Impact of Heterogeneous Neutrality Rules with Competitive Content Providers

Khushboo Agarwal
IIT Bombay
Mumbai, India
agarwal.khushboo@iitb.ac.in

Patrick Maillé
IMT Atlantique, IRISA
Rennes, France
patrick.maille@imt.fr

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

***Abstract*—Network neutrality has recently been repealed in the United States, leading to a worldwide Internet with different imposed policies. We build and analyze in this paper a game-theoretic model representing the interactions between users, network providers and content providers in this heterogeneous regulation context, and investigate the impact of two neutrality relaxation policies in a part of the world on all actors, compared with a fully-neutral network. Our results show that neutrality repeal may *only* favor the ISP in the differentiation-authorized zone, but no other actor, and that it can be worse off for everybody if the regulation procedures are very strict in the neutral area.**

***Index Terms*—Network neutrality, regulation, game theory, interactions, competition**

I. Introduction

The *network neutrality* debate is still active, more than 15 years after Tim Wu first coined the term [15]. While a consensus was seeming to emerge among regulators toward protecting neutrality (in the USA from the FCC in 2015 [5] and in Europe with the BEREC 2016 Net Neutrality guidelines [2]), major countries like the United States have recently taken steps to repeal those protections to favor market freedom and stimulate economic growth, by "remov[ing] unnecessary regulations to promote broadband investment" [6].

Detailed technical interpretations slightly differ among countries and stakeholders, but network neutrality can be summarized as the principle according to which "all traffic should be treated equally, without discrimination, restriction or interference, independent of the sender, receiver, type, content, device, service or application" [2]. In particular, in neutrality-enforced networks, network service providers (or ISPs, Internet Service Providers) are not allowed to charge their customers (users, or content providers (CPs)) extra for an improved service. For more on net neutrality, the arguments of both sides, and the history of the debate, the reader is advised to look at [7], [9]–[11], [13]–[15] and references therein.

With the different regulation stances among countries, we end up with a global Internet network where some parts are subject to neutrality rules–which can be seen as constraints for ISPs and protections for users and CPs–, while others are not and ISPs have the flexibility to create differentiated services. But the network being global, those two worlds interact: users in neutral areas can access content hosted in non-neutral areas, and vice-versa, so that the decisions made in an area (e.g., service qualities) can affect the whole internet ecosystem.

978-3-903176-32-4 © 2021 IFIP

The goal in this paper is to investigate the impact of those regulatory disparities on all the actors involved: ISPs, users, and CPs. In a preliminary work [12], we considered two areas, one neutral and one non-neutral (that can be seen as, e.g., the European Union and the United States after net neutrality regulations have been repealed, respectively), with some CPs based in each area. The CP demands (and hence, revenues) were assumed to depend only on the quality their users experienced, and CPs then had to select the most favorable quality for that purpose, when available. Our conclusions suggested that the type of regulatory relaxation (e.g., allowing the non-neutral ISPs to only offer quality improvement over a reference situation, or imposing a ratio between the highest and lowest quality levels) can have dramatically different consequences for stakeholders, ranging from benefitting all CPs and users to benefitting only ISPs at the expense of CPs and users.

An aspect that was missing in the model of [12], and that we develop here, is the price competition among CPs: in addition to playing on the quality, we now allow CPs to decide the price to charge for their service, and we introduce a specific demand function to model the interactions among CPs. The objective of that new model is to get closer to reality, with prices strongly affecting demands, so as to anticipate who the winners and losers of neutrality rules relaxation will be.

The comparison of the outputs in the three scenarios (fully neutral, partially neutral, and totally non-neutral in a zone) illustrate that repealing neutrality is always worse for CPs, users, and the ISP in the neutral area, whatever the neutrality level imposed in the neutral zone; only the non-neutral ISP may benefit from it. Even worse, it may lead to some content being inaccessible for some users, and no winner at all if neutrality rules are strict for CPs in the neutral area.

This paper is organized as follows. Our main assumptions are detailed in Section II. Section III develops, as a reference situation, the case when the whole network is neutral. Section IV treats the case where the CPs located in the neutral area cannot choose the quality for their flows crossing the non-neutral area, while that possibility is added in Section V. Each time, we find numerically the outcomes that can be expected and observe their implications for the stakeholders. Section VI draws some conclusions and directions for future work.

II. Model

A. Topology: two peering ISPs

We consider a simple network topology, as in [12], with two countries/areas in interactions with potentially different neutrality rules and a single ISP in each (all ISPs can be aggregated otherwise). With respect to [12], we here deal with CPs in competition, adding a level of game; we thus focus on the impact of this competition by considering a CP denoted by $\mathrm{CP_D}$ in the area potentially applying differentiation and another $\mathrm{CP_N}$ in the neutral area. We also introduce the price charged by CPs to users. We assume a peering link between areas, with no charge between ISPs.

B. Service qualities

Let q_N be the performance level offered by the neutral ISP. For the differentiated ISP, we will consider two scenarios in order to make comparisons: first the case where it is also neutral (single class of service with QoS q_D), and then the case where it is non-neutral (two offered qualities q_L and q_H). All qualities are assumed to be in $[0, 1]$. When users in Area $i \in \{N, D\}$ download/upload content to the CP in the same area, traffic only goes through the ISP i and the experienced quality is the one selected (no choice in case of neutrality, but a choice may be possible in the differentiated area) by CP i in its host zone. On the other hand, when accessing CP j from the other area, traffic goes through both ISPs, and overall performance is assumed to be the product of the two ISP qualities $q = q_{\mathrm{N}} \cdot q_{C_j}$, as illustrated in Figure 1. A typical example of such a product form is when QoS is the probability of successful transmission and losses occur independently on both networks.

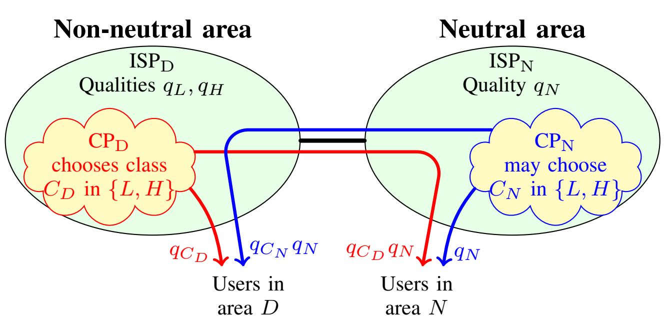

Fig. 1. Qualities perceived by users, depending on their host ISP and the host ISP of the CP they use, in the non-neutral scenarios (in the neutral scenario, $q_L = q_H = q_D$).

C. Monetary exchanges

This paper focuses on the determination of qualities by ISPs, but prices are also involved in the model (and decided through another game or by a regulator; on the other hand prices by CPs are decided in this paper). The per-unit-of-volume prices (paid by CPs to their host ISP) are p_N (in the neutral area), and p_L and p_H for performance levels q_L and q_H, respectively, in the non-neutral area if differentiation is implemented. If no differentiation is implemented in Area D, the per-unit-of-volume price is fixed to p_D. CPs on the other hand get revenue from two different sources:

- A per-unit-of-volume gain from advertisement a_i for CP i, with $i \in \{N, D\}$. Indeed advertisement revenue can reasonably be assumed proportional to the amount of data "sold";
- Revenue from users, assumed in this paper proportional to the consumed volume of data. We denote by r_i, for $i \in \{N, D\}$ the per-unit-of-volume price for data of CP i.

All those monetary flows are illustrated in Figure 2.

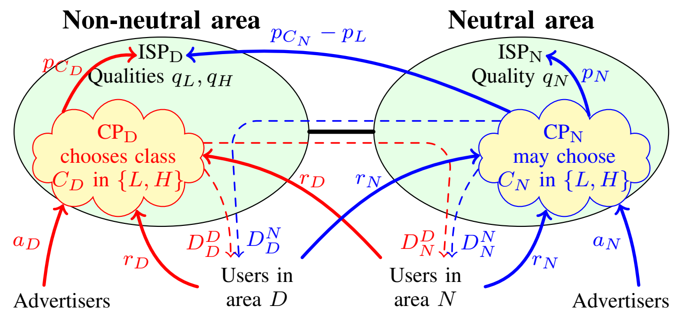

Fig. 2. Monetary flows (per unit of volume) in the model (solid lines), in the non-neutral scenarios (in the neutral scenario, $q_L = q_H = q_D$). The dashed lines represent the data flow volumes. Note that CPs only pay their host ISP, for all their outgoing flows, except when $\mathrm{CP_N}$ selects the quality q_H for its flows crossing $\mathrm{ISP_D}$ (in that case that CP pays $\mathrm{ISP_D}$ for the extra quality).

D. User demands

We finally denote by D_i^j the demand for content of CP j from customers in area i. Demand also depends on all prices and qualities, but we remove this dependence in the notation for sake of clarity and conciseness.

Following the ideas in [3], [4], user CP selection is from a discrete choice model. Using a Logit model, the valuation, or level of satisfaction, of a user u in Area j for a CP i is random and given by $V_{u,i,j} = v_{i,j} + \kappa_{u,i,j}$, where

- $v_{i,j} = \beta \log\left(\frac{q_{i,j}}{r_i}\right)$ with β a sensitivity parameter. A logarithmic form of utility is justified by the Weber-Fechner Law, a key principle in psychophysics describing the general relationship between the magnitude of a physical stimulus and its perceived intensity within the human sensory system [8]. The fraction in the log is the quality per monetary unit.
- The $\kappa_{u,i,j}$ are i.i.d. random variables following a Gumbel distribution with mean 0, which leads to simple analytical formulas for the user repartition among choices.

We also assume that there is a fictitious quality per unit of price, $q_0' > 0$, corresponding to the minimal quality under which users prefer to subscribe to no CP.

This leads to the proportion (or demand, assuming a total volume 1) of users D_N^N (resp. D_N^D) of the neutral area choosing CP N (resp. CP D), since users in Area N have the choice between no CP (with quality per unit price q_0'), CP N (with q_N/r_N) and CP D (with $q_N q_{C_D}/r_D$) [1]:

$$D_N^N = \frac{(q_N/r_N)^\beta}{(q_N q_{C_D}/r_D)^\beta + (q_N/r_N)^\beta + (q_0')^\beta} \tag{1}$$

$$D_N^D = \frac{(q_N q_{C_D}/r_D)^\beta}{(q_N q_{C_D}/r_D)^\beta + (q_N/r_N)^\beta + (q_0')^\beta} \tag{2}$$

(the remaining part chooses the outside option–not subscribing–, estimating that the offered quality per unit of money is not sufficient). Without loss of generality, we assume a mass 1 of potential demand in the neutral area.

Similarly, the demand of content from users in Area D is D_D^N (resp. D_D^D) for CP N (resp. CP D), given by, assuming a total potential demand mass m_D,

$$D_D^N = m_D \frac{(q_N q_{C_N}/r_N)^\beta}{(q_{C_D}/r_D)^\beta + (q_N q_{C_N}/r_N)^\beta + (q_0')^\beta} \tag{3}$$

$$D_D^D = m_D \frac{(q_{C_D}/r_D)^\beta}{(q_{C_D}/r_D)^\beta + (q_N q_{C_N}/r_N)^\beta + (q_0')^\beta}. \tag{4}$$

Note that, with respect to our first paper on heterogeneous neutrality rules [12], the demand function is totally different to take into account the competition between CPs.

E. Utilities

Utilities of CPs and ISPs are represented by their revenues. For CPs, it is their demand times the unit gain (advertisement plus subscriptions), to which the transmission cost to the host ISP has to be subtracted. This gives U_N^{CP} and U_D^{CP} for the CPs in respectively Area N and D:

$$\begin{aligned} U_D^{CP} &= (a_D + r_D - p_{C_D})(D_N^D + D_D^D) \\ U_N^{CP} &= (a_N + r_N - p_N)(D_N^N + D_D^N) + (p_L - p_{C_N})D_D^N. \end{aligned}$$

The difference for the CP in the neutral area comes from the fact that it may not only have to pay p_N to ISP N, but also the price difference to ISP D to be in the upper class, if chosen, for the traffic of users in Area D: If CP N chooses the low quality for its flows on ISP D, i.e., $C_N = L$ then there is no extra fee and all its flows are charged p_N. This latter case corresponds to the current situation where CPs are charged only by their host ISP and not the distant one, which is specifically what triggered the net neutrality debate.

The utilities of ISPs are made of their revenue minus the cost of the architecture for providing a given quality. Following [12], the cost f_i borne by an ISP $i \in \{N, D\}$ is made of the demand level at the quality times the (unit) cost $c_i(q)$ to provide this level:

$$\begin{aligned} f_{\rm N} &= \left(D_N^D + D_N^N + D_D^N\right) c_N(q_N) \\ f_{\rm D} &= (D_N^D + D_D^D) c_{\rm D}(q_{C_D}) + D_D^N c_{\rm D}(q_{C_N}), \end{aligned}$$

with the classes chosen by the CPs. Hence the utilities:

$$\begin{aligned} U_N^{ISP} &= p_N(D_N^N + D_D^N) - f_N \\ U_D^{ISP} &= p_{C_D}(D_D^D + D_N^D) + (p_{C_N} - p_L)D_D^N - f_D. \end{aligned}$$

F. Order of decisions

Decisions are taken at different time scales:
1) ISPs play the game on the QoS levels to be offered to the CPs: the ISP in the neutral area chooses the value q_N and the ISP in the non-neutral area chooses the optimal values of q_L, q_H (or q_D in the fully neutral scenario). Note that the strategy of an ISP impacts the other in terms of demand.
2) CPs choose the class of service to be provided to the users in the non-neutral region and the price to be charged to their consumers, acknowledging the competition that they will face.
3) Users select their preferred CP.

The game is played by backward induction, meaning that players at a given level anticipate the decisions of actors playing next when optimizing their strategy.

For comparison purposes, we will consider three scenarios:
1) When neutrality is imposed in both areas.
2) When neutrality is relaxed in one of the areas. In this situation, we further split our study into two scenarios:
   1) The case where the CP in the neutral area is always served with the low quality in the differentiated ISP network (that CP flows are always treated with low quality q_L in the non-neutral area).
   2) The case where both CPs can freely select the class of service for their flows in the differentiated area.

III. Benchmark scenario: a neutral network

We first look at the benchmark case where both ISPs are neutral, for comparison purposes. The game is then reduced to the following set of ordered decisions and is (again) analyzed by backward induction:
1) ISPs play a game on the QoS to be offered to CPs, i.e., the ISP in the neutral area chooses q_N and the ISP in the "non-neutral area" (that is actually neutral here) chooses q_D.
2) CPs play a game on their charging prices r_N and r_D,
3) Users select their CP based on prices and qualities.

For a self-contained section, we rewrite the demand and utility functions with the full-neutrality restriction:

$$\begin{aligned} D_N^N &= \frac{(q_N/r_N)^\beta}{(q_N q_D/r_D)^\beta + (q_N/r_N)^\beta + (q_0')^\beta} \\ D_N^D &= \frac{(q_N q_D/r_D)^\beta}{(q_N q_D/r_D)^\beta + (q_N/r_N)^\beta + (q_0')^\beta} \\ D_D^N &= m_D \frac{(q_N q_D/r_N)^\beta}{(q_D/r_D)^\beta + (q_N q_D/r_N)^\beta + (q_0')^\beta} \\ D_D^D &= m_D \frac{(q_D/r_D)^\beta}{(q_D/r_D)^\beta + (q_N q_D/r_N)^\beta + (q_0')^\beta} \\ U_D^{CP} &= (a_D + r_D - p_D)(D_N^D + D_D^D) \\ U_N^{CP} &= (a_N + r_N - p_N)(D_N^N + D_D^N) \\ U_N^{ISP} &= p_N(D_N^N + D_D^N) - (D_N^D + D_N^N + D_D^N)c(q_N) \\ U_D^{ISP} &= p_D(D_D^D + D_N^D) - (D_N^D + D_D^D + D_D^N)c(q_D). \end{aligned}$$

Throughout the paper, we will use the following parameter values, unless mentioned otherwise: $p_N = 0.5, p_D = 0.5, q_0' = 0.8, \alpha = 0.02, m_D = 1, \beta = 1.5, a_N = 0.1, a_D = 0.1, q_N = 0.6, q_D = 0.5$.

Consider first CPs selecting their prices. Figure 3 displays the best responses of both CPs in terms of the price of the opponent on the same figure. A Nash equilibrium, that is a

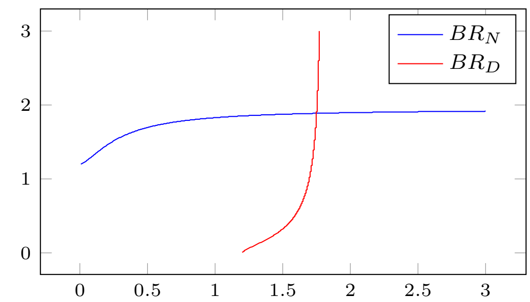

Fig. 3. CP best responses, with $q_D = 0.5, q_N = 0.6, a_D = 0.1, a_N = 0.1, p_D = 0.5, p_N = 0.5$

profile of strategies from which no player has an interest to deviate unilaterally, is then an intersection point of both curves. We can see that such an equilibrium exists and is unique. It can also be checked that best responses are increasing.

ISPs play first, but anticipating the strategies of CPs. We therefore use for each profile of qualities chosen by ISPs the corresponding Nash equilibrium in the pricing game between CPs. Figure 4 displays the revenue of ISP N in terms of q_N for several values of q_D. A maximum value is readily observed.

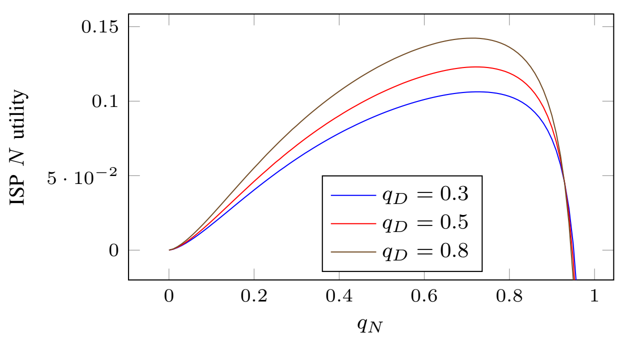

Fig. 4. ISP N utility for several values of q_D, with $a_D = 0.1, a_N = 0.1, p_D = 0.5, p_N = 0.5$

The larger the quality of the opponent, the larger the revenue of the ISP: this positive externality stems from users being more interested in network usage, impacting all zones. Note that even if the curves are distinct, the values at which the maximum is obtained are close.

This can also be observed on the best-response curves in Figure 5. Best responses seem to evolve linearly with the quality of the other ISP, and to decrease but at a very small rate. The best strategy therefore only slightly depends on the strategy of the opponent. Note that there is for this upper-level quality game a single Nash equilibrium.

For the parameters values provided at the beginning of this section, we give in Table I *(first line)* the output of the game described previously. This will be used as a benchmark for comparison with the non-neutral scenarios of the next sections.

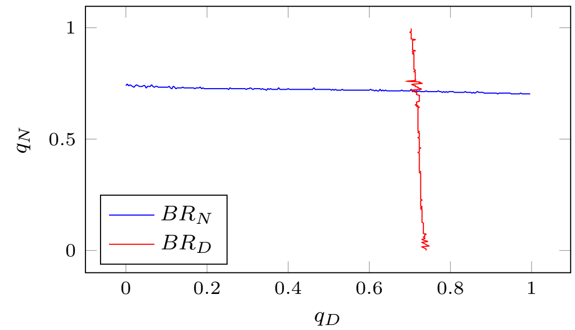

Fig. 5. ISP best responses, with $a_D = 0.1, a_N = 0.1, p_D = 0.5, p_N = 0.5$

IV. Scenario: CP in the neutral area not free to pay for quality in the non-neutral zone

We now consider the situation where the ISP in Zone D is allowed to offer a differentiated service while the one in Zone N is not allowed to (US versus Europe-like situation). To start, we assume in this section that the CP in Zone N is not allowed by its local rules to even benefit from a differentiated service for its traffic through the ISP in Zone D (to reach customers in that zone).

Demand and utility functions are as follows:

$$\begin{aligned}
D_N^N &= \frac{(q_N/r_N)^\beta}{(q_N q_{C_D}/r_D)^\beta + (q_N/r_N)^\beta + (q_0')^\beta}\\
D_N^D &= \frac{(q_N q_{C_D}/r_D)^\beta}{(q_N q_{C_D}/r_D)^\beta + (q_N/r_N)^\beta + (q_0')^\beta}\\
D_D^N &= m_D \frac{(q_N q_L/r_N)^\beta}{(q_{C_D}/r_D)^\beta + (q_N q_L/r_N)^\beta + (q_0')^\beta}\\
D_D^D &= m_D \frac{(q_{C_D}/r_D)^\beta}{(q_{C_D}/r_D)^\beta + (q_N q_L/r_N)^\beta + (q_0')^\beta}\\
U_D^{CP} &= (a_D + r_D - p_{C_D})(D_N^D + D_D^D)\\
U_N^{CP} &= (a_N + r_N - p_N)(D_N^N + D_D^N)\\
U_N^{ISP} &= p_N(D_N^N + D_D^N) - (D_N^D + D_N^N + D_D^N)c(q_N)\\
U_D^{ISP} &= p_D(D_D^D + D_N^D) - (D_N^D + D_D^D)c_D(q_{C_D} - D_D^N c_D(q_L).
\end{aligned}$$

With the order of decisions of Section II-F, to apply backward induction we start with the game between CPs. CP N chooses its price r_N, but CP D's decision has two components: one continuous (its price r_D) and one discrete (the class L or H, depending on the quality levels q_L and q_H to which its traffic will be oriented in Zone D). This makes the game more complicated to analyze, in particular computing best-responses is a bit harder. Indeed, to compute the best response of CP D in terms of a choice r_N of CP N, we need to compute the optimal price r_D^L and revenue when Class L is selected, then the optimal price r_D^H and revenue when Class H is selected, and choose the class (and associated price) giving the larger revenue, i.e.,

$$(r_D^*, C) = \arg \max_{(r,c) \in \{(r_D^L, L), (r_D^H, H)\}} U_D^{CP}(r, c)$$

where we abusively give as only inputs of the utility the price and class of CP D, omitting those for the neutral area.

Figure 6 displays CP D revenue in terms of its decision variable (price) r_D for several choices of prices r_N and the two class choices; a maximum exists, and the quality chosen by the CP may vary with the price set by the opponent.

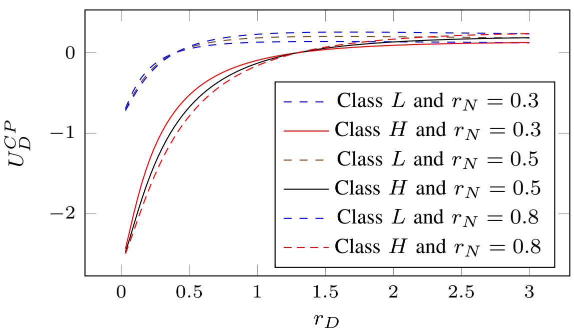

Fig. 6. CP D utility in terms of r_D, with $q_L = 0.5, q_H = 0.685, q_N = 0.6, a_D = 0.1, p_L = 0.5, p_H = 1.4$

To graphically find a Nash equilibrium in this game with two components for CP D, we can just draw:

- two best-response curves for CP N in terms of r_D: one corresponding to the selection of Class L by CP D and the other to the selection of Class H, drawn in two different colors;
- the best response value r_D^* in terms of r_N for CP D with a color (the same as above) used when the optimal class is L and the other color when it is H.

A Nash equilibrium is then an intersection point between a best-response curve of CP N with a best-response curve of CP D with the same color. Figure 7 illustrates this; here there is a single Nash equilibrium, where CP D selects Class H.

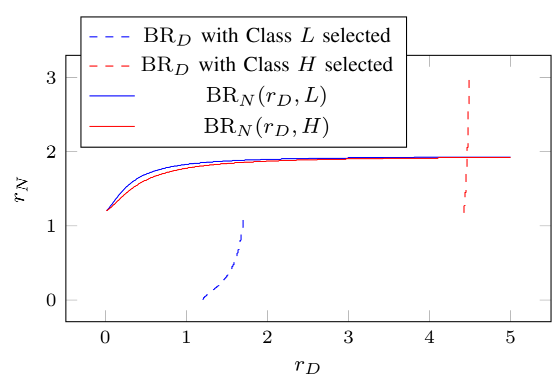

Fig. 7. CP best responses, with $q_L = 0.5, q_H = 0.685, q_N = 0.6, a_D = 0.1, a_N = 0.1, p_L = 0.5, p_H = 1.4, p_N = 0.5$

Figure 8 shows with different colors the class chosen by the CP in the non-neutral area, for each couple (q_L, q_H) (with $q_H \geq q_L$). The result is as expected: when q_H is close to q_L, it is not worthwhile to "upgrade" to Class H, but there there is a threshold for each value of q_L over which it becomes valuable. Moreover, the larger q_L the larger the difference of quality is required to opt for Class H (translated as an enlarged band as q_L increases).

Now consider the game on qualities among ISPs. Figure 9 displays in 3D the ISP best responses, with ISP D playing

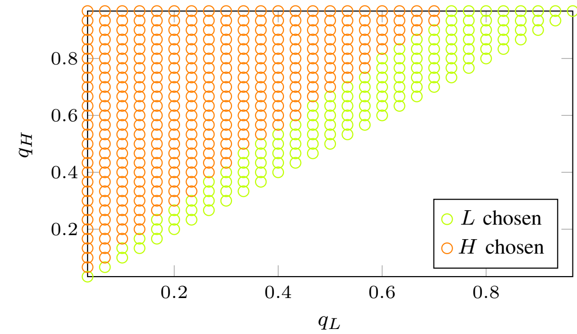

Fig. 8. Chosen quality class C_D in terms of (q_L, q_H), when $q_N = 0.6, a_D = 0.1, a_N = 0.1, p_L = 0.5, p_H = 1.4, p_N = 0.5$

a two-dimensional strategy (selecting q_L and q_H). A Nash

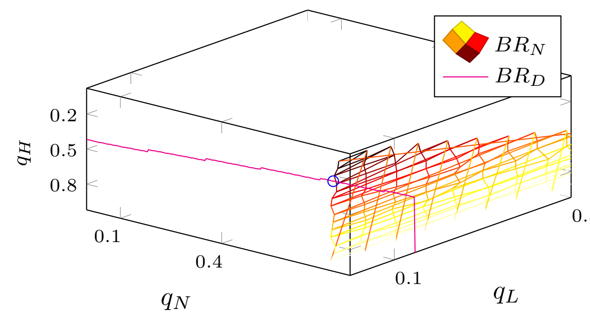

Fig. 9. ISP best responses, with $a_D = 0.1, a_N = 0.1, p_L = 0.5, p_H = 1.4, p_N = 0.5$

equilibrium can be observed, actually located at $q_L = 0$.

Table I *(second line)* summarizes the equilibrium output of the game with partial neutrality. Comparisons will be made in Section VI, but it has to be noted that $q_L = 0$ is different from just defining a single quality class since it impacts the foreign customers. It "forces" the local CP to choose the high class but gives no service to the customers abroad.

V. Scenario: All CPs can differentiate service in the non-neutral area

Now the CP in the neutral area (CP N) can also ask for service differentiation in Zone D.

Since here both CPs have two decision variables (class and price), the Nash equilibrium is computed as follows:

- We draw two curves of best response of CP N in terms of r_D (one for each possibility of selected class), in two different colors. Each time, we differentiate whether CP N selects L or H by using a dashed or plain line.
- We do the same for CP D *versus* r_N.

As before, the trade-off is between a low price with low (cheap) quality, and a high price with higher quality. A Nash equilibrium is then an intersection point between best-response curves *with corresponding quality selections*, that is,

$$\begin{cases} (r_N, q_{C_N}) &= \text{BR}_N(r_D, q_{C_D}) \text{ with class } C_N \text{ selected} \\ (r_D, q_{C_D}) &= \text{BR}_D(r_N, q_{C_N}) \text{ with class } C_D \text{ selected,} \end{cases}$$

with $C_i \in \{L, H\}$ the quality selected by CP i. Figure 10

q_L^*	q_H^*	q_N^*	r_D^*	r_N^*	$(U_D^{CP})^*$	$(U_N^{CP})^*$	$(U_D^{ISP})^*$	$(U_N^{ISP})^*$	$(D_D^D)^*$	$(D_D^N)^*$	$(D_N^D)^*$	$(D_N^N)^*$
$q_D^* = 0.71$		0.72	2.022	2.033	0.517	0.523	0.1379	0.1374	0.198	0.121	0.120	0.200
0.0	0.25	0.73	4.044	2.3025	0.0868	0.3758	0.044077	0.08752	0.0210	0.0	0.0106	0.19755
0.0	0.5667	0.74667	4.35	2.7805	0.2826	0.4529	0.1737	0.09074	0.05683	0.07817	0.03428	0.15723

TABLE I

COMPARISON OF EQUILIBRIUM OUTCOMES FOR THE FULLY-NEUTRAL SCENARIO (*first line of results*), THE PARTIALLY-NEUTRAL SCENARIO (*second line*) AND THE NON-NEUTRAL SCENARIO (*last line*).

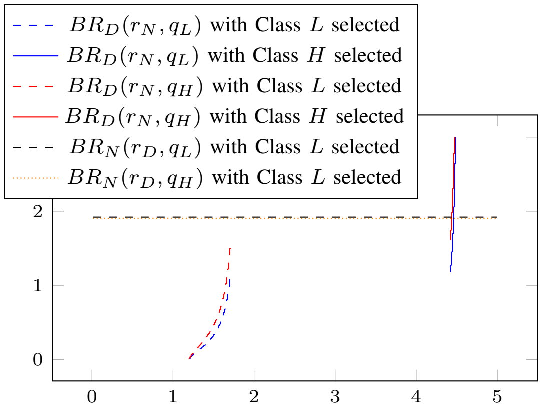

Fig. 10. CP best responses, with $q_L = 0.5, q_H = 0.685, q_N = 0.6, a_D = 0.1, a_N = 0.1, p_L = 0.5, p_H = 1.4, p_N = 0.5$

illustrates that there is here also a single Nash equilibrium. Note that both curves $BR_N(r_D, q_L)$ and $BR_N(r_D, q_H)$ are very close to each other with our set of parameters, and Class H is never selected by CP N.

Figure 11 displays in terms of (q_L, q_H) (with other parameters fixed) the zones over which qualities L or H are selected by CPs: (I, J) with $I, J \in \{L, H\}$ means CP D chooses I and CP N chooses J. Again, when the difference between qualities

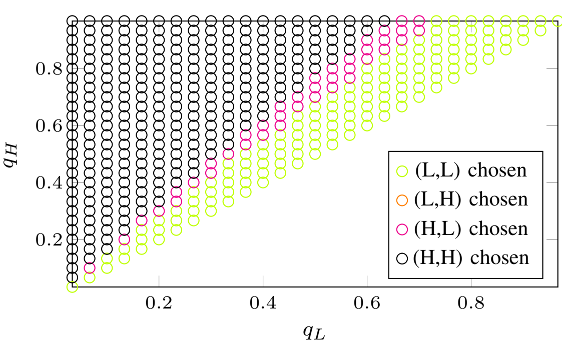

Fig. 11. Chosen qualities classes (C_D, C_N) in terms of (q_L, q_H) , when $q_N = 0.6, a_D = 0.1, a_N = 0.1, p_L = 0.5, p_H = 1.4, p_N = 0.5$

is low, both CPs prefer to stay with Class L, while when it is high, they both prefer H, with the required difference increasing with the quality q_L. In between, there is a band of values where CP D only prefers H, because the class choice impacts all its traffic and has therefore more importance.

As before we can 3D-plot the ISPs best responses for the quality game, they give here again $q_L = 0$ for the Nash equilibrium, but with slightly different values of q_N and q_H.

Table I *(last line)* summarizes the output of that game. Note that allowing the CP in the neutral zone to choose its class of service in the non-neutral zone ends up with all content accessible, in contrast to the previous case where content from CP N was only accessible in Zone N (since $q_L = 0$).

VI. COMPARISONS AND CONCLUSIONS

Table I summarizes the main metrics at equilibrium in the three scenarios. Several points are worth noticing.

First observe quality levels: relaxing neutrality constraints leads to $q_L = 0$, i.e., forcing to select the "premium" service to have some service at all. But this premium service is actually worse than in the fully neutral situation, and for the partially-neutral scenario is not even accessible to CPs hosted in the neutral area, leading to those CPs not being reachable by users in the non-neutral region. In summary, in terms of quality:

- the fully-neutral scenario should be preferred,
- but if neutrality is not imposed in zone D (e.g., in the United States), then the regulator of the neutral area would prefer the non-neutral situation to the partially-neutral one, and allow its CPs to choose their quality abroad and attract some demand.

Regarding the prices r_D, r_N charged by CPs to users, as the constraints are relaxed (on neutrality for ISPs, on quality choices for CPs), those prices tend to increase in both areas.

As a result (of qualities decreasing and prices increasing), demands decrease when leaving the fully-neutral situation. In the neutral zone, the total demand of the CP $(D_N^N + D_D^N)$ is slightly larger in the non-neutral case than in the fully-neutral case, even if demand from users within its zone decreases. For CP D, the demand from both zones is larger in the fully-neutral than in the partially-neutral case. Note however that the cumulated demand from users in the neutral zone $(D_N^N + D_N^D)$ is slightly larger in the partially-neutral situation.

In terms of CP utilities, in accordance with their position in the debate, a fully-neutral situation is better. But a non-neutral scenario is preferred to a partially-neutral one, for both CPs.

As regards ISP utilities, the partially-neutral case is the worst for both, while as expected the ISP in the non-neutral (resp., neutral) zone prefers the non-neutral (resp., neutral) scenario. This can be a justification for a direct transition between those extremes. In a cooperative world looking at the sum of ISP utilities, the neutral scenario is the best.

In summary, our results suggest that *i)* only the non-neutral ISP benefits from relaxing neutrality rules, *ii)* if non-neutrality is allowed in a zone, then it is better to avoid the partially-neutral situation: CPs in the neutral zone should be allowed to select quality for their flows crossing the non-neutral zone.

REFERENCES

[1] M. Ben-Akiva and S. Lerman. *Discrete choice analysis*. The MIT Press, Cambridge, Massachusetts, 1985.

[2] BEREC. Berec guidelines on the implementation by national regulators of european net neutrality rules. Document number: BoR (16) 127, Aug 2016. available at https://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_practices/guidelines/6160-berec-guidelines-on-the-implementation-by-national-regulators-of-european-net-neutrality-rules.

[3] 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*, 2013.

[4] 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.

[5] Federal Communications Commission. Protecting and promoting the open internet, April 2015. available at https://www.federalregister.gov/documents/2015/04/13/2015-07841/protecting-and-promoting-the-open-internet.

[6] Federal Communications Commission. Restoring internet freedom, Jan 2018. available at https://docs.fcc.gov/public/attachments/FCC-17-166A1.pdf.

[7] T.M. Lenard and R.J. (Eds.) May. *Net Neutrality or Net Neutering: Should Broadband Internet Services be Regulated*. Springer, 2006.

[8] P. Maillé, P. Reichl, and B. Tuffin. Economics of Quality of Experience. In Antoniadis, Antonis, Stiller, and Burkhard, editors, *Telecommunications Economics - Selected Results of the COST Action IS605 Econt@Tel*, pages 158–166. Lecture Notes in Computer Science 7216, Springer Verlag, 2012.

[9] P. Maillé, P. Reichl, and B. Tuffin. Internet governance and economics of network neutrality. In A. Hadjiantonis and B. Stiller, editors, *Telecommunications Economics - Selected Results of the COST Action IS0605 EconTel*, pages 108–116. Lecture Notes in Computer Science 7216, Springer Verlag, 2012.

[10] P. Maillé, G. Simon, and B. Tuffin. Toward a net neutrality debate that conforms to the 2010s. *IEEE Communications Magazine*, 54(3):94–99, 2016.

[11] P. Maillé and B. Tuffin. *Telecommunication Network Economics: From Theory to Applications*. Cambridge University Press, 2014.

[12] 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.

[13] A. Odlyzko. Network neutrality, search neutrality, and the never-ending conflict between efficiency and fairness in markets. *Review of Network Economics*, 8(1):40–60, 2009.

[14] H. Schulzrinne. Network neutrality is about money, not packets. *IEEE Internet Computing*, 22(6):8–17, 2018.

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