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Analyzing Network (Non-)Neutrality for Monopolistic, Competing, or Vertically Integrated Content Providers with a Unified Model

Vedant Joseph Kumar*, Patrick Maillé†, Bruno Tuffin‡

August 31, 2022

Abstract

This paper deals with the hot and sensitive network neutrality debate. It designs a model simultaneously encompassing several scenarios regarding the content-providing market structure: a monopolistic content provider, competitive ones, and a vertically-integrated one facing a non vertically-integrated competitor. We each time compare the outputs when non-neutral, weak neutral or strong neutral policies are applied, in order to get insights regarding the possible consequences of each type of neutrality regulation.

1 Introduction

The network neutrality debate has been active for about two decades, and is not settled yet, due to the several dimensions it encompasses, the evolution of regulations in a variety of countries, and the appearance over time of new technologies and practices that raised neutrality-related questions [4, 17, 21].

In short, *network neutrality* refers to the principle according to which all information transiting in telecommunication networks should be treated the same. In particular, no economic consideration should affect whether some set(s) of flows, of traffic originators or destinations, of applications, or of devices, receive a preferential or degraded treatment. The term was first coined by Tim Wu in 2002 [28], and the question has drawn a lot of attention from academia, user associations, regulators, and all the decision makers involved in the content supply chain, from content providers to end users. One generally observes quite strong stances regarding neutrality questions, in one direction or another depending on the type of actor: Internet Service Providers (ISPs) providing the “pipes” for information to circulate tend to argue against neutrality, defending their

*IMT Atlantique/IRISA

†IMT Atlantique/IRISA

‡Inria, University of Rennes, CNRS, IRISA

freedom of enterprise to manage their business as they want; Content Providers (CPs) benefiting from those pipes refuse to be held hostage of ISPs' whims and greed, and argue that differentiation harms innovation; user associations also defend neutrality principles on the grounds of freedom of speech, protection of privacy, and preservation of the openness spirit that prevailed since the infancy of the internet. The debate has been intense worldwide, with laws passed in most countries in general to preserve neutrality, but also policy shifts. A typical example is the United States, initially in favor of neutrality by applying the Communications Act to the internet, then considering ISPs just as information service providers in 2002, thereby dissociating them from laws regulating telecommunications, then establishing rules for an open internet in 2005 (therefore re-establishing neutrality as a leading principle), before a new change of policy in 2017 under the Trump administration against neutrality [21], likely to be overturned again. It is therefore of primary importance to understand the impact of neutrality or non-neutrality decisions on internet actors and on society.

Several aspects of neutrality have been investigated in the literature, even only considering the three "basic" types of actors –CPs, ISPs, users–while the internet ecosystem involves many other actors. The approaches differ in terms of the market structure (monopolistic ISP/monopolistic CP [2, 3], monopolistic ISP/competing CPs [11], competing ISPs/monopolistic CP [7], competing ISPs and CPs [5], vertical integration between an ISP and a CP [6, 9, 12, 14]), how neutrality is modeled/interpreted (type of differentiation applied [24], pricing schemes [2, 10]), and how user behavior is modeled (through individual utility functions with heterogeneity among users [24], or aggregated demand functions, either linear [2, 3] or based on attraction models [7]).

Note that there exists an extensive literature focusing on other aspects related to neutrality, such as (non exhaustively) incorporating into the picture transit ISPs [18], advertising [22, 23], zero rating practices [16, 20, 27], heterogeneity among countries [1, 19], impact on investment [6, 24], etc. We aim here at focusing on the relations between the three main actors of the neutrality debate: end users, ISPs, and CPs. Even in this context, from what we have described in the previous paragraph, the literature covers a wide range of situations, providing elements of response regarding the relevance of neutrality regulation, but using a quite heterogeneous set of models. As a consequence, it remains complicated to separate what in the conclusions comes from the techno-economic situation or from the specific modeling chosen for that situation. In this paper, we aim at building a unified model, to be applied to three different situations, in order to ease the comparison between the conclusions drawn for each. The three scenarios involve a monopolistic ISP, as is still the case in many places (including the US) and it is the situation where neutrality questions are the most critical: it is indeed often argued that ISP competition would significantly reduce neutrality issues, since users could be driven away by non-neutral ISPs [15]¹. In the

¹See also <https://medium.com/skycoin/net-neutrality-and-the-tyranny-of-the-isps-3f2414f91fce>

monopolistic-ISP setting, we will consider the following possibilities as regards CPs:

- non-competing CPs, i.e., CPs with non-overlapping services, so that each CP can be considered as monopolistic in its service field (we will then model only one CP);
- CPs in (fair) competition, i.e., with the same kind of relationship to the ISP;
- competing CPs, but with one CP being vertically integrated with (i.e., controlled by the same entity as) the ISP.

In each of those scenarios, we intend to analyze the impact of (non-)neutrality through our common model, in order to give insight regarding the need for (or the possible risks from) neutrality regulation. The model presented here has been hinted in [21], but without the full analysis presented in this paper.

The remainder of the paper is organized as follows. Section 2 introduces the unified economic model that will be used to study all scenarios, including the modeling of the preferences of all actors, their interactions, and the definitions of neutrality. The scenario of a monopolistic CP is treated in Section 3, and will serve as a baseline for comparisons. Sections 4–5 respectively analyze the situation of competitive CPs, and the case of a vertically-integrated CP competes with a non-integrated one. Each time we compare the outputs for neutral, weak-neutral and non-neutral policies. Section 6 provides a comparison of the outputs for those three scenarios, which is possible thanks to the common model applied. The goal is to determine what neutrality policies could be “recommended” when we have monopolistic CPs, or competitive CPs with or without vertical integration. Finally, Section 7 concludes and gives perspectives of future research.

2 General model

This section presents the common model that will be applied to all three content-providing market structure settings. It includes three types of actors, namely an ISP, some content provider(s), and end-users. For each type, we specify below how we model their preferences and their decision variables. We finally specify in which order decisions are made and affect each other.

2.1 Internet Service Provider (ISP)

Throughout this paper, we consider only one ISP (we studied competition among ISPs in [7]), as this situation is still predominant in many regions. Additionally, removing possible ISP competition increases the power of the (hence monopolistic) ISP, that can play on prices without fearing dramatic customer churn; this should better highlight the potential gains from non-neutral behaviors.

We consider the ISP as a profit-oriented actor, that will therefore focus on its **total revenue** as the objective (utility) function. We do not include infrastructure investments in the model: we assume those have been made previously, and the ISP intends to maximize the revenue from its existing infrastructure. Depending on the situation, there can be one or two decision variables for the ISP, that correspond to sources of revenue:

- in all scenarios, the ISP gains revenue from user subscriptions. The decision variable is the flat-rate **subscription price**, that we denote by p_A per time unit.
- When side payments are allowed, the ISP also chooses a **side payment** level q_i to charge each CP i per mass unit of subscribers and per time unit (this can be interpreted as the ISP charging CP i per volume unit—a setting closer to what non-neutrality proponents advocate—if we make the additional assumption that the average volume consumed on CP i by each of its subscribers does not change as prices vary). Such side payments being forbidden (which we will call strong neutrality) then corresponds to forcing q_i to equal 0 for each CP i .

Summarizing, if we denote by θ_A the mass of users subscribing to the ISP only (and not to any CP), and by θ_i the mass of users subscribing to CP i (in addition to the ISP), the utility (revenue per time unit) of the ISP can be expressed as

$$U_A = p_A \theta_A + \sum_{i=1}^n (p_A + q_i) \theta_i, \quad (1)$$

with n the number of CPs considered (in the paper we will consider $n = 1$ or $n = 2$). Note that the CPs we consider in this paper offer comparable services, so that users will subscribe to at most one of them.

2.2 Content Providers (CPs)

Our model considers subscription-based CPs, each CP i charging a (flat rate) **subscription price** p_i (per time unit, and per subscriber mass unit), that constitutes their decision variable. As the ISP, those actors are assumed to focus on their revenue per time unit, that will be proportional to their mass of subscribers, and amputated by the possible side payment applied. Mathematically, with θ_i the mass of subscribers to CP i and q_i the side payment to the ISP, the utility of CP i is

$$U_i = (p_i - q_i) \theta_i. \quad (2)$$

2.3 Users

In this paper, we consider either one or two CPs. In the latter case, we assume CPs are providing the same kind of service, so that no user should be interested in subscribing to both. As a result, a given user has the following options:

- subscribe to the ISP but not to any CP, a choice that we will label as A ;
- subscribe to the ISP and a CP i (for the additional service), a choice we label as i ;
- not subscribe to any service, a choice we label as 0.

Users react differently to the situation they are faced with, each user having their individual preferences. But their aggregated choices are expected to follow some intuitive trends, like an option attracting less users if its price increases. To encompass those aspects, we apply a discrete-choice model (as in [7]), where each option has a “base” utility value that is common to all users (and depends on the prices), but also includes a user-specific part that we treat as a random variable. Specifically, we assume that the utility that a user u associates to each option o is of the form

$$\alpha_o \ln(1/\text{perceived_cost}_o) + \kappa_{u,o} \quad (3)$$

where all $\kappa_{u,o}$ (among users and options) are considered as independent random variables following a standard Gumbel distribution [7], the perceived cost accounts for the price and service available, and α_o is a parameter quantifying the sensitivity to the perceived cost for that option. The deterministic part $v_o := \alpha_o \ln(1/\text{perceived_cost}_o)$ represents the average valuation for an option that has a perceived price perceived_cost_o .

Note that the use of the logarithmic function can be interpreted as linked to human perceptive capabilities to stimuli (like touch or sound, for which the perceived intensity is logarithmic in the stimulus intensity); that link can be done as well as regards the perceived Quality of Experience [26].

Finally, the perceived costs that we consider are as follows:

- Subscribing to a CP (an option i) gives access to the whole set of resources the user is interested in, that we normalize to 1. But the cost perceived when paying for a CP may be different due to different reputations and content; to model that aspect we introduce a reputation parameter β_i for CP i , assuming $\beta_1 = 1$ without loss of generality. This leads to a perceived cost when subscribing to CP i (plus ISP A):

$$\text{perceived_cost}_i = \beta_i p_i + p_A.$$

- Subscribing to the ISP only gives access to less content, which we model through an increase in perceived price resulting from the dissatisfaction of not benefiting from the CP’s content, by a factor $k > 1$: hence

$$\text{perceived_cost}_A = k p_A.$$

- Not subscribing to anything is also associated to a perceived cost, that we denote by p_0 .

Under those assumptions, if each user selects the option offering them the highest utility, users will spread among options in proportion to the terms $(\text{perceived_cost}_o)^{-\alpha_o}$ [7]. Therefore, assuming (without loss of generality) a total user mass of one, if one CP is present we have the following expressions for the mass θ_o selecting each option $o \in \{0, A, 1, \dots, n\}$.

$$\theta_0 = \frac{(p_0)^{-\alpha_0}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}} \quad (4)$$

$$\theta_A = \frac{(kp_A)^{-\alpha_A}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}} \quad (5)$$

$$\theta_i = \frac{(p_A + \beta_i p_i)^{-\alpha_i}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}} \quad i = 1, \dots, n. \quad (6)$$

2.4 User and Social Welfare

To measure user and overall satisfaction, we define in this subsection user and social welfare.

In line with [8], we start by defining user welfare UW' as the aggregated utility from users, looking at the difference with the case when there is no service. In other words:

$$UW' = \mathbb{E}[\max(0, V_A - V_0, V_1 - V_0, \dots, V_n - V_0)].$$

Define $Z := \max(0, V_A - V_0, V_1 - V_0, \dots, V_n - V_0)$. We then get for $z \geq 0$,

$$\begin{aligned} \mathbb{P}[Z \leq z] &= \mathbb{P}[(V_A - V_0 \leq z) \cap (V_1 - V_0 \leq z) \cap \dots \cap (V_n - V_0 \leq z)] \\ &= \mathbb{P}[(V_0 \geq V_A - z) \cap (V_0 \geq V_1 - z) \cap \dots \cap (V_0 \geq V_n - z)] \\ &= \frac{\exp(v_0)}{\exp(v_0) + \exp(-z)(\exp(v_A) + \sum_{i=1}^n \exp(v_i))}. \end{aligned}$$

Then we can get

$$\begin{aligned} UW' &= \mathbb{E}[Z] = \int_{z=0}^{+\infty} \mathbb{P}[Z > z] dz \\ &= \log \left(1 + \exp(v_A - v_0) + \sum_{i=1}^n \exp(v_i - v_0) \right) \\ &= \log \left(1 + \frac{p_0^{\alpha_0}}{(kp_A)^{\alpha_A}} + \sum_{i=1}^n \frac{p_0^{\alpha_0}}{(p_A + \beta_i p_i)^{\alpha_i}} \right). \end{aligned} \quad (7)$$

But it would make sense to express user welfare in monetary units, particularly if we want to be consistent when adding users' and providers' utilities to define social welfare. We therefore apply the transformation $p_0 \times (\exp(\cdot) - 1)$, to obtain

$$UW = p_0 \frac{p_0^{\alpha_0}}{(kp_A)^{\alpha_A}} + p_0 \sum_{i=1}^n \frac{p_0^{\alpha_0}}{(p_A + \beta_i p_i)^{\alpha_i}}. \quad (8)$$

Social welfare SW is then defined as the sum of user welfare and the revenues of the ISP and CP(s):

$$\begin{aligned}
SW &= UW + U_A + \sum_{i=1}^n U_i \\
&= p_0 \frac{p_0^{\alpha_0}}{(kp_A)^{\alpha_A}} + p_0 \sum_{i=1}^n \frac{p_0^{\alpha_0}}{(p_A + \beta_i p_i)^{\alpha_i}} \\
&\quad + p_A \left(1 - \frac{p_0^{-\alpha_0}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}} \right) \\
&\quad + \sum_{i=1}^n p_i \frac{(p_A + \beta_i p_i)^{-\alpha_i}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}}. \tag{9}
\end{aligned}$$

From now on in our developments, to limit the number of parameters we assume $\alpha_0 = \alpha_A = \alpha_1 = \dots = \alpha_n = \alpha$.

2.5 Differentiation, Weak and Strong Neutrality

The proposed model presents the advantage of allowing several variations of neutrality, namely differentiation, weak and strong neutrality, mathematically interpreted as per the following definition.

Definition 1. *Non neutrality (or differentiation) means allowing the ISP to charge a different side payment q_i to each CP i ($1 \leq i \leq n$).*

Weak neutrality means allowing a side payment, but no differentiation among CPs: hence imposing the constraint $q_i = q \forall i \in \{1, \dots, n\}$.

Strong neutrality means not allowing any side payment: $q_i = 0 \forall i \in \{1, \dots, n\}$.

Of course, weak and strong neutrality are different only if at least two CPs are considered. In that case, neutrality will mean *strong* neutrality.

2.6 Order of decisions

We assume the decisions are made in the following order.

1. First, the ISP selects its subscription price p_A and (if allowed) the side payments q_i for each CP i ;
2. Then each CP i select its subscription price p_i ;
3. Finally users adapt and select an option.

As we assume each decision maker is able to anticipate the subsequent reaction of the others to their actions, we have a Stackelberg game [13] with the ISP as the leader, CP(s) being both followers (of the ISP) and leaders (for users), and users as followers. The classical method to analyze such interactions is called *backward induction*, and consists in analyzing the reactions of followers to determine how leaders act (i.e., start with the decisions made last).

3 A baseline scenario with one CP

We first start with the baseline situation with one CP. Users' proportions are then (recall that we take $\beta_1 = 1$)

$$\theta_A = \frac{(kp_A)^{-\alpha_A}}{(kp_A)^{-\alpha_A} + (p_A + p_1)^{-\alpha_1} + p_0^{-\alpha_0}} \quad (10)$$

$$\theta_1 = \frac{(p_A + p_1)^{-\alpha_1}}{(kp_A)^{-\alpha_A} + (p_A + p_1)^{-\alpha_1} + p_0^{-\alpha_0}} \quad (11)$$

$$\theta_0 = \frac{(p_0)^{-\alpha_0}}{(kp_A)^{-\alpha_A} + (p_A + p_1)^{-\alpha_1} + p_0^{-\alpha_0}}. \quad (12)$$

With $\alpha_0 = \alpha_A = \alpha_1 = \alpha$, according to the order of decisions described in Section 2.6 and the anticipation of decisions, the CP will choose its subscription price p_1 knowing what will be the distribution of the mass of users given in Equations (10) to (12). To simplify the writing, we introduce the quantity $Q := (kp_A)^{-\alpha} + p_0^{-\alpha}$. The optimal price value p_1^* is obtained by equating $\frac{\partial U_1}{\partial p_1}$ to zero, that is,

$$\frac{-Q\alpha p_1 + Q\alpha q_1 + (p_A + p_1)^{1-\alpha} + Q(p_A + p_1)}{(p_A + p_1)^{1+\alpha}((p_A + p_1)^{-\alpha} + Q)^2} = 0.$$

Unfortunately, solving this equation is intractable for a general α , hence a recourse to (simple) numerical investigations. In the simplified case where $\alpha = 2$ on the other hand, the above equation reduces to solving $p_1^2 - 2p_1q_1 - p_A^2 - 2p_Aq_1 - 1/Q = 0$, with only one non-negative solution

$$p_1 = q_1 + \sqrt{(p_A + q_1)^2 + \frac{1}{Q}}. \quad (13)$$

The optimization of the revenue U_A for the ISP by choosing p_A and q_1 is performed numerically.

Since our goal is to compare the optimal decisions and the resulting outcomes between non-neutral and neutral situations, we have similarly to analyze what happens when neutrality is imposed. To do then, we just enforce (that is, substitute) $q_1 = 0$ in the above equations, which simplifies the derivations, the ISP only playing with p_A and for the case $\alpha = 2$ Equation (13) being reduced to $p_1 = \sqrt{p_A^2 + \frac{1}{Q}}$.

It is interesting to compare neutral and non-neutral prices, demands and welfare values when the model parameters vary, in particular the parameter $k > 1$, that represents basically the ratio between the amount of content available with the CP to the amount available without it, and hence quantifies the power of the CP. To limit the number of parameters, consider again $\alpha_A = \alpha_1 = \alpha_0 = \alpha$. The analysis is done in [21, Chapter 4] in the case $\alpha = 2$, with the observation that surprisingly, non-neutrality is better than neutrality as regards user welfare and social welfare, even if the more powerful the CP (the larger k), the lower

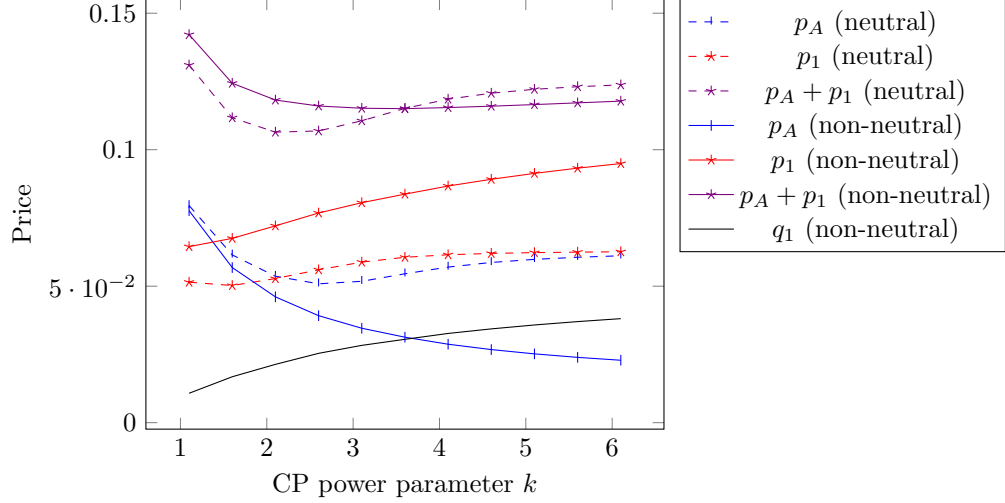


Figure 1: Prices at the outcome of the game (monopolistic CP) in terms of the CP power k in both neutral and non-neutral scenarios, when $p_0 = 0.1$ and $\alpha = 3$.

those welfare values. Figure 1 shows the prices at the outcome of the game in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$ and $\alpha = 3$. It can be checked that prices p_A , p_1 and q_1 are monotone with respect to the CP power parameter k in the non-neutral case but not in the neutral case. Neutrality “reduces” the ISP price but increases the CP price (which has to transfer the side payment cost to users). Note that in the non-neutral case, the full price $p_A + p_1$ is not monotone with k , and depending on k this full price is smaller in the neutral case than in the non-neutral case (when k is small), or larger (when k is large(r)): as in the case $\alpha = 2$, users may benefit from a non-neutral situation in a powerful-CP scenario.

Figure 2 and Figure 3 display the utilities, welfare and user distribution under the same conditions. As expected, the ISP prefers non-neutrality, while it is the opposite for the CP. User welfare and social welfare both decrease as k increases, meaning that having a too powerful CP might not be desirable, but whatever the value of k , non neutrality leads to larger welfares. In terms of user choices (Figure 3), the larger k , the larger θ_0 , hence the less subscribing customers, in accordance with the reduced user welfare. As k increases, the proportion θ_A of users subscribing only to the ISP is decreasing at equilibrium, since k large means there is a big improvement in utility by adding a CP subscription to a basic ISP one. Moreover, non neutrality leads to more customers subscribing to the ISP only than in the neutral case (due to a smaller p_A).

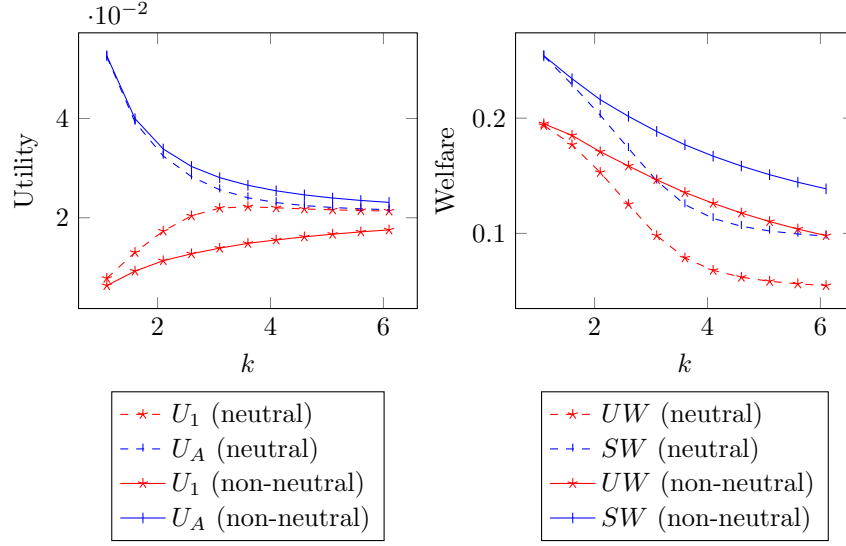


Figure 2: Utilities (left panel) and welfares (right panel) at the outcome of the game in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$ and $\alpha = 3$.

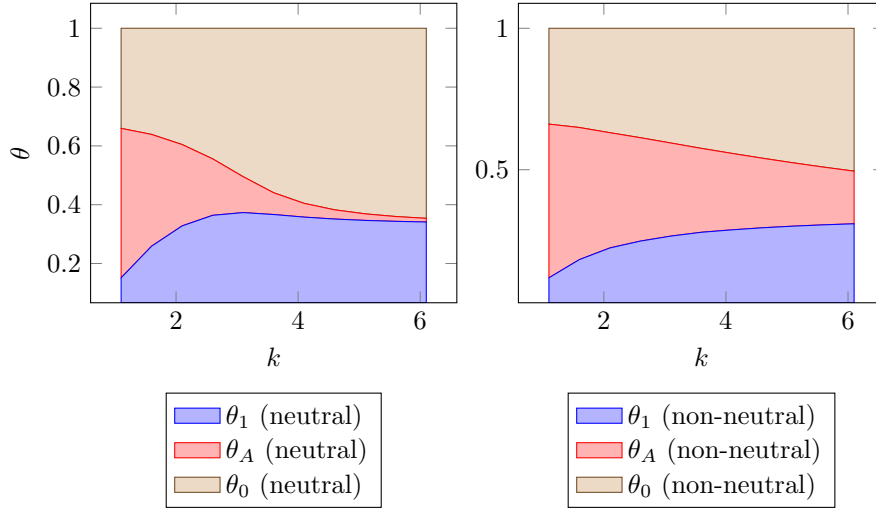


Figure 3: Distribution of users in the neutral (*left*) and non-neutral (*right*) scenarios at the outcome of the game in terms of k , when $p_0 = 0.1$ and $\alpha = 3$.

4 Impact of competition at the CP level

Let us now check what happens in the case of competitive CPs, to see how competition impacts the outcomes in both neutral and non-neutral scenarios, and possibly what could be recommended in terms of regulation.

We again simplify the competition analysis with $n = 2$ and $\alpha_0 = \alpha_A = \alpha_1 = \alpha_2 = \alpha$, which leads to the following proportions of user choices:

$$\begin{aligned}\theta_0 &= \frac{p_0^{-\alpha}}{(p_A + p_1)^{-\alpha} + (p_A + \beta_2 p_2)^{-\alpha} + (k p_A)^{-\alpha} + p_0^{-\alpha}} \\ \theta_A &= \frac{(k p_A)^{-\alpha}}{(p_A + p_1)^{-\alpha} + (p_A + \beta_2 p_2)^{-\alpha} + (k p_A)^{-\alpha} + p_0^{-\alpha}} \\ \theta_1 &= \frac{(p_A + p_1)^{-\alpha}}{(p_A + p_1)^{-\alpha} + (p_A + \beta_2 p_2)^{-\alpha} + (k p_A)^{-\alpha} + p_0^{-\alpha}} \\ \theta_2 &= \frac{(p_A + \beta_2 p_2)^{-\alpha}}{(p_A + p_1)^{-\alpha} + (p_A + \beta_2 p_2)^{-\alpha} + (k p_A)^{-\alpha} + p_0^{-\alpha}}.\end{aligned}$$

As in the case with one CP, playing anticipatively, we have to determine p_1 and p_2 for any fixed values of p_A and the side payments $(q_i)_{i=1,2}$. This is done through a non-cooperative game between CPs, for which we look for a Nash equilibrium, that is a point (p_1, p_2) from which no CP has an interest to unilaterally deviate [25]. If such a point exists and is unique, we then consider it as the outcome of the game. In our numerical investigations of this model, although we have not analytically proved existence and uniqueness we have always obtained a unique Nash equilibrium. With the method to compute those prices determined, the ISP then maximizes p_A , as well as q in the weakly-neutral scenario, or (q_1, q_2) in the non-neutral case.

We display (with again $\alpha = 3$, $p_0 = 0.1$ and also now $\beta_2 = 1.5$) the values of prices, utilities and welfares at the outcome of the game in respectively Figure 4, Figure 5 and Figure 6. It can be readily checked on Figure 4 that in the weakly neutral scenario the side payment $q = q_1 = q_2$ is simply set to 0, in other words, the ISP's best interest is to be neutral. In the non-neutral case, we still have $q_2 = 0$ but $q_1 > 0$ (with $\beta_1 = 1$ and $\beta_2 = 1.5$) for small values of k : as CPs get more powerful, neutrality becomes the optimal situation, but not otherwise: it can be better to impose a payment to the popular CP 1. Varying k does not seem to impact significantly prices except maybe when $k = 1$ for which p_A is larger. As regards the neutrality policy that is enforced, the impact on prices, and as a result on utilities, welfare and market share seem insignificant, suggesting no regime is "best". On the other hand, as in the monopolistic-CP case of the previous section, having more powerful CPs k decreases welfare, maybe suggesting other regulatory measures, aimed at reducing CP power, if user welfare is to be protected.

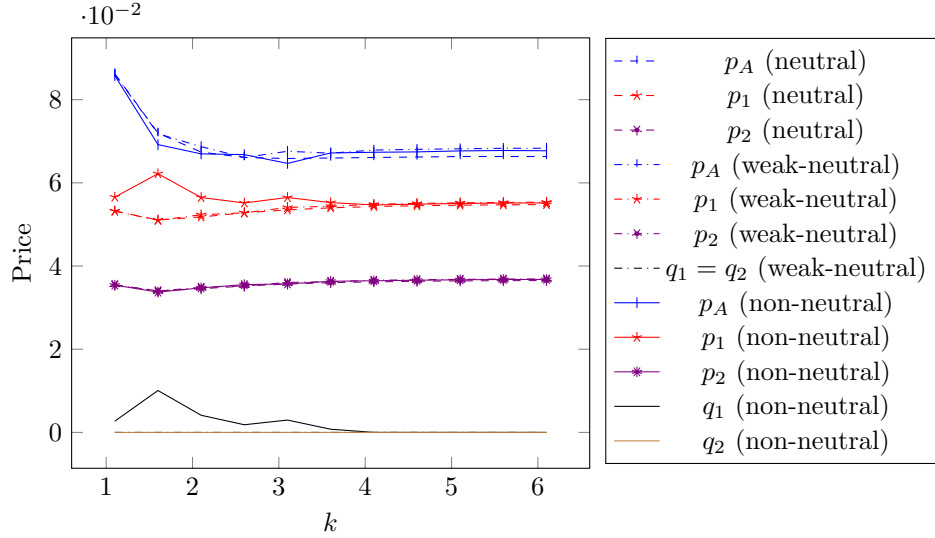


Figure 4: Prices at the outcome of the game with two CPs in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

5 Vertical integration of the ISP and a CP

It may also happen that the ISP offers a content service: the ISP and a CP, say CP 1 without loss of generality, are then said to be *vertically integrated* [17]. Such a situation raises concerns about unfair payments asked to competing CPs, thereby distorting the competition among CPs. We propose to analyze this situation in the present section.

The utility (or revenue) of the vertically-integrated CP/ISP entity (1) and (2), restricted here to two CPs, then gives

$$U_{\text{Vert}} = (p_A + p_1)\sigma_1 + (p_A + q_2)\sigma_2 + p_A\sigma_A, \quad (14)$$

while the utility of CP 2 is still

$$U_2 = (p_2 - q_2)\sigma_2.$$

The decisions are again taken at different time scales, as described in Section 2.6, and the problem solved by *backward induction*.

We start by restricting side payments to be non-negative.

Figure 7 shows that in the vertically-integrated scenario, there is no side payment, even when such payments are allowed. As a consequence, the other prices are the same whatever the implemented neutrality policy.

Since prices do not depend on the neutrality policy, utilities and welfare are the same too. We therefore choose in Figures 8 and 9 for comparison sake to display the utilities, welfare and user distribution for both non-integrated

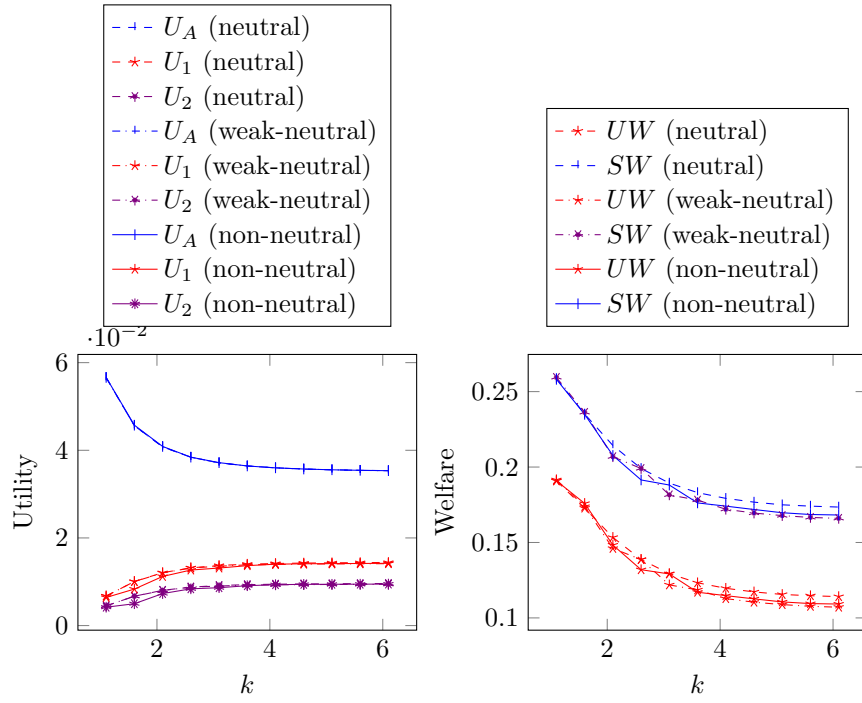


Figure 5: Utilities and welfares at the outcome of the game with two CPs in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

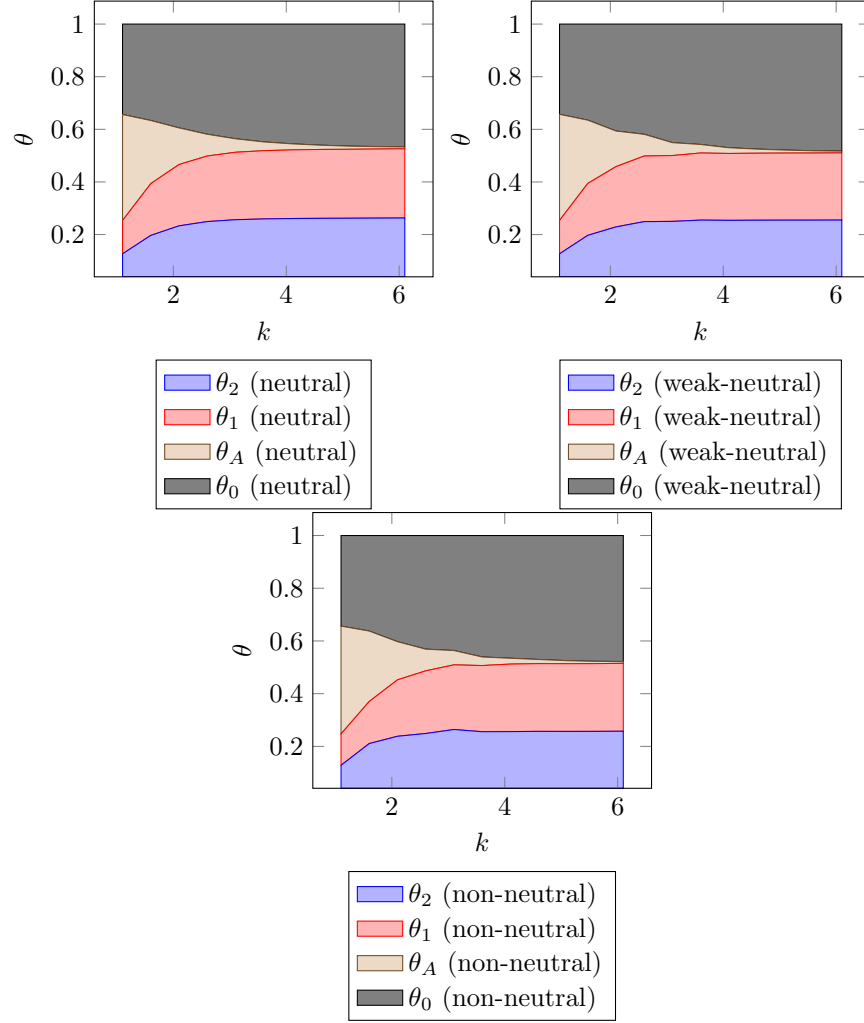


Figure 6: User distribution at the outcome of the game with two CPs in terms of k in strongly neutral, weakly neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

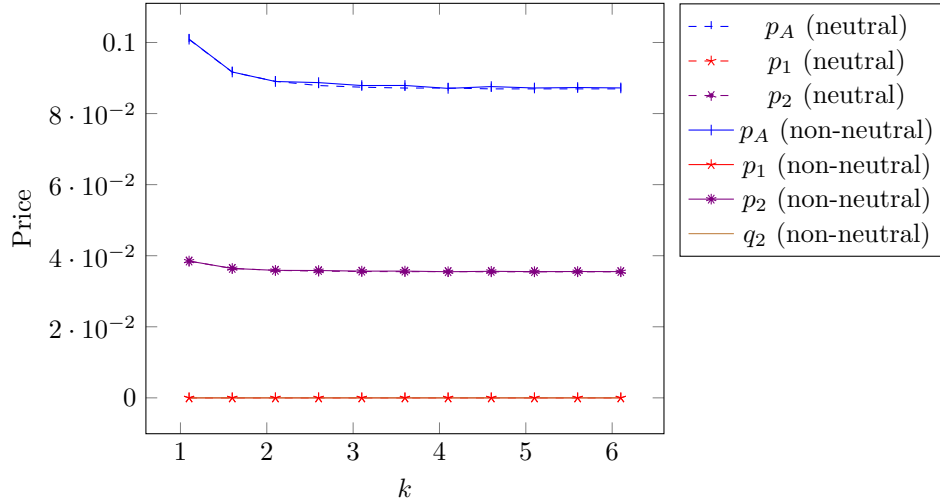


Figure 7: Prices at the outcome of the game with two CPs (one integrated) in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

(the previous section) and integrated cases. We also plot the sum $U_A + U_1$, to compare with the payoff for the integrated entity. This illustrates the fact that the coordination between the ISP and CP 1 allowed by integration yields extra revenue to the federation, with respect to the non-cooperative case.

Integration affects the non-integrated CP (that is, reduces U_2), which was expected. On the other hand, as can be seen on the right panel of Figure 8, both user welfare and social welfare are increased by integration, and only slightly affected by k , while an increasing CP power affects welfare in non-integrated cases. Surprisingly then, a regulator may want to favor integration. In terms of user distribution, Figure 9 illustrates that integration helps incentivize users to subscribe to at least a service (a smaller θ_0), and the proportion subscribing to the integrated duo is larger (something expected).

But, particularly in this integrated case, it could make sense for the ISP to allow *negative* payments, meaning for example that subsidies to users on one end can help the vertically-integrated player to win more on the other end. Again, note that in the integrated case we do not distinguish “weak” and “strong” neutrality, since differentiating between CPs does not make sense (the side-payment is perceived only by the non-integrated CP). Figures 10, 11 and 12 give respectively the prices, utilities and welfares at the output of the game. Even in this case of possible subsidies (possibly negative p_1), the optimal choice for the ISP is to be neutral, i.e., to set $q_2 = 0$, hence both neutrality regimes lead to the same outcomes. But it is then optimal for the integrated ISP-CP to *pay* users for accessing to CP 1, by choosing $p_1 < 0$: this both attracts more users toward the ISP, and away from CP 2 that incurs an extra cost while preferring

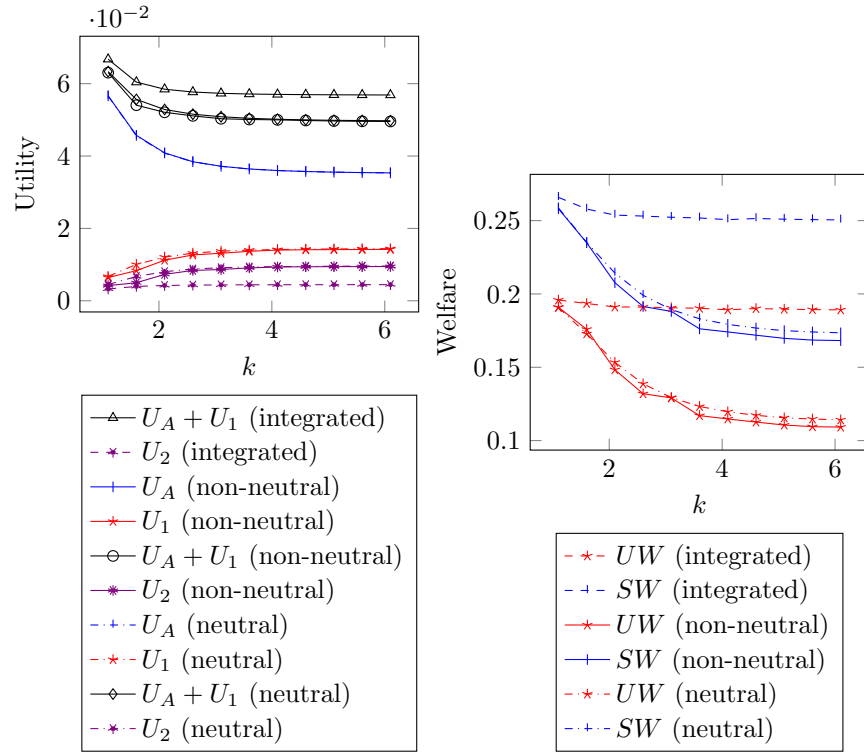


Figure 8: Utilities and welfare at the outcome of the game with two CPs (one integrated, non-negative prices) compared with the non-integrated cases, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$. For the integrated case, side payments are null even in the non-neutral setting, hence only one set of curves.

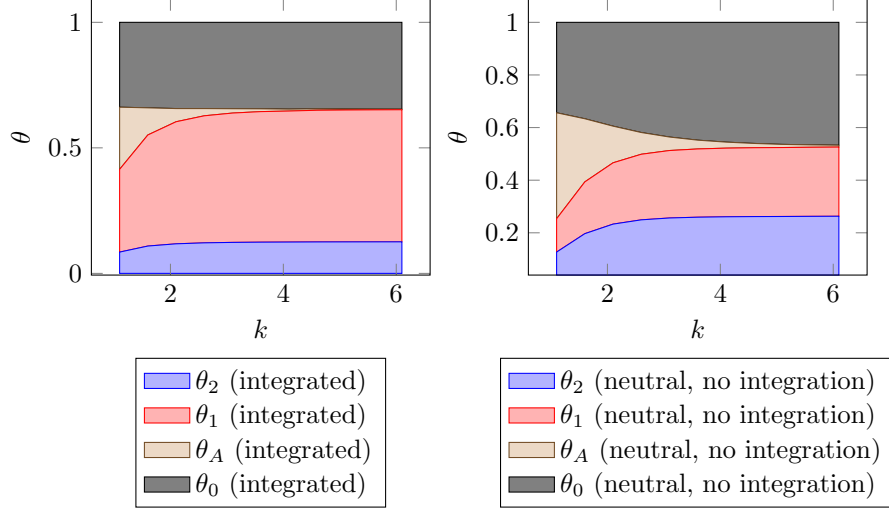


Figure 9: User distribution at the outcome of the game with two CPs, with one integrated CP and non-negative prices (*left*), and two non-integrated CPs in the neutral case (*right*) in terms of k , when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

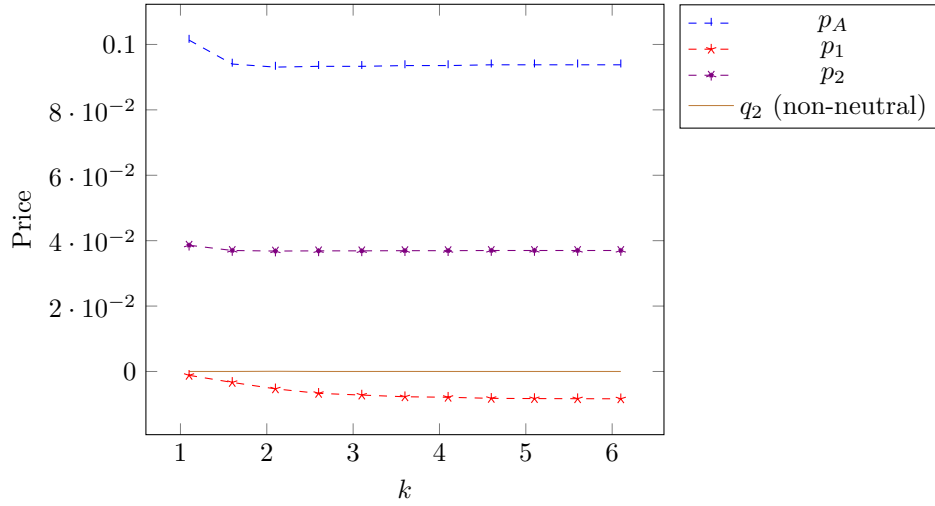


Figure 10: Prices at the outcome of the game with two CPs (one integrated, negative prices allowed) in terms of k in both neutrality regimes (curves coincide since the side payment q_2 is set to 0 in the non-neutral case), when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

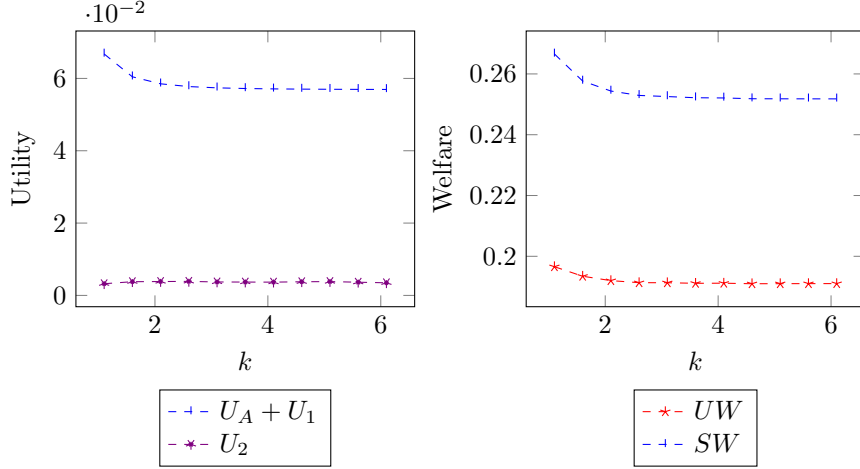


Figure 11: Utilities and welfares at the outcome of the game with two CPs (one integrated, negative prices allowed) in terms of k in both neutrality regimes (curves coincide as the side-payment is set to 0 in the non-neutral case), when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

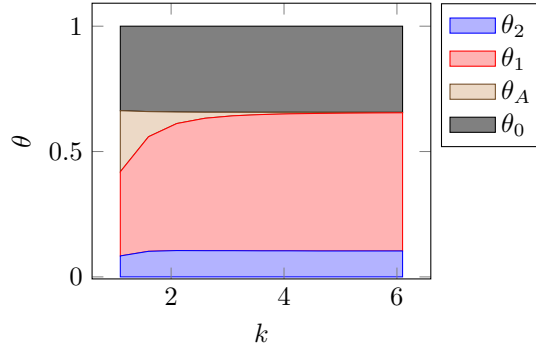


Figure 12: User distribution at the outcome of the game with two CPs (one integrated, negative prices allowed) in terms of k in both neutrality regimes (since the side payment is set to 0 in the non-neutral case), when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

CP 1 comes with a reward.

We can also note that CP power does not have an important effect on utilities and welfare; it mostly modifies the distribution between those subscribing to the ISP only and those choosing the integrated option.

6 Discussion

Previous sections analyze the three CP market structures (monopoly, duopoly and integration, with two possibilities for the latter case) separately. In this section we take advantage of our unified model to investigate the differences among those scenarios, in particular when an “optimal” neutrality policy is implemented. “Optimal” can be here in the sense of optimizing a given objective, like the revenue for the ISP implementing side payments (e.g., if the ISPs gets to choose the neutrality regime, for example through sufficient lobbying), or optimizing welfare for a regulator seeking to impose the policy benefitting most to society.

We therefore draw in Figure 13 (respectively Figure 14) simultaneously the output curves in monopoly, duopoly and integrated cases, but at the neutrality policy optimizing the ISP revenue (respectively social welfare), that is when the neutrality policy decision is taken by the ISP (respectively a regulator). Note that optimizing user welfare instead of social welfare for a regulator yields similar curves and is therefore omitted here.

Remark that the curves are actually the same in Figures 13 and 14, meaning that who decides the neutrality policy may not be an issue. Indeed, in the monopoly case non-neutrality is preferred both by the ISP and by the regulator, and in all other cases neutrality is preferred (again for both objectives). Our comparison among scenarios highlights that welfare (even user welfare, focusing only on users) is maximized when there is an integrated ISP-CP, and that the advantage increases with CPs’ power. In terms of user welfare, a monopolistic CP may be preferred to a duopoly if CP power is relatively low, but it is the opposite when k is large. The subscription price to the ISP is the smallest in the case of a monopolistic CP, in which case non-neutrality is chosen, but then the subscription price to CP 1 is larger (and zero in the integrated case, even negative when allowed).

7 Conclusions and future work

In this paper, we design (yet another) model to analyze the impact of neutrality policies on the different actors, namely users, ISP and CPs. The model’s interest is to allow at the same time to handle non-, weak-, and strong-neutrality, and different scenarios of monopoly, duopoly and of a vertically-integrated ISP-CP, allowing to compare those situations. The main conclusions from our experiments are that

- i) Imposing neutrality seems useless, as letting the ISP select (possibly null)

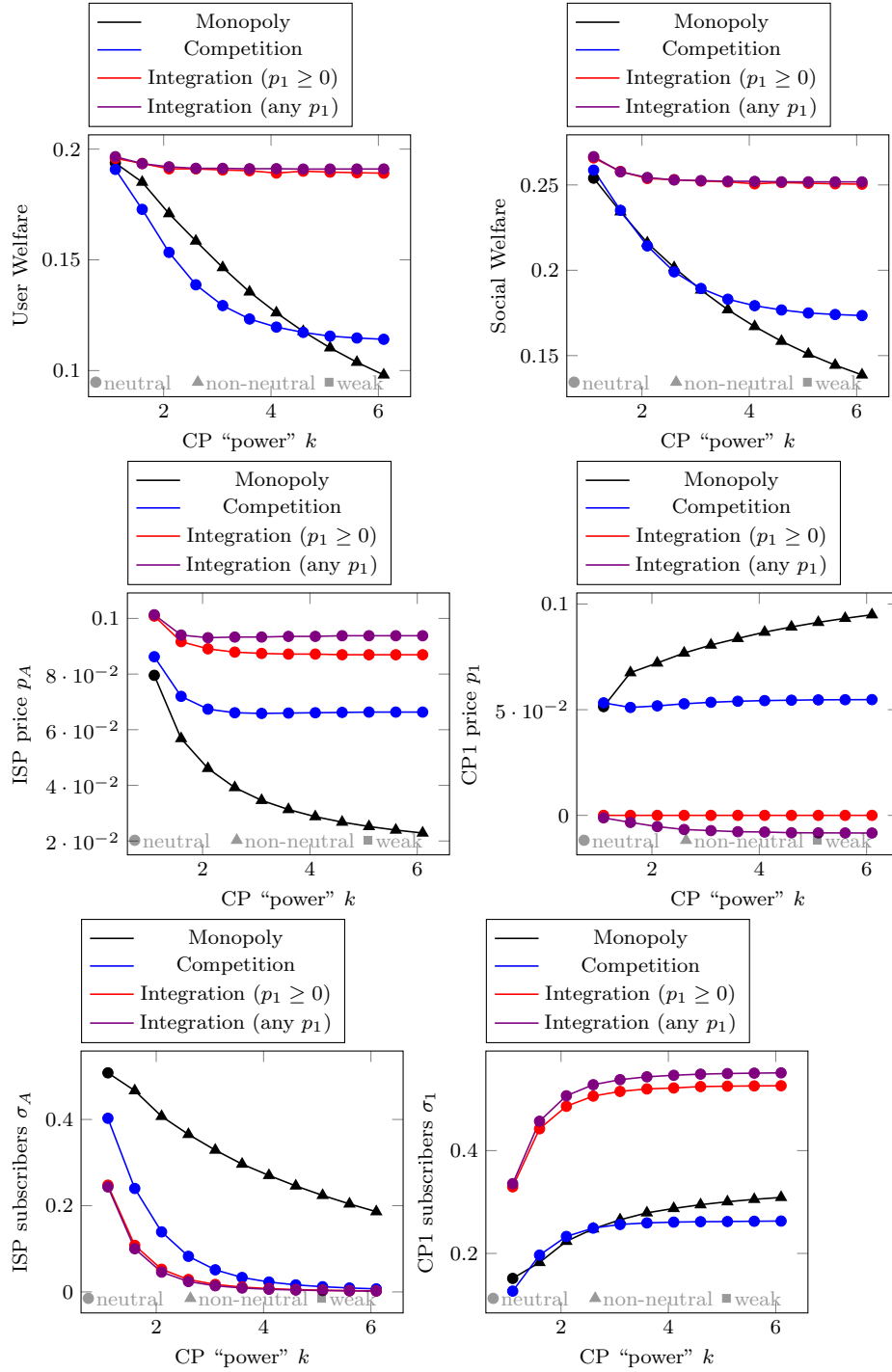


Figure 13: Equilibrium values when the neutrality regime is chosen by the ISP, for $\alpha = 3$

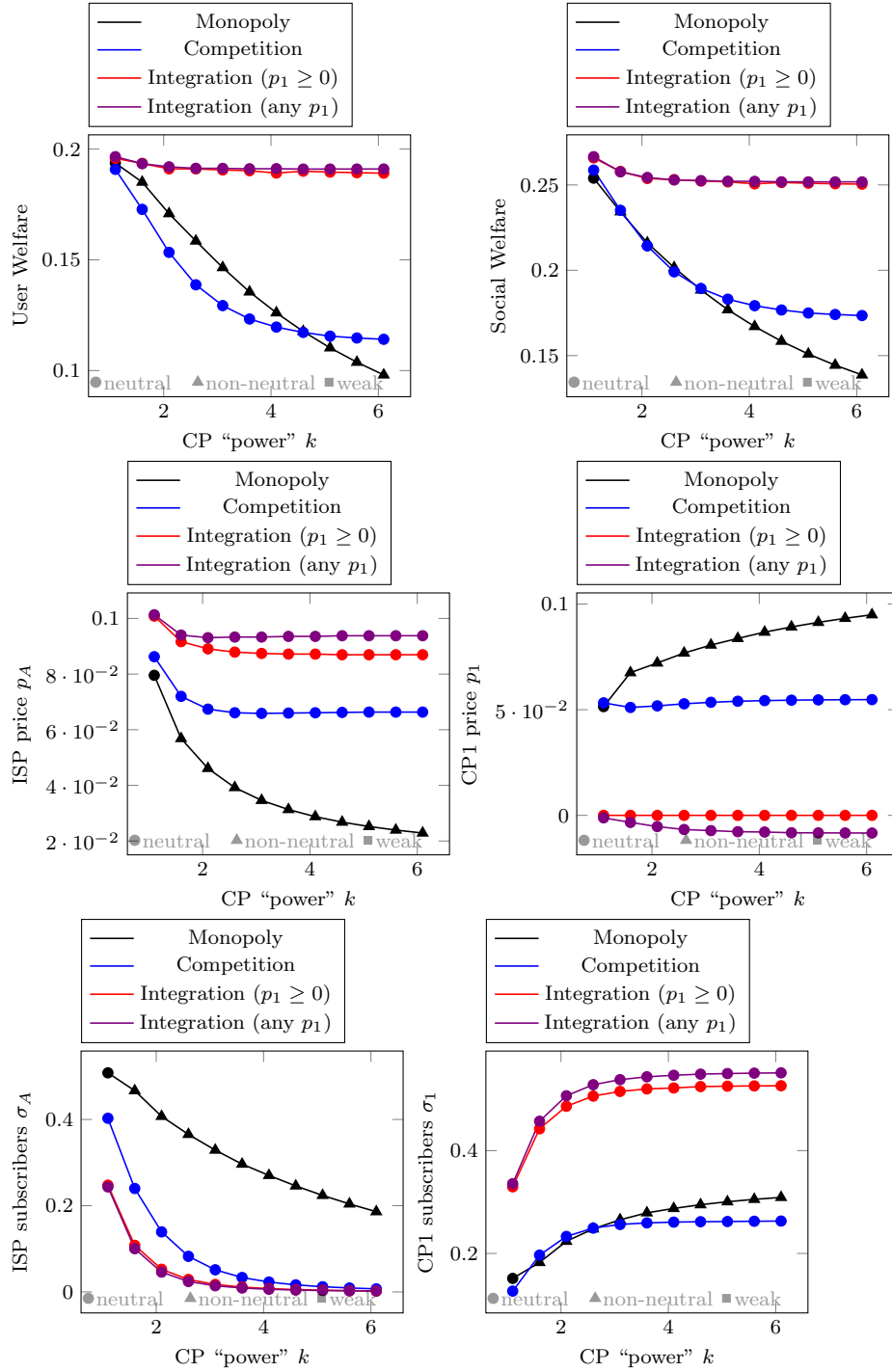


Figure 14: Equilibrium values when the neutrality regime is chosen to maximize Social Welfare, for $\alpha = 3$

side-payments leads to the same situation as forbidding those side payments when it benefits society: in other words, deciding who chooses the neutrality policy does not impact the output.

ii) If weak neutrality is imposed in the competitive case, then the ISP implements a neutral policy, and with powerful CPs such a policy is chosen even in the absence of any neutrality regulation.

iii) Vertical integration leads to neutral policies being implemented by the federation, and is the market structure leading to the highest social and user welfare.

References

- [1] K. Agarwal, P. Maillé, and B. Tuffin. Impact of heterogeneous neutrality rules with competitive content providers. In *Proc. of IFIP/IEEE International Symposium on Integrated Network Management (IM)*, Bordeaux, France, May 2021.
- [2] E. Altman, P. Bernhard, S. Caron, G. Kesidis, J. Rojas-Mora, and S. Wong. A study of non-neutral networks with usage-based prices. In *Proc. of 3rd ETM Workshop*, Amsterdam, The Netherlands, Sept 2010.
- [3] E. Altman, A. Legout, and Y. Xu. Network non-neutrality debate: An economic analysis. In *Proc. of Networking*, pages 68–81, Barcelona, Spain, May 2011. LNCS 6641, Springer Verlag.
- [4] L. Belli and P. (Eds.) De Filippi. *Net neutrality compendium: Human rights, free competition and the future of the Internet*. Springer, 2016.
- [5] S. Caron, E. Altman, and G. Kesidis. Application neutrality and a paradox of side payments. In *Proceedings of the Re-Architecting the Internet Workshop*, 2010.
- [6] J.P. Choi and Kim B.C. Net neutrality and investment incentives. *The RAND Journal of Economics*, 41(3):446–471, 2010.
- [7] P. Coucheney, P. Maillé, and B. Tuffin. Impact of reputation-sensitive users and competition between ISPs on the net neutrality debate. *IEEE Transactions on Network and Service Management*, 10(4):425–433, 2013.
- [8] P. Coucheney, P. Maillé, and B. Tuffin. Network neutrality debate and ISP inter-relations: Traffic exchange, revenue sharing, and disconnection threat. *Netnomics*, 1(3):155–182, 2014.
- [9] P. Crocioni. Net neutrality in Europe: Desperately seeking a market failure. *Telecommunications Policy*, 35(1):1 – 11, 2011.
- [10] G. D’Acquisto, P. Maillé, M. Naldi, and B. Tuffin. Impact on retail prices of non-neutral wholesale prices for content providers. In *NGI 2012: 8th Euro-NF Conference on Next Generation Internet*, pages 111–117, Karlskrona, Sweden, June 2012.

- [11] X. Deng, Z. Feng, and C.H. Papadimitriou. Power-law distributions in a two-sided market and net neutrality. In *Proceedings of 12th Conference on Web and Internet Economics (WINE 2016)*, pages 59–72, Montreal, Canada, 2016.
- [12] N. Economides and J. Tag. Network neutrality on the internet: A two-sided market analysis. *Information Economics and Policy*, 24(2):91–104, 2012.
- [13] D. Fudenberg and J. Tirole. *Game Theory*. MIT Press, Cambridge, Massachusetts, 1991.
- [14] J. Fudickar. Net neutrality, vertical integration, and competition between content providers. Working Papers 2015014, Berlin Doctoral Program in Economics and Management Science (BDPEMS), 2015.
- [15] H. Guo, S. Bandyopadhyay, A. Lim, Y.-C. Yang, and H.K. Cheng. Effects of competition among internet service providers and content providers on the net neutrality debate. *MIS Q.*, 41(2):353–370, jun 2017.
- [16] B. Jullien and W. Sand-Zantman. Internet Regulation, Two-Sided Pricing, and Sponsored Data. *International Journal of Industrial Organization*, 58:31–62, May 2018.
- [17] T.M. Lenard and R.J. (Eds.) May. *Net Neutrality or Net Neutering: Should Broadband Internet Services be Regulated*. Springer, 2006.
- [18] R.T.B. Ma, D.M. Chiu, J.C.S. Lui, V. Misra, and D. Rubenstein. On cooperative settlement between content, transit, and eyeball internet service providers. *IEEE/ACM Transactions on Networking*, 19(3):802–815, June 2011.
- [19] P. Maillé and B. Tuffin. Neutral and Non-Neutral Countries in a Global Internet: What Does it Imply? In *Proc. of GECON - 16th International Conference on the Economics of Grids, Clouds, Systems, and Services*, Leeds, United Kingdom, September 2019. Springer.
- [20] P. Maillé and B. Tuffin. Wireless Service Providers Pricing Game in Presence of Possible Sponsored Data. In *15th International Conference on Network and Service Management (CNSM)*, Halifax, Canada, October 2019.
- [21] P. Maillé and B. Tuffin. *From Net Neutrality to ICT neutrality*. Springer, 2022. In Press.
- [22] J. Musacchio, G. Schwartz, and J. Walrand. A two-sided market analysis of provider investment incentives with an application to the net-neutrality issue. *Review of Network Economics*, 8(1), 2009.
- [23] J. Musacchio, J. Walrand, and G. Schwartz. Network neutrality and provider investment incentives. In *Proc. of 41st Asilomar Conference on Signals, Systems and Computers (ACSSC)*, pages 1437–1444, Nov 2007.

- [24] P. Njoroge, A. Ozdaglar, N. Stier-Moses, and G. Weintraub. Investment in two sided markets and the net neutrality debate. Technical Report DRO-2010-05, Columbia University, Decision, Risk and Operations Working Papers Series, 2010.
- [25] M. Osborne and A. Rubinstein. *A Course in Game theory*. MIT Press, 1994.
- [26] P. Reichl, R. Schatz, and B. Tuffin. Logarithmic laws in service quality perception : Where microeconomics meets psychophysics and quality of experience. *Telecommunication Systems*, 52(2):587–600, 2013.
- [27] P. Vyavahare, J. Nair, and D. Manjunath. Sponsored data: On the effect of isp competition on pricing dynamics and content provider market structures. *IEEE/ACM Transactions on Networking*, pages 1–14, 2022.
- [28] T. Wu. Network neutrality, broadband discrimination. *Journal of Telecommunications and High Technology*, 2003.