both in price *and* in quality. In this case, content $i = S, W$ has a quality q_i and is offered at price p_i. We will show that ISP will not necessarily set a higher price for the higher quality. The ISP can zero-rate the non-prioritized or the prioritized content and there are real-life examples of both. In practice, ISPs have created such situations by throttling specific content. An example of zero-rating of non-priority content is T-Mobile's Binge On program where the zero-rated video content is not available in HD (the resolution is limited to 480p). At the same time, in Europe there have been examples for zero-rated priority content. Some

[13] This logic is independent of the type of equilibrium under prioritization. In particular, even if an interior solution with priority to the strong CP does not exist, prioritization will be implemented provided that it leads to a sufficiently strong distortion in market shares combined with high value for traffic.

ISPs offered zero-rating contracts where the traffic was slowed down or eventually interrupted for all content but the zero-rated one when the monthly data cap was reached.[14] Thus, the price and quantity discrimination are not necessarily going in the same direction.

As before, let us write $p_S = p + d$, where d can be positive or negative. With priority and zero-rating, the location of the indifferent consumer x is given by:

$$v + q_S - p - d - \tau(x - a) = v + q_W - p - \tau(1 - x) \quad \Leftrightarrow \quad x = \frac{1+a}{2} - \frac{d}{2\tau} + \frac{q_S - q_W}{2\tau}.$$

Taking qualities (q_S, q_W) as given and solving the ISP's maximization problem, the optimal prices are: $d = \frac{a\tau}{2} + \frac{q_S - q_W}{2}$ and $p = v + \frac{q_S + 3q_W}{4} - \frac{\tau}{2} + \frac{a\tau}{4}$. At these prices, the market share of the CP_S is given by $\hat{x} = \frac{2+a}{4\tau} + \frac{q_S - q_W}{4\tau}$. In an interior equilibrium with priority to the strong CP, we have $q_S = 1$ and $q_W = \frac{\kappa - \hat{x}}{1 - \hat{x}}$; with priority to the weak CP, we have $q_S = \frac{\kappa - (1-\hat{x})}{\hat{x}}$ and $q_W = 1$. Similarly to the prioritization case, finding the solution involves a fixed-point problem.

Analogously to Proposition 1, we can show that when combined with zero-rating, the ISP prefers to give priority to the weak content in an interior equilibrium whenever such an equilibrium exists.

Proposition 3 *An interior equilibrium with prioritization and zero-rating exists for* $\kappa \geq 1 - \frac{(2+a)^2\tau}{16}$. *For these parameters and without side payments, the ISP always finds it profitable to prioritize the weak CP. The weak CP is also zero-rated if* $\kappa \geq 1 - \frac{a\tau}{2}$, *and the strong CP is zero-rated if* $1 - \frac{(2+a)^2\tau}{16} \leq \kappa \leq 1 - \frac{a\tau}{2}$. *However, for the ISP, prioritization combined with zero-rating results in a lower profit than zero-rating alone.*

With prioritization of the weak CP, the price differential d is equal to $\frac{a\tau}{2} - \frac{1-q_S}{2}$. It increases with a and decreases with the quality differential. Whenever the capacity is limited, the quality differential is large and the ISP zero-rates the non-prioritized content ($d < 0$). Conversely, for larger capacity, the quality differential is limited and the prioritized content is also zero-rated. In this case, price discrimination reinforces quality discrimination.

However, the profit with prioritization and zero-rating is lower than the profit with zero-rating alone as long as there is some congestion i.e. for all $\kappa < 1$. Thus, without side-payments, the ISP will use just one out of the two available instruments, the price, to discriminate between content. This is reminiscent of the results of Economides (1989), and Neven and

[14] These contracts with zero-rating and throttling were considered to be a violation of the European net neutrality regulations and later forbidden (see Krämer and Peitz, 2018 on these points).

Thisse (1989) who show that firms choose maximal differentiation in one dimension (the price in our model) and minimal differentiation in the other (the quality in our model).

Finally, could the combination of priority and zero-rating ever emerge in the presence of side payments? To provide a partial answer to this question, let us consider the following situation. Assume that $\kappa \geq 1 - \frac{a\tau}{2}$ and that the ISP chooses zero-rating in equilibrium (see the condition in Proposition 2). The weak content provider benefits from being prioritized on top of being zero-rated as its market share increases compared to the case where it is only zero-rated. Hence, it is ready to pay more for benefiting from price and quality discrimination. However, the ISP will lose revenue from the consumer side (see Lemma 3). Then if the benefit of the CP is larger than the loss of the ISP, implementing prioritization and zero-rating against compensation is mutually profitable. Formally, a sufficient condition for this is

$$\rho(x_W^{P+ZR} - x_W^{ZR}) > \pi^{ZR} - \pi_W^{P+ZR}.$$

This demonstrates that even if the combination of prioritization and zero-rating reduces ISP revenues from the user side, it can emerge at equilibrium if the revenue from the CP side is large enough to compensate it, i.e. if advertising revenue ρ is sufficiently large.

6.2 Investment in capacity

In the baseline model, we have assumed that the capacity of the ISP is exogenous. In this section we relax this assumption and let the ISP invest in costly capacity building at an initial stage of the game. Investment incentives of different regulatory regimes on the internet are an important aspect of both the policy debate and the academic literature (see e.g. Choi and Kim (2010); Economides and Hermalin (2012); Bourreau et al. (2015)). On the one hand, opponents of net neutrality claim that the additional revenue from the CP side is necessary for the ISP to finance capacity building. On the other hand, advocates of net neutrality fear that allowing preferential treatment creates perverse incentives for the ISP to keep capacity levels low in order to continue extracting benefits from the CP side.

As discussed in Section 4.4, total welfare is strictly increasing and linear in capacity level κ. Assuming the cost of capacity building $c(\kappa)$ is strictly increasing and convex, the socially optimal capacity level is given by

$$\min\{1;\ \kappa^o\} \quad \text{where} \quad c'(\kappa^o) = 1.$$

Note that the ISP's overall profit under the zero-rating regime, $\max\{\tilde{p}^{ZR};\ \rho(x^{NN}-x^{ZR})+p^{NN}\}$, is also linearly increasing in capacity, thus the ISP's investment incentives are completely aligned with the social optimum: it also builds $\min\{1;\ \kappa^o\}$. Intuitively, zero-rating, a form of price discrimination, does not require congestion to be profitable. Therefore, the ISP can capture all the benefits from improved capacity, as it is also the case under net neutrality.

On the contrary, under prioritization, the capacity level chosen by the ISP is generically socially suboptimal. There are two effects at play. First, prices under prioritization are strictly concave in capacity κ. Second, congestion reinforces the distortion on the content market created by prioritization. The lower the capacity levels, the higher the distortion is, and consequently the higher the level of side payments the ISP can extract from the prioritized CP.

Whenever prioritization is optimal, the ISP's profit equals $p_S^P+\rho(x_S^P-x_W^P)$. The investment in capacity under prioritization is given by

$$\frac{\mathrm{d}p_S^P}{\mathrm{d}\kappa}+\rho\frac{\mathrm{d}(x_S^P-x_W^P)}{\mathrm{d}\kappa}=c'(\kappa)$$

By concavity, the first term is larger (lower) than 1 if κ is lower (larger) than a threshold value κ_5. The second term represents the distortion effect and is thus always negative. Clearly, there exists a cutoff $\widehat{\rho}(\kappa)$ such that the profit-maximizing capacity level is lower than the socially optimal one if either (i) $\kappa \geq \kappa_5$ or (ii) $\rho \geq \widehat{\rho}(\kappa)$.

Proposition 4 *Under zero-rating, the ISP's investment in capacity is always at the socially optimal level of* $\min\{1;\ \kappa^o\}$. *Under prioritization, the ISP chooses a level of capacity below the socially optimal level whenever (i)* $\kappa \geq \kappa_5$ *or (ii)* $\rho \geq \widehat{\rho}(\kappa)$.

Under prioritization the ISP may have an incentive to sustain an inefficiently high level of congestion in order to extract more payments from the CP side. This happens when advertising revenues are sufficiently large, which is precisely the condition for the ISP implementing prioritization (see Proposition 2). Thus prioritization may create a trap for the ISP in the sense that a medium initial capacity level leads to reduced subsequent investment, especially for high advertising revenues, reflecting the fear of net neutrality advocates.

6.3 Vertical integration

So far we have assumed that the ISP and the content providers are independent profit-maximizing firms. However, in several important instances, ISPs zero-rate or prioritize content produced by their own subsidiaries. In the US, AT&T currently zero-rates its subsidiary DirecTV, moreover, its potential zero-rating of Time Warner content (such as CNN or HBO) has been a prominent argument in the public debate surrounding their merger.[15] In this section we investigate the effects of vertical integration between the ISP and one of the CPs.

There are two cases depending on whether the ISP is integrated with the weak or the strong CP. Considering the outcomes of the setting without integration, the former case is straightforward: the joint profit of the ISP and the weak CP is maximized whenever the weak CP is zero-rated or prioritized.

However, less clear-cut is the case of the ISP potentially giving preferential treatment to the strong CP whenever it owns it. First, consider zero-rating offers. The profit of the vertically integrated entity in case it offers zero-rating to the weak CP is $\pi_{VI}^{ZRW} = \tilde{p}^{ZR} + \rho x^{ZR}$, where the first term is the profit from the consumer side, and the second term is advertising profit. If it zero-rates the strong firm, its profit equals $\pi_{VI}^{ZRS} = p^{NN} + \rho x^{NN}$ since the best "zero-rating" contract offered to the strong CP coincides with the neutral outcome (see Section 5). If $\pi_{VI}^{ZRW} \geq \pi_{VI}^{ZRS}$ then the weak CP will be zero-rated without any side payments. If $\pi_{VI}^{ZRW} < \pi_{VI}^{ZRS}$, then the weak CP is willing to offer $\rho(x^{NN} - x^{ZR})$, its gain from increased market share, to be zero-rated. It is straightforward to show that

$$\pi_{VI}^{ZRW} + \rho(x^{NN} - x^{ZR}) > \pi_{VI}^{ZRS}.$$

Therefore the weak CP can always sufficiently compensate the vertically integrated firm to get the zero-rating contract, despite being in direct competition with it.

Second, consider prioritization. Following a similar logic, the profit of the vertically integrated entity with prioritizing the competitor is $p^P + \rho x^P$, whereas prioritizing its own content results in the profit of $p_S^P + \rho x_S^P$. Even if this latter profit is larger, the weak CP is willing to pay up to $\rho(x_S^P - x^P)$ for priority. It is straightforward to show that this sum is always sufficient to compensate the vertically integrated firm.

Intuitively, providing preferential treatment to the weak CP is so lucrative that this CP can afford to pay its vertically integrated rival enough to gain access to it. These results are summarized in the following proposition.

Proposition 5 *Whenever side payments are allowed, the weak content provider always gets preferential treatment (priority or zero-rating), even if the rival content provider is vertically integrated with the ISP.*

[15] https://www.economist.com/leaders/2018/06/16/at-and-t-and-time-warner-are-cleared-to-merge

This result stems from the assumption of efficiency of transactions in our model, in particular, the strong bargaining power of the ISP and the lack of transaction costs. If the ISP could extract surplus more efficiently under vertical integration, it would in some cases find it optimal to give preferential treatment to its own content, even if integrated with the strong CP.

Finally, note that our results are in line with Brito et al. (2014) and Guo et al. (2010) that find that paid prioritization is not necessarily offered to the integrated firms' own content, but rather to the competitor generating a higher revenue.

6.4 Heterogeneous advertising revenues

In our model, we call the strong CP the one that has a larger market share without discrimination by the ISP. Another potential difference between the CPs is their ability to monetize traffic (as in Bourreau, Kourandi, and Valletti (2015); Jullien and Sand-Zantman (2018); and Somogyi (2018)). In this extension, we investigate that case by considering $\rho_S > \rho_W$ and we show that our results are robust to this alternative specification.

In Section 5 we show that the choice of regime depends both on the valuation of traffic by the CPs and the payment the ISP can collect from the consumer side. In equilibrium, the weak CP pays less than the strong CP would be willing to pay and still secures preferential treatment because the ISP can collect more revenue from consumers when giving preferential treatment to the weak CP.

With heterogeneous advertising revenues, when traffic is more valuable for the strong CP, its bid increases relative to the bid of the weak CP. However, to overturn the regime choice of the ISP, this bid increase must be sufficiently large to compensate for the losses on the consumer side. Therefore ρ_S must be substantially larger than ρ_W to overturn the market equilibrium. In this sense, our results are robust: a limited difference between advertising revenues is not sufficient for the strong CP to gain preferential treatment.

7 Discussion

7.1 Policy implications

Previous work on net neutrality regulation compared either prioritization programs or zero-rating programs to net neutrality, never allowing the ISP to switch to the alternative preferential regime instead. Next, we highlight two potential policy interventions for which considering the three regulatory regimes within the same model is crucial to drawing the right conclusion about the welfare implications.

Ban of prioritization First, consider the regulator's choice whether to allow or ban prioritization offers. If we restrict the ISP to choose between prioritization or net neutrality, not considering the possibility of zero-rating, our model shows that the consumer surplus under prioritization is lower than under net neutrality for $\kappa \in (\kappa_3, 1)$. However, this is misleading as our model also shows that the choice of the ISP is not between priority and neutrality but between priority and zero-rating. In this case, consumer surplus is lower under priority than under zero-rating only for $\kappa \in (\kappa_4, \kappa_1)$, a proper subset of the previous interval. Furthermore, a ban on prioritization is effective only if prioritization is the optimal choice of the ISP, that is for sufficiently large values of ρ. By not considering zero-rating as a potentially harmful alternative of prioritization, models without zero-rating tend to overestimate the effects of banning prioritization.

Ban on side payments Second, we discuss the welfare consequences of a regulatory policy consisting in banning payments from the CPs to the ISP while taking a laissez-faire approach otherwise, i.e. allowing both prioritization and zero-rating programs without side payments. Whenever side payments do not influence the ISP's regime choice, they are purely transfers from the CPs to the ISP and thus inconsequential for consumer surplus. However, from Proposition 2 we know that side payments can make the ISP switch from a zero-rating regime to a prioritization regime for sufficiently high levels of congestion and advertising revenues. Such a regime change has ramifications for consumer surplus. From Lemma 5 and Figure 3, it is clear that a ban resulting in a change from prioritization to zero-rating harms consumers for $\kappa \in (\kappa^*, \kappa_4) \cup (\kappa_1, \kappa',)$, whereas the ban is beneficial for consumers for $\kappa \in (\kappa_4, \kappa_1)$.

Therefore, banning side payments can have either a positive or a negative effect on consumer surplus depending on the level of congestion. In a world without the possibility of prioritization, such a ban would have no effect on consumer surplus as zero-rating would be implemented with or without the ban. Moreover, in a world where zero-rating is prohibited, banning side payments as well would benefit consumers if and only if $\kappa \in (\kappa_3, \kappa_2)$.

The differences highlight the importance of considering all the alternative regimes within the same framework.

7.2 Conclusion

In the recent public debate about how to regulate the internet, net neutrality advocates have feared that the repeal of regulations would empower ISPs which in turn would harm consumers. On the contrary, opponents of net neutrality rules have claimed that such an empowerment of ISPs is necessary and ultimately beneficial for consumers. Our model reflects this debate by analyzing the two business practices that have recently become unrestricted in the US (prioritization and zero-rating) as new tools for the ISP to discriminate content without any inherent added value. We show that as expected, it is always in the ISPs interest to deviate from net neutrality and use one of the two business practices. In particular, the ISP implements prioritization if congestion is relatively severe and the value of content is high, otherwise it implements a zero-rating plan. Moreover, we find that for low levels of congestion zero-rating always harms consumers. Prioritization is the preferred option of both the ISP and consumers under severe congestion and high-value content, because the low price charged by the ISP to consumers is counterbalanced by large payments from the CPs. Furthermore, we find that the exclusion of a content provider is never optimal for the ISP in our model, contrary to the fears of net neutrality advocates. Finally, we show that for high-value content, vertical integration of the ISP with a CP does not lead to a socially suboptimal situation.

A first limitation of our model is that we use a Hotelling representation of demand, coupled with single-homing consumers which results in the lack of demand expansion in case of price reductions. An interesting avenue of future research is thus assuming flexible demand, either by introducing multi-homing consumers or by considering a simple spokes model. Our model investigates the ISP's intervention in the content market while assuming that CPs are rather passive. They collect advertising revenues and eventually bid for preferential treatment, but they cannot invest in making their content more attractive to consumers. A natural extension could try modelling investment incentives of CPs, as in Choi et al. (2018). Finally, modeling zero-rating and prioritization offers with competing ISPs is left to future research.

Appendix

Subscription-based business model Assume that at the beginning of the game the strong and the weak CP set subscription fees per user f_S and f_W, respectively. Then, the ISP decides on the connection price p and the surcharge d. The location of the indifferent consumer x on the Hotelling segment is:

$$v + q - p - d - \tau(x - a) - f_S = v + q - p - \tau(1 - x) - f_W \quad \Leftrightarrow \quad x = \frac{1+a}{2} - \frac{d}{2\tau} - \frac{f_S - f_W}{2\tau}.$$

Taking their effect on the marginal consumer into account, CPs maximize their total revenue from subscription fees: $f_S x$ and $f_W(1-x)$. First-order conditions imply that the optimal subscription fees are

$$f_S = \frac{\tau(3+a) - d}{3} \quad \text{and} \quad f_W = \frac{\tau(3-a) + d}{3}.$$

In this case, the price of CP_S is $\frac{2\tau a}{3} - \frac{2}{3}d$ above the price of CP_W and the location of the indifferent consumer is given by $x = \frac{3+a}{6} - \frac{d}{6\tau}$. The optimal prices charged by the ISP are:

$$d = \frac{a\tau}{2} > 0 \quad \text{and} \quad p = v + \kappa - \frac{\tau(6-a)}{4},$$

leading to a profit equal to $\pi_{ISP}^{ZR} = v + \kappa - \frac{3}{2}\tau + \frac{a\tau(12+a)}{24}$. Given that the optimal price differential, d, is strictly positive, this profit is larger than the profit under net neutrality. Therefore despite the positive subscription fees charged by the CPs, the ISP still have some room for zero-rating.

Proof of Lemma 1 There are two conditions for the existence of an interior solution of the pricing subgame when the weak CP has priority. The first is that the quadratic equation defining the location of the indifferent consumer have real root(s), which is guaranteed if and only if

$$\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau} \geq 0 \quad \Leftrightarrow \quad \kappa \geq 1 - \frac{\tau(1+a)^2}{8}.$$

The second condition is that distance between the indifferent consumer and the weaker CP is less than κ, which rewrites as

$$\frac{1+a}{4} + \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}} \geq 1 - \kappa \quad \Leftrightarrow \quad \kappa \geq \frac{1 + \tau - a\tau}{2\tau}.$$

The second condition implies the first one as $\frac{1+\tau-a\tau}{2\tau} > 1 - \frac{\tau(1+a)^2}{8}$, thus the second condition is necessary and sufficient for the existence of an interior solution of the pricing subgame when the weak CP has priority. ■

Proof of Proposition 1 In order to prove the Proposition, we will compare p_W^{INT} to all other potential equilibrium prices under the condition $\kappa \geq \frac{1+\tau-a\tau}{2\tau}$. There are six other potential equilibria: the interior solution when the strong CP is prioritized derived in the main text, the two corner equilibria (one where the strong, one where the weak CP has priority), and three semi-corner equilibria (the one where the strong CP has priority, and two where the weak CP has priority, depending on whether $x \lesseqgtr a$).

Interior equilibrium when the strong CP is prioritized: the Proposition holds if and only if the price derived in the main text, p_S^{INT} is below p_W^{INT}, i.e.

$$v+1-\tau\left(\frac{3(1-a)}{4}-\sqrt{\frac{(1-a)^2}{16}-\frac{1-\kappa}{2\tau}}\right)<v+1-\tau\left(\frac{3-a}{4}-\sqrt{\frac{(1+a)^2}{16}-\frac{1-\kappa}{2\tau}}\right).$$

Clearly, this is equivalent to

$$\frac{3(1-a)}{4}-\sqrt{\frac{(1-a)^2}{16}-\frac{1-\kappa}{2\tau}}>\frac{3-a}{4}-\sqrt{\frac{(1+a)^2}{16}-\frac{1-\kappa}{2\tau}}.$$

which rewrites as

$$a/2>\sqrt{\frac{(1+a)^2}{16}-\frac{1-\kappa}{2\tau}}-\sqrt{\frac{(1-a)^2}{16}-\frac{1-\kappa}{2\tau}}.$$

After squaring both sides of the inequality (both sides being positive) and rearranging, we get

$$\frac{(1-a)(1+a)}{16}-\frac{1-\kappa}{2\tau}>\sqrt{\left(\frac{(1+a)^2}{16}-\frac{1-\kappa}{2\tau}\right)\left(\frac{(1-a)^2}{16}-\frac{1-\kappa}{2\tau}\right)}.$$

Using that the condition in the Proposition implies $\frac{(1-a)^2}{16}-\frac{1-\kappa}{2\tau}>0$, both the term on the left-hand side and the term under the square root are positive. Squaring both sides of the inequality and rearranging results in

$$a^2>0 \quad \Leftrightarrow \quad p_W^{INT}>p_S^{INT}$$

which is what we wanted to show.

Corner equilibrium when the strong CP is prioritized: A corner equilibrium occurs when the prioritization of the stronger firm makes it so attractive that even the farthest consumer, the one located at 1 prefers buying its product. In this situation, the quality of the prioritized firm is κ, whereas the quality of its competitor is 0. The strong firm can then extract all the surplus of the farthest customer and thus charges $p_S^C = v + \kappa - \tau(1-a)$. We must then show that

$$p_S^C < p_W^{INT} \quad \Leftrightarrow \quad v + \kappa - \tau(1-a) < v + 1 - \tau\left(\frac{3-a}{4} - \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}\right)$$

which after rearranging the terms rewrites as

$$\sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}} > \frac{3a-1}{4} - \frac{1-\kappa}{\tau}.$$

Notice that the left-hand side is always positive while the right-hand side is always negative as we assumed $a < 1/7$ and $\kappa \leq 1$. Therefore $p_S^C < p_W^{INT}$ always holds.

Corner equilibrium when the weak CP is prioritized: A corner equilibrium occurs when the prioritization of the weak CP makes it so attractive that even the farthest consumer, the one located at 0 prefers buying from it. In this situation, the quality of the prioritized firm is κ, whereas the quality of its competitor is 0. The strong firm can then extract all the surplus of the farthest customer and thus charges $p_W^C = v + \kappa - \tau$. Notice that $p_W^C = v + \kappa - \tau < p_S^C = v + \kappa - \tau(1-a)$, and above we showed that $p_S^C < p_W^{INT}$, therefore $p_W^C < p_W^{INT}$ always holds.

Semi-corner equilibrium when the strong CP is prioritized: A semi-corner equilibrium occurs when the non-prioritized (weaker) firm provides 0 quality but still serves some consumers thanks to the large value of internet connection v. Such a situation arises whenever the indifferent consumer is located in the $[\kappa,1)$ interval, leading to the stronger firm providing quality κ/x. The location of the indifferent consumer x is given by

$$v + \frac{\kappa}{x} - p - \tau(x-a) = v + 0 - p - \tau(1-x),$$

which leads to two potential solutions:

$$\frac{1+a}{4} - \sqrt{\frac{(1+a)^2}{16} + \frac{\kappa}{2\tau}} \quad \text{and} \quad x_S^{SC} = \frac{1+a}{4} + \sqrt{\frac{(1+a)^2}{16} + \frac{\kappa}{2\tau}}.$$

However, it is easy to see that the first one is negative, thus we can focus our attention to x_S^{SC}, leading to the price of

$$p_S^{SC} = v - \tau(1 - x_S^{SC}) = v - \tau\left(\frac{3-a}{4} - \sqrt{\frac{(1+a)^2}{16} + \frac{\kappa}{2\tau}}\right)$$

therefore

$$p_S^{SC} < p_W^{INT} \quad \Leftrightarrow \quad \sqrt{\frac{(1+a)^2}{16} + \frac{\kappa}{2\tau}} - \sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}} < \frac{1}{\tau}.$$

Both sides of the inequality being positive, squaring them and rearranging leads to

$$L \equiv \frac{(1+a)^2}{16} + \frac{\kappa}{2\tau} - \frac{1}{4\tau} - \frac{1}{2\tau^2} < \sqrt{\frac{(1+a)^2}{16} + \frac{\kappa}{2\tau}}\sqrt{\frac{(1+a)^2}{16} - \frac{1-\kappa}{2\tau}}$$

This inequality is satisfied either if either (i) the term on left-hand side is non-positive, i.e. $L \leq 0$; or (ii) the square of both positive numbers also satisfy the inequality. (i) can be rewritten as

$$L \leq 0 \quad \Leftrightarrow \quad \kappa \leq \frac{4\tau - a^2\tau^2 - 2a\tau^2}{8\tau} + \frac{8-\tau^2}{8\tau} \equiv \kappa',$$

whereas (ii) leads to

$$\kappa > \frac{4\tau - a^2\tau^2 - 2a\tau^2}{8\tau} + \frac{4}{8\tau} \equiv \kappa''.$$

For $\tau \leq 2$ we have $\kappa'' \leq \kappa'$ thus (i) or (ii) is satisfied for any κ, therefore $p_S^{SC} < p_W^{INT}$.

For $\tau > 2$, it is easy to check that

$$\frac{1+\tau-a\tau}{2\tau} > \kappa''$$

thus the condition of the Proposition, $\kappa \geq \frac{1+\tau-a\tau}{2\tau}$, guarantees that (ii) is always satisfied, leading to $p_S^{SC} < p_W^{INT}$, which concludes this part of the proof.

Semi-corner equilibrium when the weak CP is prioritized: Finally, we investigate the equilibria leading to a situation where the non-prioritized (stronger) firm provides 0 quality while still serving some consumers due to the large value of internet connection v. Such a situation arises whenever the indifferent consumer (at position x) is located in the $[0, 1-\kappa)$

interval. In a semi-corner equilibrium the weaker firm provides quality $\kappa/(1-x)$ to the $1-x$ consumers closest to it.

We have to distinguish two cases depending on the location of the indifferent consumer. Firstly, if it is located to the right of CP1, i.e. $x \in (a, 1-\kappa)$, then x is given by

$$v + 0 - p - \tau(x - a) = v + \frac{\kappa}{1-x} - p - \tau(1-x),$$

which leads to two potential solutions:

$$x_1 = \frac{3+a}{4} - \sqrt{\frac{(1-a)^2}{16} + \frac{\kappa}{2\tau}} \quad \text{and} \quad x_2 = \frac{3+a}{4} + \sqrt{\frac{(1-a)^2}{16} + \frac{\kappa}{2\tau}}.$$

However, it is easy to show that $x_2 > 1$, thus we can focus our attention to x_1. Notice that one of the conditions for x_1 being a semi-corner equilibrium, $x_1 < 1-\kappa$, rewrites as

$$\kappa - \frac{1-a}{4} < \sqrt{\frac{(1-a)^2}{16} + \frac{\kappa}{2\tau}}.$$

The condition of the Proposition, $\kappa \geq \frac{1+\tau-a\tau}{2\tau}$, implies that $\kappa > \frac{1-a}{2}$ thus both sides of the inequality are positive. Squaring and rearranging reveals that $\kappa < \frac{1+\tau-a\tau}{2\tau}$ is a necessary condition for the existence of such an equilibrium, which is ruled out by the condition of the Proposition.

Secondly, if the indifferent consumer is located to the left of CP1, i.e., $x \in (0, a]$, then its location is given by

$$v + 0 - p - \tau(a - x) = v + \frac{\kappa}{1-x} - p - \tau(1-x),$$

which leads to

$$x_W^{SC3} = 1 - \frac{\kappa}{\tau(1-a)} \quad \text{and} \quad p_W^{SC3} = v - \frac{\kappa}{1-a} + \tau(1-a).$$

Notice that one of the necessary conditions for the existence of such a semi-corner solution is

$$x_W^{SC3} < a \quad \Leftrightarrow \quad \tau(1-a)^2 < \kappa,$$

therefore $\tau(1-a)^2 < 1$ is also necessary, otherwise it would require $\kappa > 1$.

Next, notice that the price p_W^{SC3} is decreasing in κ whereas the price p_W^{INT} is increasing in κ. We will prove $p_W^{SC3} < p_W^{INT}$ by showing that it is satisfied even at the lower bound of possible values of κ. To see this, replacing $\kappa = \tau(1-a)^2$ into the prices we have

$$p_W^{SC3} < p_W^{INT} \quad \Leftrightarrow \quad \frac{3-a}{4} - \frac{1}{\tau} < \sqrt{\frac{(1+a)^2}{16} + \frac{(1-a)^2}{16} - \frac{1}{2\tau}}.$$

It is sufficient to show that the expression on the left-hand side is negative which is equivalent to $\tau < \frac{4}{3-a}$. Using the existence condition of $\tau(1-a)^2 < 1$ derived above, it is sufficient to show that $\frac{1}{(1-a)^2} < \frac{4}{3-a}$. Solving this quadratic inequality reveals that this is satisfied for $a < \frac{7-\sqrt{33}}{8} \approx 0.157$ which in turn follows from the assumption $a < 1/7$. This concludes the proof of Proposition 1. ■

Proof of Proposition 2 For sufficiently large values of ρ, irrespectively of the value of κ the profit of the ISP under prioritization is $\rho(x_S^P - x_W^P) + p_S^P$, whereas its profit under zero-rating is $\rho(x^{NN} - x^{ZR}) + p^{NN}$. All of the terms being positive, by the Archimedean property of the real numbers, the former expression is larger for large ρ and prioritization is chosen if and only if

$$x_S^P - x_W^P > x^{NN} - x^{ZR}.$$

It is straightforward to check that the right-hand side is positive and independent of κ, whereas left-hand side, is decreasing in κ, moreover it goes to zero as κ goes to one. By continuity, for values κ to one, zero-rating is the preferred option. Next we show that for $\kappa \leq \kappa_1$, the left-hand side is larger. Indeed, $x_S^P > x^{NN}$ always holds. Moreover, for $\kappa \leq \kappa_1$ Lemma 2 implies $x_W^P < x^{ZR}$. Thus, for $\kappa = \kappa_1$, there always exists $\overline{\rho}(\kappa) > 0$ such that prioritization is the equilibrium choice of the ISP. Finally, by continuity there must exist a cut-off value κ' in the $(\kappa_1, 1)$ interval such that for all $\kappa \leq \kappa'$ the ISP chooses prioritization, and it chooses zero-rating otherwise. ■

Proof of Proposition 3 In an equilibrium with priority to the strong CP, we have:

$$p = v+1-\frac{5(2-a)\tau}{8}+\frac{3}{8}\sqrt{\tau}\sqrt{(2-a)^2\tau - 16(1-\kappa)}, d = \frac{(2+a)\tau}{4}-\frac{\sqrt{\tau}}{4}\sqrt{(2-a)^2\tau - 16(1-\kappa)} > 0,$$

$$x_S^{P+ZR} = \frac{1}{8\tau}\left(6\tau + a\tau - \sqrt{\tau}\sqrt{(2-a)^2\tau - 16(1-\kappa)}\right),$$

$$\pi_S^{P+ZR} = v + \frac{1+\kappa}{2} + \frac{1}{16}\left((2-a)\sqrt{\tau}\sqrt{(2-a)^2\tau - 16(1-\kappa)} - \tau(2-a)(6+a)\right).$$

An interior equilibrium with priority to the strong CP exists when $\kappa \geq 1 - \frac{(2-a)^2\tau}{16}$.

In an equilibrium with priority to the weak CP, we have:

$$p = v+1-\frac{(6-a)\tau}{8}+\frac{1}{8}\sqrt{\tau}\sqrt{(2+a)^2\tau - 16(1-\kappa)}, d = \frac{1}{4}\left(-\tau(2-a) + \sqrt{\tau}\sqrt{(2+a)^2\tau - 16(1-\kappa)}\right),$$

$$x_W^{P+ZR} = \frac{1}{8\tau}\left(\tau(2+a) + \sqrt{\tau}\sqrt{(2+a)^2\tau - 16(1-\kappa)}\right),$$

$$\pi_W^{P+ZR} = v + \frac{1+\kappa}{2} + \frac{1}{16}\left((2+a)\sqrt{\tau}\sqrt{(2+a)^2\tau - 16(1-\kappa)} - \tau(2-a)(6+a)\right).$$

An interior equilibrium with priority to the weak CP exists when $\kappa \geq 1 - \frac{(2+a)^2\tau}{16}$, a softer condition than for the existence of the equilibrium with priority to the strong CP.

It is obvious to show that $\pi_W^{P+ZR} \geq \pi_S^{P+ZR}$ with a strict inequality for $\kappa < 1$. When the weak CP has priority, it is also zero-rated if $d > 0$, which is equivalent to: $\kappa \geq 1 - \frac{a\tau}{2}$. This cut-off value is larger than the existence condition. Therefore, there is an non-empty parameter space $\kappa \in [1 - \frac{(2+a)^2\tau}{16}, 1 - \frac{a\tau}{2}]$ where the strong CP is zero-rated, corresponding to $d < 0$. Finally, we show that $\pi_W^{P+ZR} \leq \pi^{ZR}$. After simplifications, this inequality is equivalent to

$$\tau(2+a)^2 - 8(1-\kappa) \geq (2+a)\sqrt{\tau}\sqrt{(2+a)^2\tau - 16(1-\kappa)}.$$

Squaring both sides and simplifying, we have $\pi_W^{P+ZR} \leq \pi^{ZR}$ if $(1-\kappa) \geq 0$. ■

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