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

Vedant Joseph Kumar, Patrick Maillé
IMT Atlantique, IRISA, UMR CNRS 6074
Rennes, France
vedantsbox@gmail.com, patrick.maille@imt.fr

Bruno Tuffin
Inria, Univ. Rennes, CNRS, IRISA
Rennes, France
bruno.tuffin@inria.fr

***Abstract*—This paper deals with the (still) 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 rule to determine if regulation is recommended. We show from our data set that, among other notable results, there is no interest in imposing neutrality since the ISP choice leads to the situation benefiting to society. Furthermore, the optimal scenario for society is when there is vertical integration, in which case the integrated federation actually opts for neutrality.**

***Index Terms*—Network Neutrality, Game Theory, Vertical Integration**

I. 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 [1]–[3].

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 [4], 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 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 [3], 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 [5], [6], monopolistic ISP/competing CPs [7], [8], competing ISPs/monopolistic CP [9], competing ISPs and CPs [8], [10], vertical integration between an ISP and a CP [11]–[14]), how neutrality is modeled/interpreted (type of differentiation applied [15], pricing schemes [5], [16]), and how user behavior is modeled (through individual utility functions with heterogeneity among users [15], or aggregated demand functions, either linear [5], [6], non-linearly varying with the available throughput [8], or based on attraction models [9]).

Note that there exists an extensive literature focusing on other aspects related to neutrality, such as (non exhaustively) incorporating into the picture transit ISPs [17] or a Public Option (behaving neutrally) ISP [8], advertising [18], zero rating practices [19]–[21], heterogeneity among countries [22], [23], impact on investment [11], [15], 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

978-3-903176-59-1 ©2023 IFIP

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 [8], [24]. In the 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 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 at in [3], but without the full analysis presented in this paper. To the best of our knowledge, the three scenarios we treat have not been jointly studied through a common model.

The paper is organized as follows. Section II introduces the economic model that will be used to study all scenarios. The monopolistic-CP case is treated in Section III, and will serve as a baseline. Sections IV and V respectively analyze the situation of competitive CPs, and the case of a vertically-integrated CP competing with a non-integrated one. Section VI provides a comparison of the outputs for neutral, weak-neutral and non-neutral scenarios. The goal is to determine what neutrality policies could be “recommended”.

II. General model

This section presents the common model that will be applied to all three content-providing market structure settings, that includes three types of actors.

A. Internet Service Provider (ISP)

We consider only one ISP, as this situation is still predominant in many regions. The ISP is treated as a profit-oriented actor, focusing on its **total revenue** as the objective (utility) function. Note that we do not include infrastructure investments in the model. Depending on the situation, there can be one or two decision variables for the ISP:

• 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. 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

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

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.

B. 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

$$U_i = (p_i - q_i)\theta_i. \tag{2}$$

C. 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 (labeled A);
- subscribe to the ISP and a CP i for the additional service (labeled i);
- not subscribe to any service (labeled 0).

To encompass heterogeneity among users, we apply a discrete-choice model (as in [9]), 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

$$V_o := \alpha_o \ln(1/\text{perceived\_cost}_o) + \kappa_{u,o} \tag{3}$$

where all $\kappa_{u,o}$ are considered as independent random variables following a standard Gumbel distribution [9], 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

$$v_o := \alpha_o \ln(1/\text{perceived\_cost}_o) \tag{4}$$

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; that link can be done too for Quality of Experience [25].

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 $(\text{perceived\_cost}_o)^{-\alpha_o}$ [9]. 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 $o \in \{0, A, 1, \ldots, n\}$.

$$\theta_0 = \frac{(p_0)^{-\alpha_0}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}} \quad (5)$$

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

$$\theta_i = \frac{(p_A + \beta_i p_i)^{-\alpha_i}}{(kp_A)^{-\alpha_A} + \sum_{i=1}^n (p_A + \beta_i p_i)^{-\alpha_i} + p_0^{-\alpha_0}} \quad (7)$$

where the last line stands for $i = 1, ..., n$.

D. User and Social Welfare

To measure user and overall satisfaction, we define in this subsection user and social welfare. In line with [26], user welfare UW' is defined as the aggregated utility from users, looking at the difference with the no-service case:

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

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

$$\begin{aligned}\mathbb{P}[Z \leq z] &= \mathbb{P}\left[(V_0 \geq V_A - z) \cap \left\{\bigcap_{i=1}^n (V_0 \geq V_i - z)\right\}\right] \\ &= \frac{\exp(v_0)}{\exp(v_0) + \exp(-z)(\exp(v_A) + \sum_{i=1}^n \exp(v_i))},\end{aligned}$$

where we recall that v_o ($o \in \{0, A, 1 \ldots, n\}$) is the deterministic part of utility, defined in (4). Then we can get

$$\text{UW'} = \mathbb{E}[Z] = \log\left(1 + \frac{p_0^{\alpha_0}}{(kp_A)^{\alpha_A}} + \sum_{i=1}^n \frac{p_0^{\alpha_0}}{(p_A + \beta_i p_i)^{\alpha_i}}\right).$$

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

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

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

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

E. Differentiation, Weak and Strong Neutrality

We first define our three neutrality concepts.

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

Of course, weak and strong neutrality are different only if at least two CPs are considered.

F. 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 selects 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 [27] 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*.

III. 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 II-F, the CP will choose its subscription price p_1 anticipating 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^*

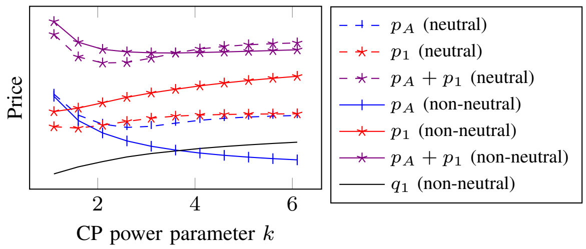

Fig. 1. Prices at the outcome of the game (monopolistic CP) in terms of the CP power k in both neutral and non-neutral scenarios, when $p_0 = 0.1$ and $\alpha = 3$.

is obtained by equating $\frac{\partial U_1}{\partial p_1}$ to zero. 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 equation reduces to solving $p_1^2 - 2p_1 q_1 - p_A^2 - 2p_A q_1 - 1/Q = 0$, with non-negative solution

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

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 analyze what happens when neutrality is imposed: we just enforce $q_1 = 0$ 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 $p_1 = \sqrt{p_A^2 + \frac{1}{Q}}$.

Let's 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. We again consider $\alpha_A = \alpha_1 = \alpha_0 = \alpha$. The analysis is done in [3, Chapter 4] in the case $\alpha = 2$, with the observation that surprisingly, non-neutrality is better than neutrality as regards user welfare and social wefare, even if the more powerful the CP (the larger k), the lower 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 $\alpha = 3$. Note that prices p_A, p_1 and q_1 are monotone with 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). 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)): for $\alpha = 2$, users may benefit from a non-neutral situation in a powerful-CP scenario.

Figures 2 and 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 and social welfares decrease as k increases: 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, 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 decreases at equilibrium: k large means there is a big utility improvement 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).

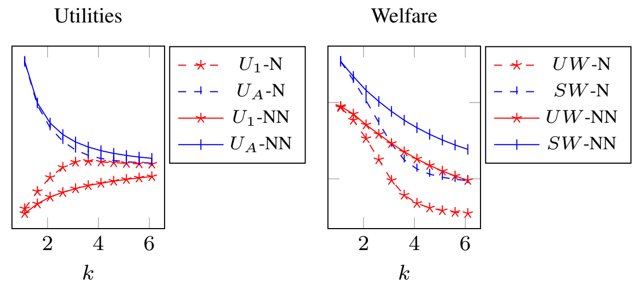

Fig. 2. Utilities and welfares at the outcome of the game in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$ and $\alpha = 3$. In the legend, N and NN respectively stand for "neutral" and "non-neutral".

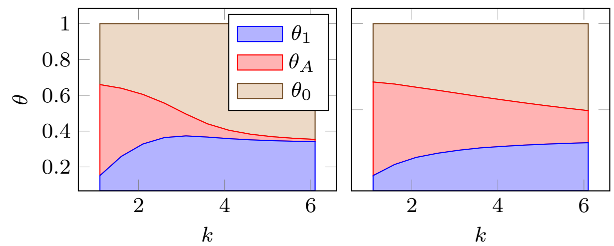

Fig. 3. Distribution of users in the neutral *(left)* and non-neutral *(right)* scenarios at the outcome of the game in terms of k, when $p_0 = 0.1$ and $\alpha = 3$. For a given value of k, the colored height gives the proportion θ_i choosing option $i \in \{0, A, 1\}$.

IV. Impact of Competition at the CP Level

Let us check how competition among CPs impacts the outcomes in both neutral and non-neutral scenarios, and possibly what could be recommended in terms of regulation.

We simplify the analysis with $n = 2$ and $\alpha_0 = \alpha_A = \alpha_1 = \alpha_2 = \alpha$, which leads to the following proportions of user choices: if $D = (p_A + p_1)^{-\alpha} + (p_A + \beta_2 p_2)^{-\alpha} + (kp_A)^{-\alpha} + p_0^{-\alpha}$, we have $\theta_0 = p_0^{-\alpha}/D$, $\theta_A = (kp_A)^{-\alpha}/D$, $\theta_1 = (p_A + p_1)^{-\alpha}/D$ and $\theta_2 = (p_A + \beta_2 p_2)^{-\alpha}/D$.

Prices p_1 and p_2 for any fixed values of p_A and the side payments $(q_i)_{i=1,2}$ are computed through a non-cooperative game between CPs, for which we look for a Nash equilibrium, i.e., a point (p_1, p_2) from which no CP has an interest to unilaterally deviate [27]. If such a point exists and is unique, we consider it as the outcome of the game. In our numerical investigations of this model, although we have not 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.

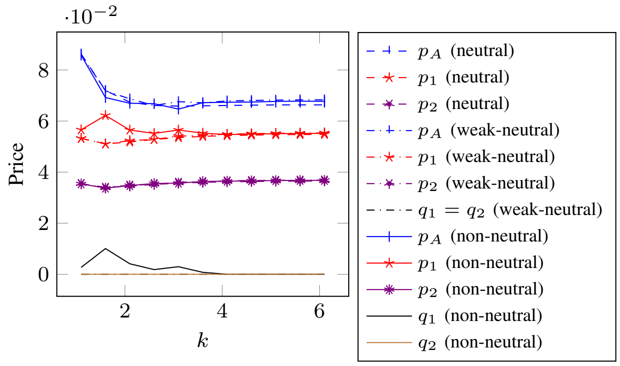

Fig. 4. Prices at the outcome of the game with two CPs in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

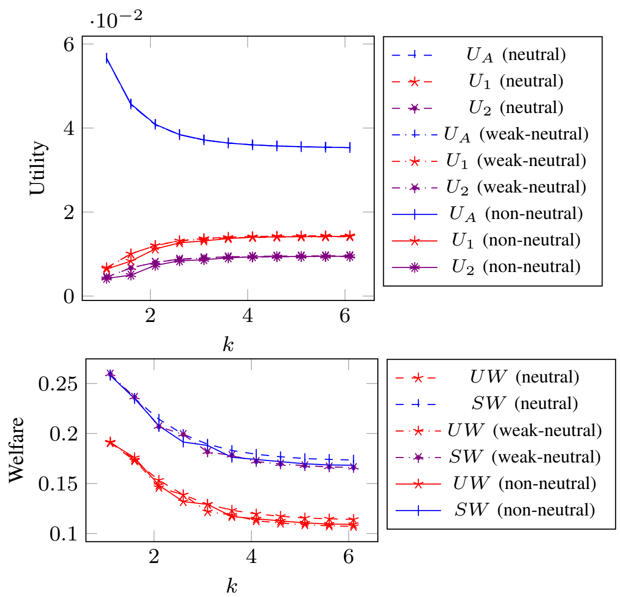

Fig. 5. Utilities and welfares at the outcome of the game with two CPs in terms of k in neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

We display the values of prices, utilities and welfares at the outcome of the game in Figures 4 and 5. It can be readily checked that in the weakly neutral scenario the side payment is simply set to 0: 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.

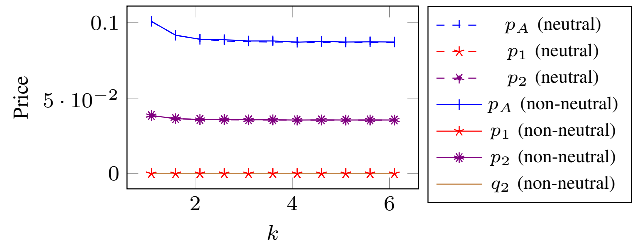

Fig. 6. Prices at the outcome of the game with two CPs (one integrated) in terms of k in both neutral and non-neutral scenarios, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

V. 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* [1]. Such a situation raises concerns about unfair payments asked to competing CPs, thereby distorting the competition among CPs.

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

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

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 II-F, and the problem solved by *backward induction*.

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

Figure 6 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 7 and 8 for comparison sake to display the utilities, welfare and user distribution for both non-integrated (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.

Integration affects the non-integrated CP (smaller U_2), as expected. But as can be seen in Figure 7, 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 8 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). Figure 9 shows the prices, utilities and

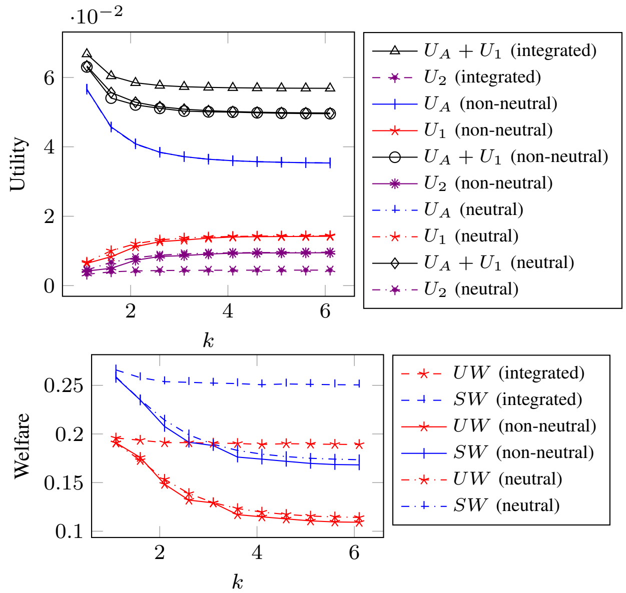

Fig. 7. Utilities and welfare at the outcome of the game with two CPs (one integrated, non-negative prices) compared with the non-integrated cases, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$. For the integrated case, side payments are null even in the non-neutral setting, hence only one set of curves.

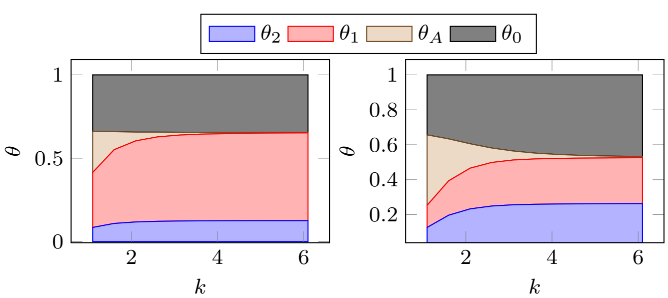

Fig. 8. User distribution at the outcome of the game with two CPs, with one integrated CP and non-negative prices *(left)*, and two non-integrated CPs in the neutral case *(right)* in terms of k, when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$. For a given value of k, the colored height gives the proportion θ_i choosing option $i \in \{0, A, 1, 2\}$.

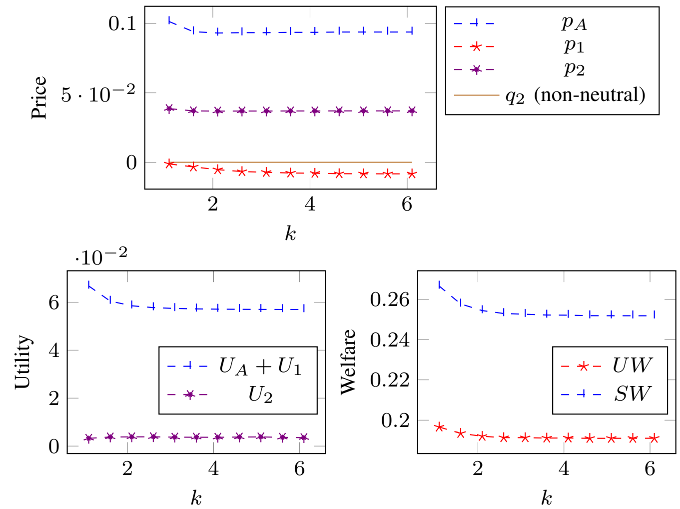

Fig. 9. Prices, utilities and welfares at the outcome of the game with two CPs (one integrated, negative prices allowed) in terms of k in both neutrality regimes (curves coincide as the side-payment is set to 0 in the non-neutral case), when $p_0 = 0.1$, $\beta_2 = 1.5$ and $\alpha = 3$.

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 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.

VI. Discussion and Conclusions

Previous sections analyze 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 compare those scenarios, in particular when an "optimal" neutrality policy is implemented. "Optimal" can be in the sense of optimizing an 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 10 the output curves in monopoly, duopoly and integrated cases, but at the neutrality policy optimizing the ISP revenue, i.e., when the neutrality policy decision is taken by the ISP. Optimizing user welfare instead of social welfare for a regulator yields similar curves and is therefore omitted here, 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 ISP subscription price 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).

Summarizing the paper, 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) side-payments leads to the same situation as

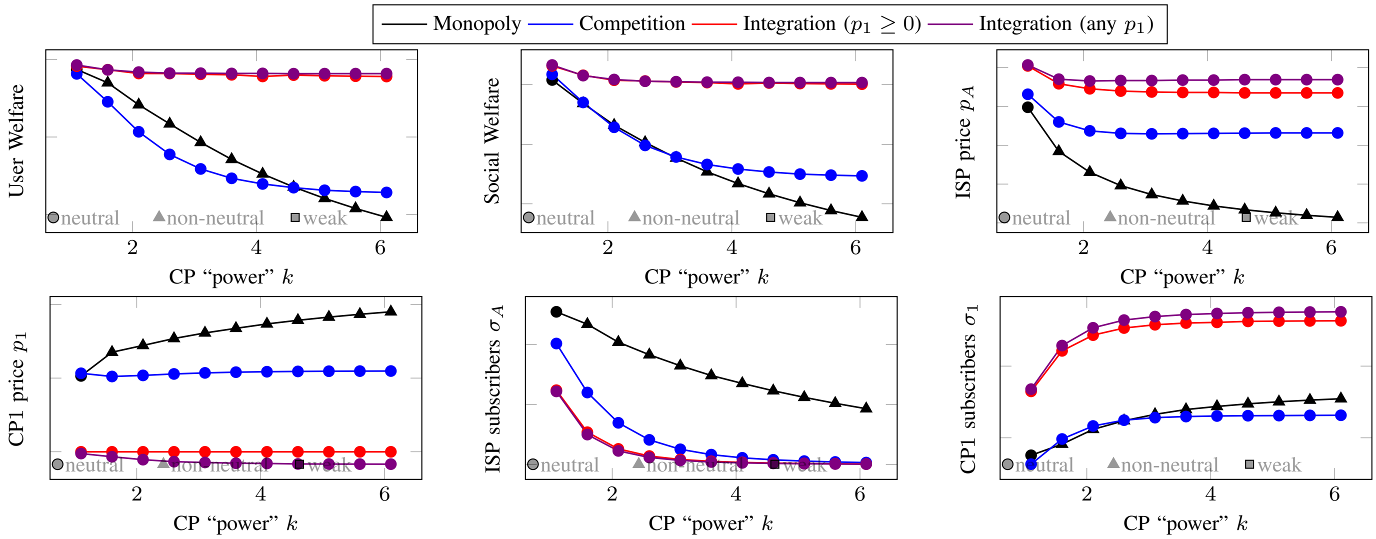

Fig. 10. Equilibrium values when the neutrality regime is chosen by the ISP, for $\alpha = 3$

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] T. Lenard and R. E. May, *Net Neutrality or Net Neutering: Should Broadband Internet Services be Regulated*. Springer, 2006.

[2] L. Belli and P. E. De Filippi, *Net neutrality compendium: Human rights, free competition and the future of the Internet*. Springer, 2016.

[3] P. Maillé and B. Tuffin, *From Net Neutrality to ICT neutrality*. Springer, 2022.

[4] T. Wu, "Network neutrality, broadband discrimination," *Journal of Telecommunications and High Technology*, 2003.

[5] 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.

[6] E. Altman, A. Legout, and Y. Xu, "Network non-neutrality debate: An economic analysis," in *Proc. of Networking*. Barcelona, Spain: LNCS 6641, Springer Verlag, May 2011, pp. 68–81.

[7] X. Deng, Z. Feng, and C. Papadimitriou, "Power-law distributions in a two-sided market and net neutrality," in *Proc. of 12th WINE*, Montreal, Canada, 2016, pp. 59–72.

[8] R. T. B. Ma and V. Misra, "The public option: a non-regulatory alternative to network neutrality," *IEEE/ACM Transactions on Networking*, vol. 21, no. 6, pp. 1866–1879, Dec 2013.

[9] 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*, vol. 10, no. 4, pp. 425–433, 2013.

[10] S. Caron, E. Altman, and G. Kesidis, "Application neutrality and a paradox of side payments," in *Proc. of the Re-Architecting the Internet Workshop*, 2010.

[11] J. Choi and B. Kim, "Net neutrality and investment incentives," *The RAND Journal of Economics*, vol. 41, no. 3, pp. 446–471, 2010.

[12] P. Crocioni, "Net neutrality in Europe: Desperately seeking a market failure," *Telecommunications Policy*, vol. 35, no. 1, pp. 1–11, 2011.

[13] N. Economides and J. Tag, "Network neutrality on the internet: A two-sided market analysis," *Information Economics and Policy*, vol. 24, no. 2, pp. 91–104, 2012.

[14] J. Fudickar, "Net neutrality, vertical integration, and competition between content providers," Berlin Doctoral Program in Economics and Management Science (BDPEMS), Working Papers 2015014, 2015.

[15] P. Njoroge, A. Ozdaglar, N. Stier-Moses, and G. Weintraub, "Investment in two-sided markets and the net neutrality debate," *Review of Network Economics*, vol. 12, no. 4, pp. 355–402, Feb 2014.

[16] G. D'Acquisto, P. Maillé, M. Naldi, and B. Tuffin, "Impact on retail prices of non-neutral wholesale prices for content providers," in *Proc. of 8th NGI*, Karlskrona, Sweden, Jun. 2012.

[17] R. Ma, D. Chiu, J. Lui, V. Misra, and D. Rubenstein, "On cooperative settlement between content, transit, and eyeball internet service providers," *IEEE/ACM Transactions on Networking*, vol. 19, no. 3, pp. 802–815, June 2011.

[18] 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*, vol. 8, no. 1, 2009.

[19] 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*, pp. 1–14, 2022.

[20] B. Jullien and W. Sand-Zantman, "Internet Regulation, Two-Sided Pricing, and Sponsored Data," *International Journal of Industrial Organization*, vol. 58, pp. 31–62, May 2018.

[21] P. Maillé and B. Tuffin, "Wireless Service Providers Pricing Game in Presence of Possible Sponsored Data," in *Proc. of 15th CNSM*, Halifax, Canada, Oct. 2019.

[22] K. Agarwal, P. Maillé, and B. Tuffin, "Impact of heterogeneous neutrality rules with competitive content providers," in *Proc. of IFIP/IEEE IM*, Bordeaux, France, May 2021.

[23] P. Maillé and B. Tuffin, "Neutral and Non-Neutral Countries in a Global Internet: What Does it Imply?" in *Proc. of 16th GECON*. Leeds, United Kingdom: Springer, Sep. 2019.

[24] H. Guo, S. Bandyopadhyay, A. Lim, Y.-C. Yang, and H. Cheng, "Effects of competition among internet service providers and content providers on the net neutrality debate," *MIS Q.*, vol. 41, no. 2, p. 353–370, 2017.

[25] P. Reichl, R. Schatz, and B. Tuffin, "Logarithmic laws in service quality perception : Where microeconomics meets psychophysics and quality of experience," *Telecommunication Systems*, vol. 52, no. 2, pp. 587–600, 2013.

[26] P. Coucheney, P. Maillé, and B. Tuffin, "Network neutrality debate and ISP inter-relations: Traffic exchange, revenue sharing, and disconnection threat," *Netnomics*, vol. 1, no. 3, pp. 155–182, 2014.

[27] M. Osborne and A. Rubinstein, *A Course in Game theory*. MIT Press, 1994.