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Abstract

Network neutrality is often mistakenly assimilated with the non-discrimination of Internet usage. Although this rough view is acceptable at first sight, as far as blocking of content or clearly anti-competitive discrimination are concerned, it becomes confusing at second sight, when the efficiency of traffic management, on the supply side, or the differentiation of consumers' requests, on the demand side, are considered. A neutrality principle ignoring traffic efficiency and demand differentiation through enforcing a strict homogeneity in the treatment of data packets on the network would prove inappropriate as it would downgrade the quality of service while not meeting consumers' needs.

In order to clarify the on-going debates, an unambiguous and formal definition of the concept of neutrality is required. In this contribution, a tentative definition is proposed, based on the economic principle of efficiency. Perfect neutrality is first shown as being efficient, i.e. welfare maximizing, in an ideal context C*. Then, by definition, the efficient network design in some real context C distinct from C* is called "C-imperfect neutrality". Depending on the specification of context C, neutrality may involve some form of efficient discrimination and becomes a flexible concept as it translates into different settings in various technological or political environments and as it may change overtime in a given environment.

This approach of "the most efficient imperfection" provides an adequate framework to discuss the main net neutrality issues presently at stake in the North-American and European scenes. Among those, we shall emphasize traffic management, segmentation of demand, funding of the next generation access networks, interference of governmental policies with networks' operations, regulation of neutrality.

Keywords

Net-neutrality, internet policy, economic efficiency, imperfect competition, regulation

1. Introduction

In this paper, we attempt to build up a formal approach to network neutrality which could help to clarify the very sensitive and not always very sensible debate around net-neutrality. The goal is to better assess the arguments of the stakeholders in presence, *i.e.* operators, content providers, web users and regulators. Which of their respective arguments are relevant and which are not?

In section 2, an accurate definition of "perfect neutrality" is proposed, based on the non-discrimination of packets circulating on a network. In section 3, we emphasize that perfect neutrality and thus non-discrimination are not economically efficient in any context. In some contexts, imperfect neutrality and thus some form of discrimination becomes the most efficient outcome. In section 4, we explicit a stylistic context C* in which perfect neutrality is efficient, *i.e.* maximizes welfare. In section 5, we define the concept of "C-imperfect neutrality" as the welfare maximizing network design in a context C different from C*. We also introduce four contrasted contexts C_i (i = 1, 2, 3, 4), illustrating the main issues presently at stake in the net neutrality debate. Those typical contexts are then successively examined, *i.e.* traffic management under a capacity constraint (section 6), demand segmentation and quality differentiation (section 7), budget constraint and contribution of content providers to the funding of access networks (section 8), interference of public policy goals with networks' management (section 9). Section 10 concludes, with a discussion about the respective roles of sectorial regulation and competition law as regards net neutrality.

2. A formal definition of perfect neutrality

Network neutrality, especially net-neutrality, is a very popular topic, feeding animated debates in several regions of the world. Despite of such a wide interest, the concept of neutrality is very seldom defined with accuracy. Consequently, protagonists may produce and defend arguments on the basis of very different underlying conceptions in a kind of Babel tower. A first and necessary stage is thus to define network neutrality in formal and unambiguous terms.

Perfect neutrality

- Let N be a network utility, such as the postal service, road transportation, electricity supply… or access to the Internet.
- Let u be the elementary "packet" carried over by network N, specified in terms of some relevant physical unit, such as a kilogram, a kilometer x passenger, a kilowatt x hour, a megabit, etc.
- Let U(t) be the global usage of network N at a given time t, *i.e.* the set of all elementary packets u that are managed by N at t.
- Let $\mathbf{x}_u(t)$ be the vector of characteristics of packet u at time t, from a user's perspective. Components of $\mathbf{x}_u(t)$ typically include the price $p_u(t)$ paid for the delivery of packet u and the quality of delivery $q_u(t)$ [1]:

$$\mathbf{x}_u(t) = [p_u(t), q_u(t)] .$$

Network N is said to be *perfectly snapshot neutral* if and only if all packets are treated on an equal footing at any given time:

$$\forall t \ , \ \forall u,v \in U(t) : \mathbf{x}_u(t) = \mathbf{x}_v(t) = \mathbf{x}(t) = [p(t), q(t)] .$$

[1] If, for the considered network N, pricing consists in a monthly lump sum payment S, giving right to the consumption of a maximal volume of V_{max} packets, as it is most often the case for the access to the Internet, then the unit price of a packet is the "equivalent" price $p_u(t) = p_u = S/V_{max}$.

N is said to be *perfectly neutral overtime* if homogeneous price and quality are moreover constant, *i.e.* p(t) = p and q(t) = q.■

The above definition of perfect neutrality refers to the treatment of elementary packets of usage. Now, what about aggregate usage, such as a web session in the case where network N is the Internet? Any aggregate usage of N at time t, *i.e.* $A \subset U(t)$, consists in a collection of packets u. Assuming that the quality of an aggregate is determined by the quality of its weakest element, then the price and quality of A easily derive from those of its constitutive packets:

$$p_A(t) = \sum_{u \in A} p_u(t) \quad , \quad q_A(t) = \min_{u \in A} q_u(t) \,.$$

The following proposition derives.

Neutrality and aggregate usage. In a perfectly snapshot neutral network N, the instantaneous price of an aggregate usage A is proportionate to its volume $V_A = |A|$, whereas the quality of service is uniform, *i.e.* the same for any aggregate usage:

$$\forall t:\ p_A(t) = p(t).V_A \quad , \quad \forall t\,,\ \forall A, B:\ q_A(t) = q_B(t) = q(t)\,.$$

Moreover, if N is perfectly neutral overtime, both price and quality of A are constant.■

The above proposition brings about an important consequence in relation to the net-neutrality debate as perfect neutrality is not synonymous with zero-pricing, rather with *linear pricing*. Price p(t) may well be strictly positive without harming neutrality. In the current economic setting of the Internet, seen as a two-sided market, the end user “EU” pays a positive price $p_{EU}(t) > 0$ through her access subscription, while content providers “CP” do not pay at all (or pay very little), *i.e.* $p_{CP}(t) \approx 0$. Of course, the latter are not free-riders as they pay upstream for their connection to the Internet backbone, but they do not pay downstream for the traffic they cause in the local access networks. This market design is consistent with perfect neutrality as far as all those who contribute effectively to the funding of an access network N do contribute on an equal basis. Nevertheless, the fact that some potential contributors structurally do not contribute invites to further thought and, in a broader scope including all potential contributors and not only the present ones, the notion of neutrality should clearly be redefined and enlarged.

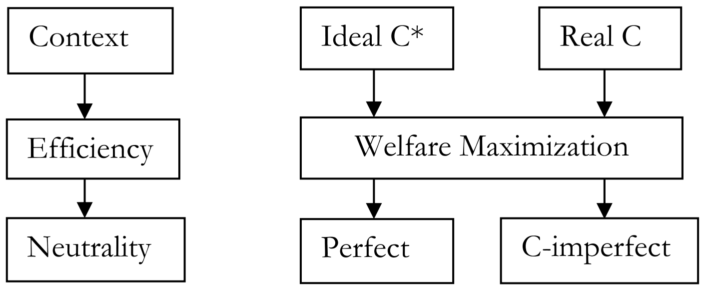
Some Internet Service Providers (ISPs) in Europe claim for a “data termination rate” similar to the call termination rate prevailing on the wholesale telephone market, *i.e.* for a strictly positive price $p_{CP}(t)$ paid by content providers. This should not be considered as an attack against neutrality, which does not forbid to set $p_{CP}(t) > 0$. Neutrality would be respected as well in the opposite market setting where content providers would be the sole contributors, *i.e.* $p_{EU}(t) \approx 0$ and $p_{CP}(t) > 0$.

We shall show (*cf.* section 8) that intermediate settings where the two sides do contribute, *i.e.* $p_{CP}(t) > 0$ and $p_{EU}(t) > 0$, although not neutral whenever $p_{CP}(t) \neq p_{EU}(t)$, might well be *efficient*, *i.e.* socially optimal. The rationale is as follows: ISPs face a binding budget constraint due to the building of next generation access networks; in order to meet this constraint they must increase their revenues through average cost pricing, which might efficiently require a rebalancing of payments across the two sides of the Internet market.

3. Is perfect neutrality equivalent to non-discrimination?

As we defined it in the previous section, the notion of perfect neutrality seems very general and could be similarly introduced in many economic or social settings outside the scope of network industries: whenever an agent “a” provides a service to some other agents “b_1”, “b_2”, “b_3”, etc., agent “a” is said to behave “neutrally” if all her clients “b_i” are served with an equal quality and are billed in proportion to their volume of consumption. At this stage, one could thus argue that neutrality is not really an original concept as it appears to coincide with the well known preexisting economic concept of *non-discrimination*. Such is not exactly the case!

The strict coincidence of neutrality and non-discrimination only holds as far as perfect neutrality is concerned and it does not resist when neutrality becomes imperfect. What we precisely propose to do here is to generalize the concept of neutrality by allowing for *imperfect neutrality* just as economic analysis allows for imperfect competition. To do so and to avoid that anything might be considered as some form of imperfect neutrality, our guideline is as follows. In a first step, we shall link neutrality with the concept of economic efficiency, *i.e.* welfare maximization. In a second step, noting that efficiency strongly depends upon context, we shall demonstrate that the efficient outcome happens to be perfect neutrality in an ideally "perfect" context C* but departs from perfect neutrality in more realistic contexts C ≠ C*. Then, by definition, the efficient network design in context C will be called "C-imperfect neutrality" (*cf.* diagram hereafter). The primary economic goal being efficiency and not neutrality *per se*, it is indeed worthwhile to identify which particular form of imperfect neutrality achieves economic efficiency in some given context.



C-imperfect neutrality is to perfect neutrality what real context C is to virtual context C*. The common root shared by the two notions of neutrality, perfect and imperfect, is contextual efficiency. From a theoretical standpoint, this approach to imperfect neutrality, namely "contextual imperfection" is much more robust than the alternative naïve approach of "selective imperfection", in which one would first specify a list L of variables eligible to discrimination and then call "L-imperfect neutrality" a network setting in which variables in L could become discriminatory while variables outside of L should remain perfectly neutral. The conceptual advantage of "contextual imperfection" over "selective imperfection" is obvious: While the latter approach requires the discretionary and exogenous choice of list L, the former one makes of imperfect neutrality both a meaningful and an endogenous concept: A meaningful concept, since imperfect neutrality is nothing but the expression of economic efficiency; And an endogenous concept, since it derives of an optimization process once a context has been thoroughly specified.

Further note that the driving idea of bridging perfect neutrality and economic efficiency is already present in the statement posted on his home page by Tim Wu, one of the pioneers of the net-neutrality concept: "*Network neutrality is best defined as a network design principle. The idea is that a maximally useful public information network aspires to treat all content, sites, and platforms equally.*" Just change the words "*maximally useful*" for the words "*welfare maximizing*" and Wu's statement may then be rephrased as the equivalence of neutrality and efficiency, or at least an asymptotic equivalence paving the way towards imperfect neutrality, as reflects the verb "*aspires to*".

What Wu does not make quite explicit in his statement and what we shall now develop in the next two sections is twofold: (*i*) In which ideal context C* the equivalence between perfect neutrality and economic efficiency holds? (*ii*) Which imperfect creature takes the place of perfect neutrality when the context is changed from C* to some C, while efficiency remains the goal?

4. Perfect neutrality and efficiency

First step is the characterization of the ideal referential C* in which perfect neutrality and efficiency are congruent. Imagine a network N where congestion would never occur. Imagine a demand homogeneous enough as it could be correctly described by a "representative consumer". Imagine that quality of service might not be personalized, *i.e.* customized according to the type of user. Imagine that access providers would not be constrained by any budget balance. Imagine that governmental policies would not interfere with network management. Imagine, imagine! Context C* is an imaginary and wonderful island, located very far from any tangible continent in the Internet planet. And in imaginary island C*, perfect neutrality is indeed the efficient design, as stated in the following proposition.

Perfect neutrality and efficiency. The property of perfect snapshot neutrality prevails at the social optimum of a network N placed in the ideal context C*.■

Proof. From the specification of C*, demand is generated by a representative user, replicated M times, M being the market size. Further assume that: (*i*) Utility w yielded by network N to the representative user at time t is an increasing function of her volume of usage v = V/M and of the minimal quality of packet delivery observed in U(t); (*ii*) Global cost Γ of N is an increasing function of the global volume of carriage V and of the maximal quality observed in U(t). Those assumptions well reflect the situation of a telecommunications network, the quality of which is measured by available bandwidth: Minimal quality affects users' experience and thus individual utility w, while maximal quality is a dimensioning factor of the capacity, influencing cost Γ. Setting:

$$W[V, \min_{u \in U(t)} q_u, t] = M.w\left[\frac{V}{M}, \min_{u \in U(t)} q_u, t\right],$$

the maximization program of net welfare writes:

$$\forall t: \max_{V, q_u}\left\{W\left[V, \min_{u \in U(t)} q_u, t\right] - \Gamma\left[V, \max_{u \in U(t)} q_u, t\right]\right\}.$$

By a maximin/minimax argument, a necessary condition for optimality is $q_u = q$ for any u in U(t). Otherwise, min q_u could be increased without affecting max q_u, which would increase W at both V and Γ unchanged and thus increase net welfare W – Γ (or max q_u could be decreased without affecting min q_u, which would decrease Γ at both V and W unchanged and thus increase net welfare W – Γ).

Eventually, net welfare simply writes W(V,q,t) – Γ(V,q,t). Assuming that usage is subject to satiety and network's operation exhibits decreasing returns to scale, W(V,q,t) is a concave function and Γ(V,q,t) is a convex function with respect to V and q. Then, maximal net welfare is reached for volume of usage V = V*(t) and level of quality q = q*(t), such that the marginal utility of an increase in usage (*resp*. in quality) equates the associated marginal cost:

$$W_V(V, q, t) = \Gamma_V(V, q, t) \quad , \quad W_q(V, q, t) = \Gamma_q(V, q, t)$$

$$\Rightarrow V = V^*(t), \; q = q^*(t).$$

As the (inverse) demand function for usage writes $p = W_V(V, q, t)$, the optimum may be decentralized through the marginal cost pricing rule:

$$\forall u \in U(t): \; p_u(t) = p^*(t) = \Gamma_V[V^*(t), q^*(t), t].$$

Thus, perfect snapshot neutrality of network N prevails at the social optimum in context C*: Homogeneous quality q*(t) and uniform pricing p*(t) of packets hold at any time t.■

Note that, according to the above proposition, the optimal network is perfectly snapshot neutral but is not necessarily perfectly neutral overtime, as optimal price and quality do vary in the case where the utility and cost functions vary as well. Indeed, this is not the exception but rather the rule in network industries, because of time-of-day or seasonal variations of demand reflecting variations in the utility of usage and causing variations in the network's load and thus cost. If the stability of price and quality were imposed, for the sake of some norm of inter-temporal equity, then this would be inconsistent with efficiency.

Perfect neutrality in networks, just as perfect competition in markets, is only a fiction, a very useful one, but just a fiction! By contrast, the reality of networks, as the reality markets, is built on imperfection! Nevertheless, this principle of reality does not affect the not less universal principle of efficiency: imperfection might not prove to be so imperfect as it looks at first sight, provided that it stands as the most efficient thing to do in some real context C different from the referential C*, far from the "pure" assumptions of perfect neutrality. In other words, what should be aimed at in practice is the "best possible imperfection". Imperfect neutrality is a relative concept, conditional to a given background and fully defined only once this background C is fully specified.

Remark finally that if perfect neutrality is not realized, it is not so because perfection is by definition out of reach, but rather because the "virtual" conditions under which perfection would be the most efficient solution are not met in practice. Nevertheless, perfect neutrality may still usefully be set as a driving principle or rule. The regulatory authority then observes the deviations from this principle and it assesses whether those deviations may be justified by some specificities of the context or whether they constitute an abuse. *Mutatis mutandis*, this is exactly what competition authorities do with markets: although perfect competition is set as the theoretical reference of efficient market organization, only imperfect competition does exist and its damageable deviations, such as an abuse of market power or an eviction strategy, are placed under watch and severely punished whenever duly established.

5. Imperfect neutrality

Perfection is the "best" and thus the "must" in a virtual and ideal context of reference. When the context becomes real, then the face of perfection is changed into that of the "most efficient imperfection", *i.e.* the best and thus the must within the particular frame shaped by the real context under consideration. Contrary to perfection which is simple and unique, imperfection is complex and diverse. What appears as efficient in some world may well be inefficient in another world. Conversely, what looks inefficient with respect to some criteria might prove to be efficient with respect to some other.

In formal terms, the relative concept of efficient imperfection may be defined rigorously in the following way.

Efficient Imperfection

- Let P be the *property* under study in its perfect version "perfect P", typically "perfect network neutrality".
- Let F be the *objective function* F, *i.e.* what must be maximized in order to deserve the label of "efficient imperfection", typically net social welfare.
- Let C denote a *context*, *i.e.* constraints shaping the domain within which objective F should be maximized. C is analytically defined by the list of adjustable variables and the specification of their inter-relationships and intervals of variation.
- Let C* be the *context of reference*, in which "perfect P" maximizes F and let C ≠ C* be some other context.

Then, by definition, "C-imperfect P" is the outcome of the maximization of function objective F in context C.■

Context C* is very useful indeed in order to establish the principle of net-neutrality. But when one shifts from normative to positive analysis and thus tries to take reality into closer account, many forms of "imperfect neutrality" may and must be explored, each one being associated with a particular context C of optimization. In the following sections we shall successively consider four such contexts, selected in the perspective of shedding some light upon the main issues addressed in the ongoing net neutrality debate.

- Context C_1 incorporates technical constraints arising from *traffic management* on an infrastructure with limited capacity. Other technical constraints may arise from requirements in terms of security and resilience of networks.
- Context C_2 reflects the *segmentation of demand* in response to the diversity in users' needs, potentially yielding a heterogeneous quality and a non uniform pricing of usage.
- Context C_3 involves a budget constraint which may arise if current revenues do not allow access providers to fund the renewal and upgrading of their network equipment whenever they must face a massive traffic growth.
- Context C_4 integrates the public policy constraints set by governments over electronic communications networks, such as the protection of privacy, the deterring of illicit and odious content, or the defense of intellectual property.

Adding or relaxing one or several constraints in the transition from virtual context C* to real context C_i amounts to restricting or extending the domain of welfare maximization. Consequently, the network's social optimum is displaced. If new constraints are added to the ones already existing in C*, then the *first best* optimum, *i.e.* perfect neutrality, is changed into a *second best* optimum which complies with the additional restrictions C_i – C*. And if some constraints in C* are removed, such as in the transition from C* to C_2, then the first best is changed for a super first best, a case where imperfection happens to be more efficient than perfection!

6. Traffic management

In context C_1, *i.e.* in presence of a limited capacity K, congestion may occur in network N and volume of usage V is constrained at each time t by inequality $V \leq K$. Two periods should then be distinguished. During the off-peak period P^{off}, the first best solution is feasible, *i.e.* $V^*(t) \leq K$, whereas during the peak period P^{on}, the first best solution infringes the capacity constraint, *i.e.* $V^*(t) > K$. In the peak period, the second best price $\bar{p}$ must exceed the first best price p* in order to push the demand down to the level K of the capacity. Thus, if $\bar{p}(K,t)$ and $\bar{q}(K,t)$ solve for p and q the system:

$$t \in P^{on}: \; W_q(K,q,t) = \Gamma_q(K,q,t) \;, \qquad p = W_V(K,q,t) \,,$$

then the C_1-constrained optimum writes:

$$t \in P^{on}: \begin{cases} V = V^*(t) \\ q = q^*(t) \\ p = p^*(t) \end{cases} \qquad t \in P^{off}: \begin{cases} V = K \\ q = \bar{q}(K,t) < q^*(t) \\ p = \bar{p}(K,t) > p^*(t) \end{cases} .$$

Because of the capacity constraint, packets are not treated as well on-peak as they are off-peak: quality is lower and price is higher as compared to the first best optimum. Of course, the situation would be much worse if demand were not monitored by price, as the excess of demand would create an uncontrolled saturation of the capacity resulting in a drastic fall in quality and in a possible network blockage.

Note that perfect snapshot neutrality does not prevail at peak times $t \in P^{on}$, since price and quality vary with t whereas the constrained volume K of traffic is stable. In the lack of a capacity constraint, perfect snapshot neutrality would imply constant price and quality overtime for a constant level of traffic. Imperfect neutrality thus involves an inter-temporal discrimination, for the sake of techno-economic efficiency.

A similar analysis could be carried out, by replacing the temporal dichotomy on-peak *vs.* off-peak by the spatial dichotomy congested *vs.* non congested routes. Instead of time-of-day discrimination, route discrimination would then prevail in the optimized and thus imperfectly neutral network.

7. Demand segmentation

Traffic management in the presence of peaks, *i.e.* context C_1, is a situation where a constraint, namely the limited network capacity, makes second best optimality departing from perfect neutrality. The other way round, perfect neutrality may itself appear as a constraint which impedes the realization of a "better" optimum. In contexts C* or C_1, neutrality is somehow "embedded" when pre-assuming that any of the M users of network N enjoys the same quality of service q(t) at a given time t. Consider now a heterogeneous market profile, in which M_P users enjoy some "premium" quality q_P, whereas the $M_B = M - M_P$ others are offered the basic quality $q_B < q_P$. In this new context C_2, net social welfare at time t writes:

$$M_B \,.\, w\left(\frac{V_B}{M_B}, q_B, t\right) + M_P . \, w\left(\frac{V_P}{M_P}, q_P, t\right) - \Gamma(V_B, q_B, t) - \Delta\Gamma(V_P, q_P, t) \,,$$

where V_B (*resp.* V_P) denotes the basic (*resp.* premium) aggregate usage and $\Delta\Gamma$ denotes the incremental cost of handling premium usage.

In the particular case where $M_P = 0$, $M_B = M$ and thus $\Delta\Gamma = 0$, the above expression of net welfare reduces to the one prevailing in context C* of a homogeneous quality setting (*cf.* section 4). By changing constraint $M_P = 0$ for the more flexible one $M_B + M_P = M$ and by increasing the number of degrees of freedom from two to four (as volume and quality are now split in two), the optimum is necessarily improved and the welfare increased.

This is certainly not a surprise: Discrimination offers more possibilities for optimization, thus yielding a better optimum. This means that if the Devil hides somewhere, it is certainly not in the discrimination itself but rather in the nature of the maximized objective. If the objective function F is social welfare (as we do assume here), then discrimination will indeed bring about an improvement but if the objective function is the profit of the network's operator, then a simple surplus accounting shows that consumers are worse off under quality discrimination than under perfect neutrality. In other words, the less regulation is able to compel operators to consider consumers' surplus in their decisions, the more the net neutrality principle – although suboptimal – appears as a justified precaution principle.

Note that in the case where the regulator allows access providers to sell premium quality, then basic quality must be carefully controlled in order to avoid strategies of eviction. In the absence of control, operators would indeed be tempted to increase their profits by downgrading the basic access to the network, thus giving to their clients an artificial and forced incentive to migrate towards the premium access. To prevent such a harmful behavior, the third European telecommunications package, released at the end of year 2009, empowers the National Regulation Authorities (NRAs) to set and to enforce minimal quality standards for the access to the Internet, provided that the evidence of a market failure is first made and that the regulatory design for quality control is well proportionate (*cf.* section 10).

Only vertical quality differentiation has been considered above (level of q). Horizontal differentiation is also clearly present, as quality appears to be a vector **q** rather than a scalar q. A video game addict, a YouTube viewer, or an average web-surfer do not equally value the different components of the quality vector **q**: some users praise a large bandwidth, others prefer a low "latency" (short time lag between two successive packets), whereas others wish a moderate "jitter" (regularity in the pace of packet delivery). Accounting for these differentiated needs implies departing from perfect neutrality and practicing an efficient discrimination in the well understood interest of the community of all network's users.

8. Budget constraint

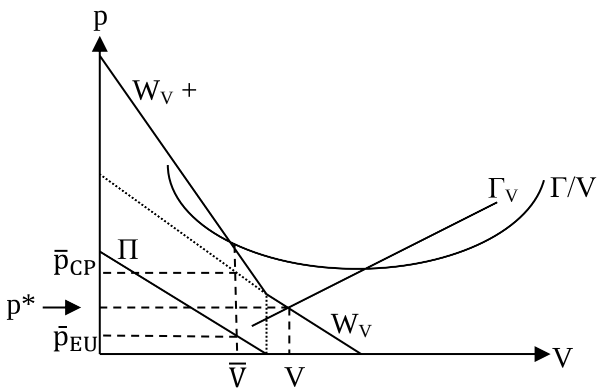
Because of the Internet traffic explosion, especially due to the success of video user generated content, operators must increase network capacity and they may thus face a budget constraint if their current revenues prove insufficient to do so. They claim that the content providers, as they cause the traffic growth, should financially contribute to the extension and the modernization of access networks, together with the end users. Such is context C_3.

Denote $\Pi(V,q)$ the profit that content providers or video platforms derive from their audience, when the latter generates a volume of usage V on an access network of quality q. This profit is essentially coming from advertisement revenues and it is an increasing function of V and q. Once extended to the two sides of the Internet market, net social welfare writes $W(V,q) + \Pi(V,q) - \Gamma(V,q)$, where W denotes (as above) the gross welfare of end users and Γ denotes the network's cost (time t being skipped here for the sake of simplicity).

Assume that, due to the saturation of advertising expenses, the marginal profit $\Pi_V(V,q)$ of content providers is decreasing with respect to V and reaches zero beyond some threshold of volume. Assume further that the solution (V^*,q^*) of the free maximization of $W + \Pi - \Gamma$ is such that $\Pi_V(V^*,q^*) = 0$. Under these assumptions, only end users are billed at the first best optimum and they pay a price equal to marginal cost (*cf.* figure):

$$p^* = W_V(V^*,q^*) = \Gamma_V(V^*,q^*) .$$

Content providers are not billed and this market setting is efficient since the activity of those agents does not yield significant marginal revenue for themselves ($\Pi_V = 0$) whereas it generates a significant externality, namely the marginal utility $W_V > 0$ of end users.



However, this first best solution is not consistent with context C_3, ruled by the budget constraint:

$$(p_{CP} + p_{EU}).V = \Gamma(V,q) ,$$

in which p_{CP} is the price paid by content providers and p_{EU} is the price paid by end users. Given the demand functions $p_{CP} = \Pi_V$ and $p_{EU} = W_V$ of content providers and end users, respectively, the second best optimum $(\bar{V},\bar{q})$ is solution of the system:

$$W_V(V,q) + \Pi_V(V,q) = \frac{\Gamma(V,q)}{V} \ ,$$
$$W_q(V,q) + \Pi_q(V,q) = \Gamma_q(V,q) \ .$$

Prices $\bar{p}_{CP}$ and $\bar{p}_{EU}$ respectively paid by content providers and end users immediately derive as:

$$\bar{p}_{CP} = \Pi_V(\bar{V},\bar{q}) \quad , \quad \bar{p}_{EU} = W_V(\bar{V},\bar{q}) \ .$$

In brief, C_3-imperfect neutrality leads to average cost pricing, instead of marginal cost pricing at first best optimum. Provided that $\Pi_V(V,\bar{q}) > 0$ (*cf.* figure), the average cost of network is shared (not necessarily equally) between content providers and end users. Price $\bar{p}_{CP}$ might for instance be implemented through the introduction of a data termination rate in the market of Internet interconnection. This solution does not seem however to be favored by a majority of telecom regulators in Europe, due to the heavy informational and transaction costs which would be incurred if it had to be implemented.

9. Public policy constraints

As communication networks – especially electronic communication networks – link people together, they constitute a strategic social equipment: they are both a place of intense social interaction where fundamental human rights might become problematic and a convenient instrument that governments might contemplate for the implementation of a large variety of public policies, being directly or indirectly associated with the network's main function.

In the case of the Internet, securing the network against hacking, ensuring privacy, defending intellectual property, deterring pedophilia and child pornography online, maintaining national security, providing data to the Justice Department… feature within the list of *a priori* "acceptable" motivations for public intervention. These many forms of governmental interference with networks' management shape a complex context C_4, in which neutrality cannot clearly be kept in its perfect conception. Moreover, as human rights are at stake, economic efficiency cannot be the only driving force in the search for the "best possible imperfection": ethics also plays a key role. The four following aspects deserve particular attention.

1. Any governmental request translates into technical constraints for the operators and thus into a cost: data storage and retrieval or traffic surveillance are costly procedures and operators must be compensated for their cooperation. This in turn serves efficiency as the Government has then an economic incentive to restrict its interventions to the very scope of what is really necessary and proportionate in order to fulfill its goals.
2. Field C_4 of acceptable public interventions is not unlimited. An infringement of free speech or a political censorship are certainly unacceptable, but they unfortunately are not unconceivable as sadly show the abusive practices of some countries where fundamental human rights are not ranked at the first place of political values. In a democratic regime, one may reasonably be confident in the legitimacy of governmental policies. However, some of those policies may be questioned and priorities should be set. For instance, the protection of children against online pedophilia and pornography meets a large consensus (although not so easy to implement), whereas the defense of intellectual property through Deep Packet Inspection (DPI) is a much more controversial topic (at least in France, the country of HADOPI!), all the more as alternative and less intrusive policies are possible in this case, such as licensing legal distribution of music on the Internet just as it is already done for radio.
3. Once a public policy is democratically acknowledged as being legitimate enough to interfere with networks' operation, bounds should then be set as regards the way this policy is implemented. In order to depart the least possible from neutrality, it is important that the discriminatory actions that are implied by the concerned policy should be ordered directly by

Government (or by Police or by Justice) and should never be undertaken at the own initiative of operators or even regulators. Erecting a "Chinese wall", *i.e.* giving the "privilege" of non-neutral decisions to the sole Government, while preserving neutrality as much as possible within the scope of action of operators and regulators, appears as a wise safeguard. In 2009, this critical issue has been the object of an acute debate between the European Commission, Parliament and Council, which delayed the publication of the last telecom package by almost one year!

4. Contrary to contexts C_1, C_2 and C_3, context C_4 involves law and ethics as well as economics. Rather than maximizing efficiency with respect to constraints, here the problem consists in reaching the least unsatisfactory trade-off between several conflicting rights, none of which is clearly predominant *ex ante*. For instance, through restricting the open circulation of data or inhibiting some functions in web applications, protection of privacy may enter in conflict with the freedom of speech and the freedom of innovation. The defense of intellectual property may enter in conflict with both free speech and privacy, through limiting peer to peer exchanges and through scrutinizing the origin, destination and content of packets. Deterring child pornography online may enter in conflict with freedom of speech, whenever an insufficiently spotted procedure would eliminate as well a naked body in a medical board and a naked body in a pornographic picture. These some examples show that, in order to optimize within C_4 where welfare is essentially a multidimensional objective, a multi-criteria analysis is necessary. Although the theoretical corpus of law & economics may help to carry out such an analysis, it is likely that reasonably acceptable solutions will spontaneously emerge from social experience and case law.

10. Conclusion: Neutrality, regulation and competition

Net-neutrality is topical to introduce this joke of mine about regulators. Question: "What is the motto of the perfect regulator?" Answer: "If something exists, then let's regulate it! And if something does not exist, then let's make it a principle!" From such a standpoint, net neutrality is apparently the regulator's dream as it exists and it does not exist all at the same time: indeed, as discussed above, neutrality exists under many imperfect forms and it does not exist under its perfect version, which remains a utopia. But the regulator's dream… might soon turn into the regulator's nightmare! Why?

Firstly, setting neutrality as a regulatory principle, or even inscribing it in a legislative text, may prove as pernicious *ex post* as it looks attractive *ex ante*, because of the following dilemma. Whether the neutrality principle is stated in such general terms as it does not clearly translate into any specific obligation made to the operators and then it is useless. Whether the principle comes with a detailed list of its modalities of implementation and those might soon become obsolete and inappropriate in a sector where the pace of evolution is so exceptionally rapid. Still worse, such an over-detailed specification could hinder the innovation process.

Secondly, regulators may face serious difficulties of legitimacy when attempting to regulate net neutrality. This is obvious in the United States where the FCC holds very light prerogatives and a fragile legal basis in matter of information services, as opposed to communication services. The regulator repeatedly failed to enforce successive neutrality rulings, which were systematically attacked in justice by the major American network operators. The situation seems to be more open in Europe, where the current telecom package empowers the national regulators to settle disputes opposing operators and content providers and to set minimal norms of quality for the access to the Internet. Nevertheless, the conditions of empowerment are rather stringent, with restrictions as concerns the scope of relevant disputes, and with the obligation for a regulator to first demonstrate a market failure before getting the agreement of the Commission to regulate quality.

Consequently, the best regulator of net neutrality might not be the sectorial regulator, but rather the market itself and competition law in last resort. In a country as France, where the market of Internet access provision is competitive enough, a violation of net neutrality is a much more risky behavior for access providers than in a country as the United States, where the customers are more captive due to the low competitive pressure in a monopolistic or duopolistic market structure. Competition being the most appropriate regulator of net neutrality appears as a consistent scheme, remembering the analogy made above between perfection *vs.* imperfection of competition, on the one hand, and perfection *vs.* imperfection of neutrality, on the other hand (*cf.* section 4). Competition and neutrality are much more than just two parallel lines: They are linked to one another through many bridges.

- Attacks against neutrality, such as a blockage or a heavy slowing down of traffic are most often the outcome of an anticompetitive behavior from some access provider which is present as well in the market of content provision and aggressively defends its own interests in this market against those of its competitors. Then, restoring a fair competition also restores neutrality.
- Vertical restrictions, typically an exclusive agreement of online content distribution signed by a content provider and an access provider, reduce the availability of content for end-users, thus harming neutrality. By controlling the scope and duration of such agreements, a competition authority serves both competition and neutrality at the same time.

Even if the driving force of the net neutrality regulation must be competition, the authorities in charge of enforcing competition law cannot act alone as they would not hold all the necessary skills and information. They must cooperate with several sectorial regulators, in charge of electronic communications, of the audiovisual sector, of personal data protection, etc. As the digital revolution has led to the marriage of pipes and content and to the convergence between all types of content, regulation in its broadest meaning will have to become more and more cooperative, bringing together (if not merging) several independent administrative authorities and public institutions in a global co-regulatory scheme.

Moreover, as innovation is a Darwinian process, which cannot thus be planned nor ruled in a technocratic way, the regulation of the digital ecosystem will also have to become less and less prescriptive and more and more participative, by mobilizing around the co-regulators all the “species” of the Internet market, including access providers, content providers, equipment suppliers, without forgetting the customers. The latter indeed became “prosumers” and they are the very first concerned by the quality and the diversity of their online environment. In this new perspective of participative co-regulation, close to the notions of “multi-stakeholderism” and “heterarchy” proposed by the economists studying institutions, the regulator is no longer a “problem solver” but rather a “solution facilitator”. Net-neutrality appears as an ideal topic for initiating this new approach to regulation, inspired in a way by Socratic maieutics.

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