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Net neutrality at internet backbone provider level

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**NET NEUTRALITY AT INTERNET BACKBONE
PROVIDER LEVEL**

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NET NEUTRALITY AT INTERNET BACKBONE PROVIDER LEVEL

Abstract

This paper analysis the Internet interconnection market and combine the main technical (i.e. service quality) and economic aspects (i.e. profits and utility) characterizing relations between market players (end users, EUs; Internet Service Providers, ISPs; Internet Backbone Providers, IBPs) in order to determine possible economic outcomes in the strategic interaction between them.

The proposed model enables a comparison to be made between expected values of social welfare (i.e. EU utility and profits of both ISPs and IBPs) on the current scenario (Best Effort) and considering two classes of priority in the traffic routing. Finally we illustrate the model's applicability to an example of network.

Key words: Net Neutrality, pricing, competition, service quality , Internet interconnection

1. INTRODUCTION

In order to ensure the reachability of the entire Internet network, the transport system of the Internet traffic requires a set of interconnections between networks managed by autonomous administrative units (AS, Autonomous System) (Faratin *et al.*, 2008). The ASs play different roles in the process of transporting traffic across the Internet network: some are transport service providers (i.e. Broadband Service Providers), others are mainly Internet traffic sources (i.e. Content Providers, CPs), and finally end users (EUs) emit and receive traffic.

In general, the market dynamics depend on the complex interaction between interconnected ASs. The ASs are placed at different levels of the Internet hierarchical structure. According to BEREC (2012), the traffic transport service is essentially carried out by two types of Internet Broadband Providers: the Internet Service Providers (ISPs) that provide Internet access for EUs and CPs; the Internet Backbone Providers (IBPs), which allow the entire Internet network to be reached by the ISPs.

The transport of Internet traffic is subject to the regime of 'Net Neutrality' (NN), according to which flows corresponding to different applications, transmitters or receivers do not differ in terms of price or routing policy (Economides and Tåg, 2012).

Given the increasing demand for real-time applications (video conferencing, video calls, etc.) supported by the Internet, in recent years the debate has focused on the possibility for ISPs to apply a premium price to CPs for a differentiated service. In particular, the literature assesses the economic impact of introducing quality-based traffic differentiation (QBD) from the viewpoint of EUs, ISPs and CPs (Economides and Hermalin, 2012; Choi and Kim, 2010; Economides and Tåg, 2011; others). Consistent with some of the models used in existing literature regarding the NN (Guo, Cheng and Bandyopadhyay, 2012; Choi and Kim, 2010; others), the proposed model has the aim to evaluate the impact of traffic differentiation on the profitability of the ASs and the welfare of the entire industry. In particular, we assume that traffic flows could present different priority, according to which the traffic is charged differently.

Combining technological characteristics (i.e.: quality of service) and economic determinants (i.e.: prices and profits for ISPs and IBPs, and EU utility), the model derives

the possible economic outcomes of the interaction between the market players, assuming that each market player pursues the maximization of its objective function (i.e. profit/utility) in a context of strategic interaction.

The paper is organized as follows: Section 2 describes the model of an interconnection market. Section 3 refers to the relevant aspects of the interaction among the market players. Furthermore this section illustrates the model's applicability to an example of network and provides some results; Section 4 summarizes the paper and provides conclusions and some suggestions for future research.

2. THE MODEL

2.1 Market players

The process of Internet traffic transport on the Internet network is managed by Internet Broadband Providers. They can be classified into two categories – ISPs and IBPs – on the basis of their position in the Internet hierarchy: ISPs provide an Internet access service to the source/destination of Internet traffic (i.e. CPs and EUs), while IBPs provide ISPs with transit service (wholesale service).

The relationship between CPs/EUs and ISPs and between ISPs and IBPs are of a customer-supplier type and foresee payment by the clients to the respective Internet Broadband Providers for the services provided (transit agreements). The Internet Broadband Providers (ISPs and IBPs) may also establish horizontal agreements (i.e. on the same hierarchical level), usually peering (BEREC, 2012).

It is assumed that an estimate of total traffic demand (i.e. originated both from CPs and EUs) for each ISP is known. This is represented by an origin/destination matrix (O/D matrix).

Since each market player is an independent decision maker, each one makes its own choice in order to maximize its objective function. The decision-making variables and objectives for each type of player (ISP, IBP or EU) are described in Subsection 2.2 and 2.3, respectively.

2.2 Decision-making variables: prices and Internet traffic allocation among IBPs

We assume that ISPs are multi-homing (Armstrong, 2006) and determine their choice on how to distribute the Internet traffic among the various IBP suppliers, considering the service quality of potential IBPs (q_{ij} , relatively IBP j), their interconnection prices (P_j) and the supplier accessibility (d_{ij} , relatively IBP j).

Quality of service

Consistent with Huston (1999) and Van Mieghem, Neve and Kuipers (2001), we assume that a function of the average length ($f_{q_{ij}}$) of the routes followed by traffic flows constitutes a proxy for the quality of the IBP j service provided to the ISP i (q_{ij}). We define $f_{q_{ij}}$ as follows ([1]):

$$f_{q_{ij}} = c * l_{ij} + d * n_{ij} \quad (c, d > 0) \quad [1]$$

where l_{ij} is the average physical length of the path of the flows routed by the ISP i towards the IBP j ; n_{ij} represents the average number of hops of the routed paths (i.e. the average number of ASs crossed by the traffic flows).

Price of Internet backbone service

The price per unit of capacity required by the IBP (P_j). The price applied by the IBP j can be broken down as follows ([2]):

$$P_j = x + \gamma_j \quad [2]$$

where x is the part of the P_j common to all IBPs, whereas γ_j represents the eventual premium price that the IBP j deserves for its higher quality with respect to its competitors.

IBP accessibility

As regards the third decision-making factor of the ISPs, we assume that supplier accessibility is measured in terms of the ISP's physical distance (d_{ij}) to the nearest IBP's access point. It is also assumed that the matrix for the IBP accessibility is known.

Purchasing choice for ISP

We assumed that the ISPs give an overall evaluation (U_{ij}) of all potential suppliers based on the three parameters defined above (i.e. quality, price and distance) and allocate their flows among IBPs using the Logit model (McFadden, 1974) ([3]):

$$s_{ij} = \frac{e^{U_{ij}}}{\sum_{x \in X_i} e^{U_{ix}}} = \frac{e^{gq_{ij}-d_{ij}-fP_j}}{\sum_{x \in X_i} e^{gq_{ix}-d_{ix}-fP_x}} = \frac{e^{gq_{ij}-d_{ij}-f\gamma_j}}{\sum_{x \in X_i} e^{gq_{ix}-d_{ix}-f\gamma_x}} \quad [3]$$

where s_{ij} is the percentage of the traffic the ISP i assigns to the IBP j ; X_i is the set of potential IBP suppliers of the ISP i ; f and g are positive coefficients. As shown in the formula [3], the purchasing choice for each ISP depends only on price differences among the competing IBPs (γ_j).

The volume of traffic purchased by each ISP is obtained from formula [3], as shown below ([4]):

$$K_{ij} = s_{ij} * F_i \quad [4]$$

where F_i is the total demand for traffic emitted and received by customers connected to the ISP i .

Price of Internet Access Service

In order to consider higher revenues for an ISP when the quality of its service (q_i) increases, the access price they establish is determined from the quality of the service provided as follows ([5]):

$$p_i = a_l + b_l * q_i \quad [5]$$

where a_l and b_l are positive coefficients.

The average quality of the ISP service depends on the service quality of its IBP suppliers ($q_{ij} = -fq_{ij}$) and we compute it as their weighted average ([6]):

$$q_i = \sum_{x \in X_i} s_{ij} q_{ij} = - \sum_{x \in X_i} s_{ij} f q_{ij} \quad [6]$$

The average quality of service for the *QBD* scenario derives from the weighted average of qualities of each of the two services, calculated as in [6].

2.3 Objective functions

In accordance with decisions set out in Subsection 2.2, costs and revenues of the Internet Broadband Providers can be determined. In particular access costs for the ISPs correspond to the revenues of the IBPs. The profits for the ISPs and the IBPs are calculated, as shown in the formulas [7] and [8]:

$$\Pi_{ISP_i} = EU_i * (p_i - c_i) - \sum_j (K_{ij} * P_j) = EU_i * (p_i - c_i) - \sum_j [K_{ij} * (x + \gamma_j)] \quad [7]$$

where EU_i is the number of EUs accessing the Internet through the ISP i ; p_i is the ‘flat’ subscription fee that the ISP i asks its customers for its service; c_i is an estimate of the cost incurred by the ISP i to serve each EU (unit cost).

IBP profit is calculated using the formula [8]:

$$\Pi_{IBP_j} = \sum_i K_{ij} (P_j - C_j) = \sum_i [K_{ij} * (x + \gamma_j - C_j)] \quad [8]$$

Where C_j is the cost of the physical ports required for interconnection between ISPs and IBPs.

Finally, we assume that the utility function of generic EU connected to the ISP i ($U(EU_i)$) is decreasing in the price paid and increasing in the quality of the service, as follows ([9]):

$$U(EU_i) = a_2 - p_i + b_2 * (q_i + c_2) \quad [9]$$

where a_2 , b_2 and c_2 are positive coefficients. The average consumer utility for the *QBD* scenario derives from the weighted average of utilities produced by the two types of service, calculated as in [9].

2.4 The 2 scenarios: Net Neutrality and quality-based differentiation

Net Neutrality implies non-discrimination of price and/or management of traffic based neither on the transmitter/receiver, nor on related content. Consistent with existing literature on Net Neutrality (Choi and Kim, 2010), we assume that under the regime of Net Neutrality Internet traffic is routed in accordance with the ‘Best Effort principle’ (BE), since neither the ISPs nor the IBPs can cause a deliberate degradation in the quality of service for any part of the traffic. In general, this principle imply that the ISPs and the IBPs ‘do their best’ to get Internet traffic to destination. Consistent with the definition of the

proxy of the quality ([1]), we assume that the simulation model of the routing of Internet traffic flows on the inter-domain network (i.e. composed of several ASs) prefers paths that are of inferior length.

In the scenario characterized by the QBD, it is assumed that both the IBPs and ISPs might require a premium fee to their customers in order to give their traffic flows priority over other flows. For the reasons given above, we assume that the traffic with low priority continues to be managed with the BE algorithm. Therefore the traffic routing on the network are simulated by applying the chosen routing algorithm before to the O/D matrix of priority traffic, then to the rest of the traffic flows.

3. STRATEGIC INTERACTION ANALYSIS

We assume that neither ISPs nor IBPs are able to commit to coordinated strategies. Furthermore the IBPs set their prices according to the function by which ISPs decide to share their traffic between them ([3]) and the ISPs set their prices depending on their quality ([5]).

In the model proposed in Section 2 the service quality of the IBPs is both one of the drivers of capacity purchasing choice of ISPs ([3]) and the result of interaction between traffic flows on the network ([1]). In fact this interaction is affected by negative network externalities, that is different distributions of ISP demands towards the IBPs imply different allocations of network bandwidth capacity to flows. This fact affects the route choice and, consequently, the quality of IBP services. In other words, as shown in Figure 1, the traffic distribution established by each ISP i (s_{ij}) translates into traffic capacity acquired from each IBP j (K_{ij}). Based on network capacities, flows are routed towards IBPs. These flows, interacting with each other, are involved in capacity disputes in case of congestion and consequently do not follow the best route. This fact negatively affects service quality of IBPs (q_{ij}).

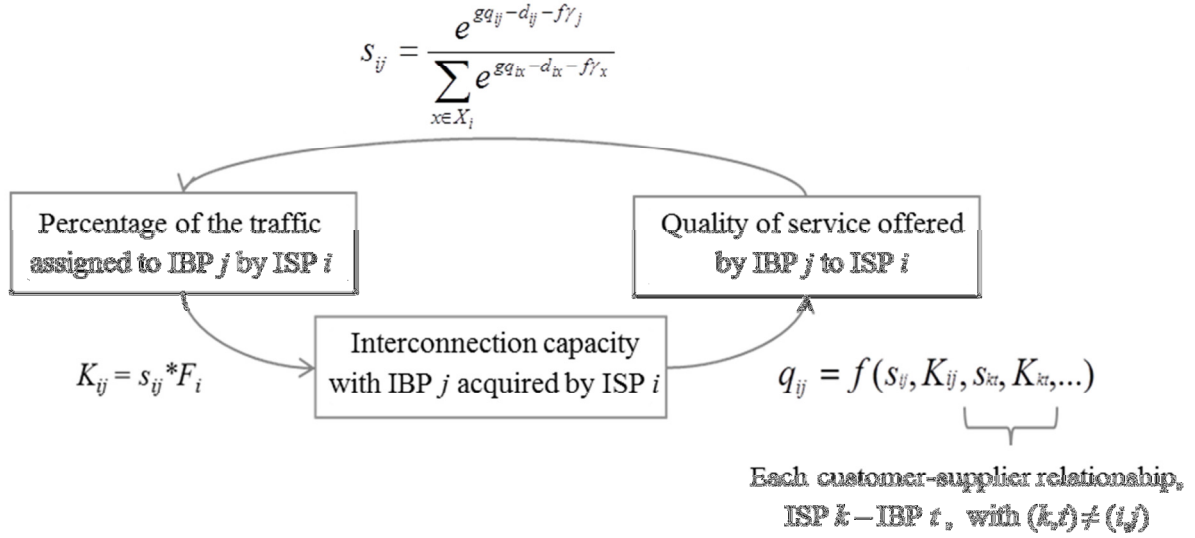


Figure 1. Relationship between IBP quality services and ISP purchasing choices

In order to associate market players payoffs (i.e. profits for ISPs and IBPs, and utility for EUs) to sets of strategies of ISPs, IBPs and EUs, taking into account the above-mentioned feedback loop (Figure 1), we propose a computation algorithm. The first step of this algorithm consists in the generation of all possible scenarios. Each scenario is identified by a vector (S) of size equal to the number of customer-supplier relationships. Vector S contains the shares of ISP demand allocated to each IBP (s_{ij}).

In the second step, for each of the possible scenarios traffic routing on the network is simulated by using the routing algorithm.

Therefore, the average quality of service (q_{ij}) (for each customer-supplier relationship) is calculated on the basis of routes associated to traffic flows (i.e. the route choice depend on the routing policy), as defined in [6].

Then we compare the values of the IBP services (U_{ij}) which correspond to the set of ISP

purchasing choices (S) of the considered scenario (i.e. U_{ij} for which $s_{ij} = \frac{e^{U_{ij}}}{\sum_x e^{U_{ix}}}$), and the

value of U_{ij} , calculated net of the IBP prices (U_{ij}'). Therefore, for each IBP j , γ_j is derived from formula [3], as follows ([10]):

$$\gamma_j = (1/f) * (U_{ij}' - U_{ij}) = (1/f) * (U_{ij} + d_{ij} + g * q_{ij}) \quad [10].$$

3.1 Results of the example of network

This subsection illustrates the results of the model applied to the example of network shown in Figure 2.

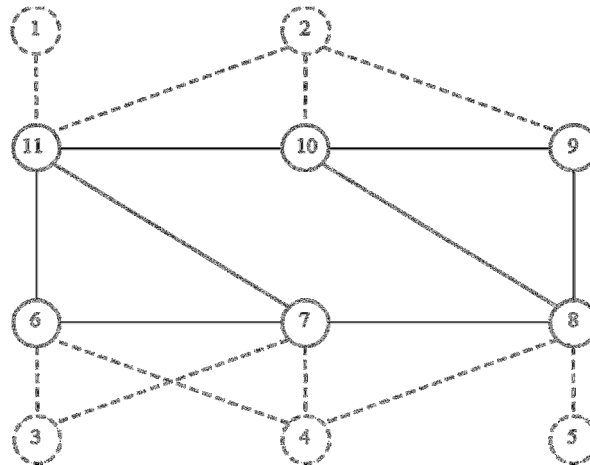


Figure 2. Example of Internet network

In Figure 2 the dashed nodes (labeled 1-5) represent the ISPs. The other nodes (labeled 6-11) represent the IBPs. The dashed arcs connect the ISPs to the IBPs and represent vertical relationships (i.e. customer-supplier type); the arcs drawn with a solid line represent horizontal peering relationships between IBPs. Furthermore, it is assumed that each arc in Figure 2 is bi-directional, that is, it represents two links (one for each travel direction of data flow on the arc).

We assume that the routing algorithm considers only routes composed of less than 5 hops. This means that each path can be identified by maximally 6 nodes (i.e. the source node, the destination node and 4 transit nodes). The number of the available paths for the example of network is 193.

Without losing generality, we assume that the traffic distribution shares (s_{ij}) and percentages of priority traffic are discrete and, in particular, that can be multiple values of 10%, that is $s_{ij} \in \{10\%, 20\%, \dots, 100\%\}$ and $PP \in \{0\%, 10\%, 30\%, 50\%, 70\%, 90\%\}$ ($PP = 0\%$ identifies the BE routing policy). For the example of network 11,664 different distribution of traffic (S) are found. Each of them is associated with the 6 possible values

for PP . Therefore, the total number of scenarios to be evaluated is $11,664 * 6 = 69,984$. Then traffic flows are simulated for each scenario.

A first analysis of the scenarios leads to exclude those for which all traffic of the O/D matrix cannot be routed. In these cases, the saturation of some links makes disconnected the graph composed of the link with remaining capacity. In addition, for some scenarios a vector of coefficients y_i for which ISP traffic distributions corresponds to S does not exist.

Consistent with the objective of profit/utility maximization pursued by the market players (both the Internet Broadband Providers and the EUs), the scenarios corresponding to dominated strategies are excluded. In this first instance, we assume that PP is an exogenous variable (actually it is decision-making variable) and determine the outcomes of the market players for each PP value. In other terms, we exclude a scenario if, given PP and the traffic distribution strategies of any other ISP, the traffic allocation strategy of an ISP corresponds to a smaller profit than some other strategy.

The number of scenarios that are not found to be dominated and excluded is 26: 4 corresponding to $PP = 10\%$, 4 corresponding to $PP = 30\%$, 2 corresponding to $PP = 50\%$, 7 corresponding to $PP = 70\%$, 5 corresponding to $PP = 90\%$, 4 corresponding to $PP = 0\%$.

Figure 3 shows the results of the simulations. The diagram shows the average utility values for the total group of EUs in relation to PP values. Figure 3 evidences that for small values of PP , the EU utility increases because the quality of priority service is significantly high. Moreover, since the quantity of priority traffic is small, the impact of discrimination on the network routing capability of the traffic without priority is not significant.

A further increase in PP enhances the total utility due to a higher quantity of traffic routed with high quality. In particular the effect of the increase in quality of priority service counterbalance the effect of the decrease in quality of standard service.

For PP close to 50% this trend reverses. This is due to the fact that an increase in priority traffic reduces the quality of priority service as priority flows create congestion (i.e. the competition among priority flows for bandwidth allocation increases). Moreover the quality of standard service is probably further decreased.

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When PP is close to 100%, there is a unique priority class (i.e. there is not any discrimination) and quality of priority traffic is equal to the quality of traffic for $PP = 0\%$.

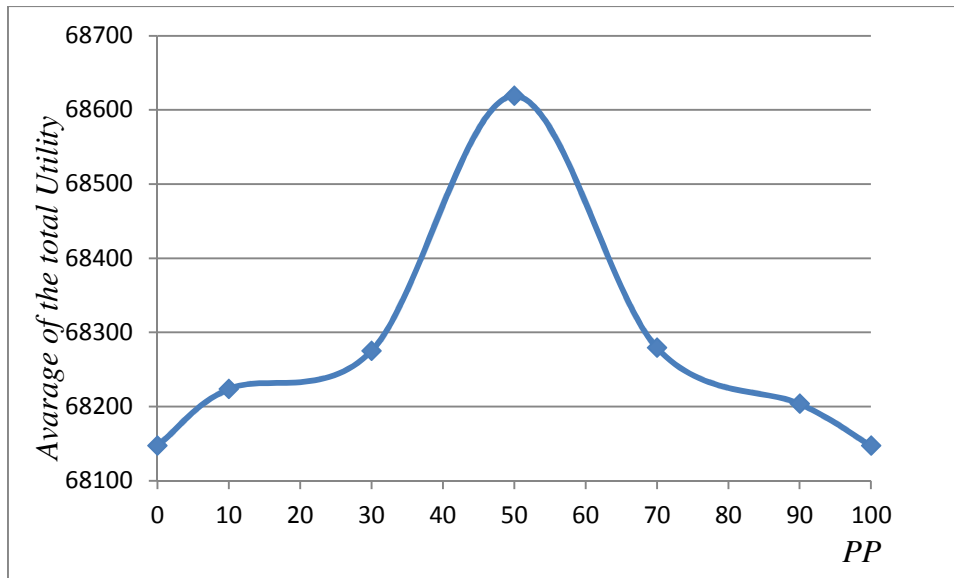


Figure 3: Total utility of EUs corresponding to different PP values

With regards to total profits of the Internet Broadband Providers, Figure 4 shows that the cost condition of the ISPs potentially enable them to perceive economic benefit generated by the introduction of QBD. In fact, the profits of the ISPs have the same trend of the EU utility. On the other hand, with the model input chosen, the total profits of the Internet backbone market do not register sensitive changes at different PP values.

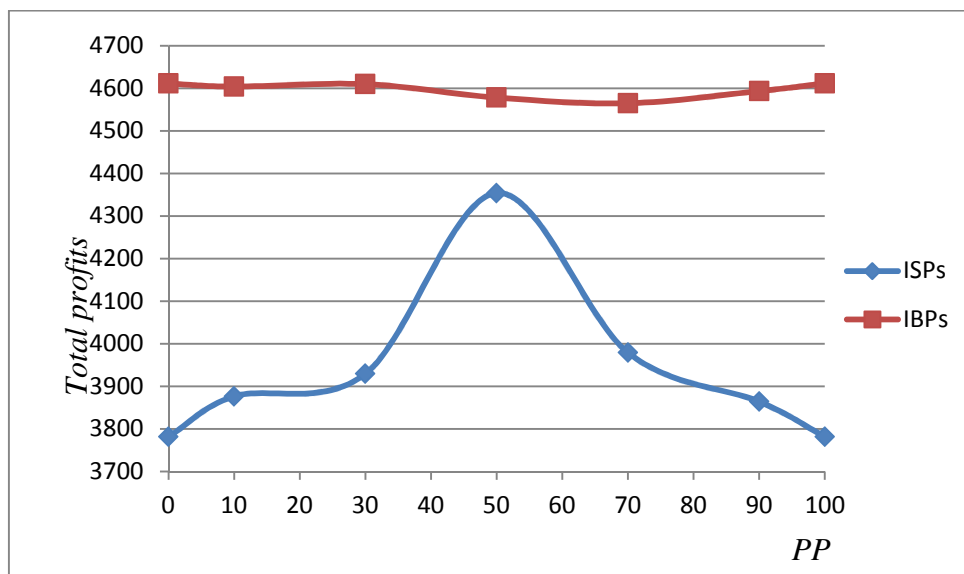


Figure 4: Total profits of the Internet Broadband Providers

After removing the former assumption (i.e. PP was considered an exogenous variables) we evaluate the remaining scenarios from the EU perspective. We exclude scenarios for which, ISP traffic allocation among IBPs being equal (S), the choice of a different PP value generate a higher EU utility. The number of the remaining scenarios is 16: 1 corresponding to $PP = 10\%$, 3 corresponding to $PP = 30\%$, 2 corresponding to $PP = 50\%$, 6 corresponding to $PP = 70\%$, 4 corresponding to $PP = 90\%$.

As the number of the remaining scenarios cannot be further reduced, we estimate the outcomes of all market players (i.e. profits/utilities) at each value of PP , by calculating their arithmetic means (thus we implicitly assume that, given PP value, each scenario has the same occurrence probability). Moreover we attribute an occurrence probability to each EU choice (PP), proportionally to the expected utility estimated.

Tables 1, 2 and 3 show the comparisons between the expected profits of the ISPs, of IBPs and the EU utility in the two cases considered (NN and QBD).

	$\pi(\text{ISP}_1)$	$\pi(\text{ISP}_2)$	$\pi(\text{ISP}_3)$	$\pi(\text{ISP}_4)$	$\pi(\text{ISP}_5)$
NN	562.71	587.24	774.65	1061.87	795.07
QBD	598.80	657.17	836.45	1072.71	815.60
$\Delta\%$	+6.41	+11.91	+7.98	+1.02	+2.58

Table 1: Comparison of the ISP expected profits with NN and QBD

	$\pi(\text{IBS}_6)$	$\pi(\text{IBS}_7)$	$\pi(\text{IBS}_8)$	$\pi(\text{IBS}_9)$	$\pi(\text{IBS}_{10})$	$\pi(\text{IBS}_{11})$
NN	893.39	469.85	1,365.56	316.38	374.85	1,191.29
QBD	798.87	569.50	1,345.57	276.79	439.33	1,144.54
$\Delta\%$	-10.58	+21.21	-1.46	-12.51	+17.20	-3.92

Table 2: Comparison of the IBP expected profits with NN and QBD

	$\pi_{\text{tot}}(\text{ISP})$	$\pi_{\text{tot}}(\text{IBP})$	$U_{\text{tot}}(\text{EU})$	SW
NN	3,781.54	4,611.31	68,147.27	76,540.12
QBD	3,980.74	4,574.61	68,289.46	76,844.81
$\Delta\%$	+5.27	-0.80	+0.21	+0.40

Table 3: Expected outcomes of the market players and social welfare (SW) with NN and QBD

Table 3 shows that the introduction of quality-based traffic differentiation produces an increase of the expected social welfare mainly due to an increase in ISP profits. The total

profit of the IBPs presents a small decline although 2 of 6 IBPs expect to increase their profits (IBP 7 and IBP 10), as shown in Table 2.

Figure 5 shows the social welfare both in case PP is assumed as an exogenous variable (red points) and in case it is considered a decision-making variable (blu points).

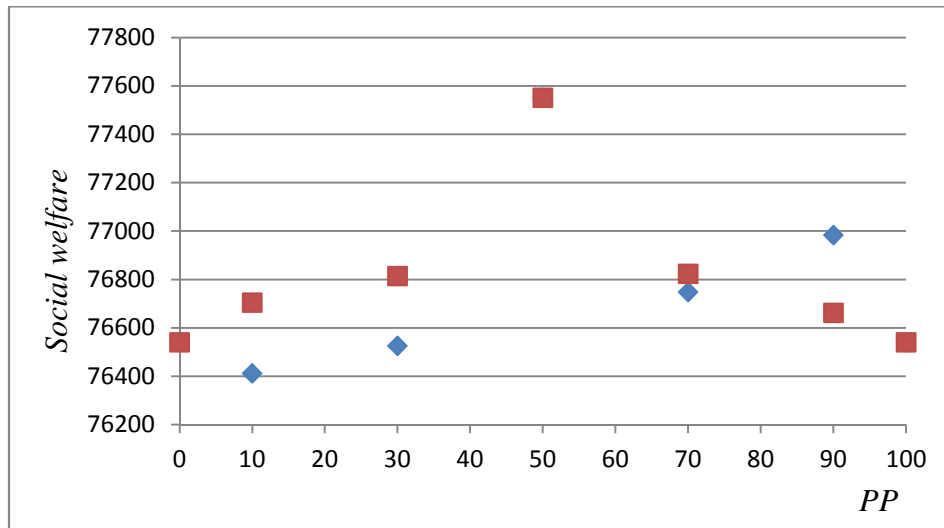


Figura 5: Social welfare with and without cooperation among ISPs and EUs

Figure 5 shows that $PP = 50\%$ corresponds to the set of scenarios that presents the highest average social welfare (the red and blu points are overlapped). In particular, in both the cases considered (PP as exogenous or decision-making variable) $PP = 50\%$ could potentially be the best EU choice in order to maximizes their utility (Figure 3) and for ISP profits (Figure 4) (the IBP profits are almost the same as shown in Figure 4). However this result is not generally obvious. In fact, it could happened that, although a PP choice could be socially efficient and convenient for all players in a cooperative environment (red points), in the interaction game (von Neumann and Morgenstern, 1944) EUs exclude some potentially beneficial scenarios (e.g. those for which $PP = 50\%$) since corresponding to dominated strategies. In other terms, in some cases the cooperation among market players could avoid to incur in the ‘Prisoner dilemma’ (Flood, 1958) for which some strategies, even if they appear in the best interests of the players, are not chosen.

The results presented in this subsection strictly depend on the price and utility functions chosen. The formulas proposed ([2], [5] e [9]) have the objective to provide a conceptual

model in order to include the competition effect on individual outcomes of the market players.

Formula [2] suggests that IBP prices should be related to their competitive advantages (quality and accessibility) relatively to each other ([3]). Therefore the competition among IBPs depends on the relative importance given to quality, price and accessibility on the supplier overall evaluation. In other terms, the impact of q_{ij} , P_j and d_{ij} on U_{ij} (and therefore on s_{ij}) depends on the coefficients used in [3] (i.e. g and f).

Formula [5] aims to associate a better service quality for ISPs to higher revenues (i.e. higher prices) and therefore the balance of the transit costs and EU price when their own quality chances depends critically on the incidence of quality on the price charged (i.e. b_1 in [5]). Moreover in the example of network proposed, the ISPs are not affected by competition as IBPs.

Formula [9] has the object to evaluate the net benefit for EUs, balancing their costs (Internet access price) and their benefits related to service quality. Therefore EU utility variation when service quality changes refers to the specific coefficients chosen for the simulation (i.e. a_2 , b_2 e c_2 in [9]).

Furthermore the effect of congestion on service quality depends on the interconnection system (i.e. the network graph), on the link capacities and on the traffic demand (i.e. O/D matrix). In fact, these input affect the decreasing rate of quality for any increase in traffic volume.

In conclusion, the results shown for the example of network do not constitutes general conclusion for the NN debate, but an analysis of a specific market.

4. SUMMARY AND CONCLUSION

Consistent with existing literature on NN (Choi and Kim, 2009; Economides and Tåg, 2012; Guo, Cheng and Bandyopadhyay, 2012; Economides, 2008), the objective of the proposed model is the analysis of the effects of NN regime on the market for the distribution of data traffic in the Internet network. Unlike the above-mentioned literature, the paper does not lead to explicit general policy guidance. However, it provides a framework to evaluate and quantify the impact of QBD on social welfare and on the

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individual actors in a specific market. In other words, the paper has provided a system of models of supply and demand for Internet Broadband Services, aimed at verifying the propensity of a market towards the change of the existing regime (NN).

In the face of growing computational complexity which is non-linear with the number of Internet Broadband Providers and their interconnections, the model shows that the interconnection market constitutes a strategic context in which the actions of each market player decisively depend on the expected strategies of other players. In fact the interconnection market can be defined as a ‘non-cooperative game over a network’ (Castelli, Longo, Pesenti and Ukovich, 2004) in which the 3 groups of players, the IBPs, ISPs and EUs, do not cooperate with each other: the IBPs’ aim is to maximize the profits generated from their backbone service prices; ISPs want to maximize their profits, by balancing their transit costs and the quality of the service offered, on which their revenues depend; in the QBD scenario the EUs decide the quantity of traffic to be served with priority in order to maximize their utility function.

The model explicitly combines technological aspects (i.e. routing of the traffic flows and quality of service) and economic aspects (i.e. profits): the ISP choice of traffic distribution among the competing IBPs depends on a function that is related to the cost/benefit ratio (i.e. transit price and quality of service) associated to each IBP; the EU choice of preferential delivery depends on both the premium price charged for priority service and the increase in quality offered respect to the standard service.

With regard to technological aspects, the simulation of the dynamics of traffic routing has determined the performance of both the Internet network (i.e. ability to satisfy traffic demand limited by the link capacity constraints) and the individual Broadband Provider (i.e. the quality of their services in situations of congestion). The model considers that for a network with finite capacity, an increase in traffic may produce congestion and, consequently, reduce the quality of the service. Therefore, in response to a growing diversification in requested internet supported digital services, it is important to evaluate the current incentive of Broadband Internet Providers to differentiate priorities in managing traffic from their customers in order to increase the quality of ‘delay-sensitive’ digital services (Bourreau, Kourandi and Valletti, 2012; Economides and Tåg, 2011) at the

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expense of others. In the QBD scenario, the possibility of applying different routing policies depending on the type of flow or the transmitter/receiver, was applied, as stated by Guo, Cheng and Bandyopadhyay (2012) and Economides and Tåg (2011). Through the simulations, therefore, an assessment was made of the impact of congestion occurrence on the overall quality of the two services (i.e. priority and BE) provided by the ISPs to EUs and by the IBPs to the ISPs. The results of the QBD scenario show that the value of priority service, perceived by the EUs, decreases with the increase in quantity of priority traffic, as a result of the increased congestion produced and affected by priority flows. In this case the difference in quality of the due services (priority service and BE service).

Finally, the model contributes to the literature on competition in the Internet interconnection market. In many articles the number of competing Broadband Providers is limited (e.g. the following authors consider duopoly competition: Little and Wright, 2000; Economides and Tåg, 2012; ...) making it impossible to evaluate the effects of competition in a market characterized by a complex system of interconnections among the providers. In fact in the proposed model the number of competing IBPs is not constrained.

In particular, when an ISP is multi-homing, the traffic demand routed towards each competing IBP is calculated on the basis of the overall attractiveness of the transit services provided by all the potential IBPs. The measure of IBP attractiveness depends on certain characteristics that are expected to play an important role in ISP purchasing decisions: price, quality and accessibility. The algorithm derive IBP price consistent with its accessibility and the quality calculated. The adoption of the Logit Model (McFaddend, 1974) makes it evident that the availability of alternative service providers in competition and the ability to do multi-homing (i.e. use more than one supplier) affect the price charged for the transit service (Armstrong, 2006) and impact on the service demand allocation to different providers (Economides and Tåg, 2012).

Although the proposed model is supported by numerous assumptions, it is suitable for the equilibriums analysis of real complex systems of interconnection between the different players involved in Internet traffic distribution. In future studies the authors will analyze the real market in order to calibrate the model and verify empirically the validity of the model assumptions. In particular, the model considers a general utility function for the

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EUs. Since CPs play a fundamental role in the interconnection market, in order to obtain a more representative model, one of the future developments of the model concerns the characterization of the CP business models: some CPs' revenues derive mainly from advertising (Economides and Tåg, 2012), while other CPs sell digital content or service (Economides, 2008). In addition, the value attributed to the priority service by the CPs differ if they have different sensitivity to transmission delays caused by congestion (Choi and Kim, 2009; Bourreau, Kourandi and Valletti, 2012).

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