Net neutrality: A progress report[☆]

Jan Krämer[a], Lukas Wiewiorra[a,*], Christof Weinhardt[a]

[a] *Karlsruhe Institute of Technology, Institute of Information Systems and Management, Englerstr. 14, 76131 Karlsruhe, Germany*

Abstract

This paper is intended as an introduction to the debate on net neutrality and as a progress report on the growing body of academic literature on this issue. Different non-net neutrality scenarios are discussed and structured along the two dimensions of network and pricing regime. With this approach, the consensus on the benefits of a deviation from the status quo as well as the concerns that are unique to certain non-net neutrality scenarios can be identified. Moreover, a framework for policy decisions is derived and it is discussed how the concept of neutrality extends to other parts of the Internet ecosystem.

Keywords: Internet, net neutrality, quality of service, pricing

1. Introduction

With the rapid development of the Internet as an ubiquitously available platform for information, entertainment and communication, the role of network infrastructure owners has shifted to an essential gatekeeper position in the information society. Therefore, the public and politicians alike are concerned about how Internet service providers (ISPs) are going to monetize access and usage of the networks in the future. This discussion on the future of the Internet is known as the net neutrality (NN) debate. It has many facets and many battlegrounds. Like many political debates it is much too often based on historic, technical or economics myths rather than a close analysis of facts. This article provides a survey of the most important academic papers that have structured the debate in recent years. Even among these papers, a widespread set of believes is found on top of which the academic analysis is conducted. Therefore, it is important to recapitulate some facts about the history and architecture of the Internet first, in order to be able to understand what has caused the ongoing NN debate.

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[*]Corresponding author. Tel: +49-721-6084-8378, Fax: +49-721-6084-8399

Email addresses: kraemer@kit.edu (Jan Krämer), wiewiorra@kit.edu (Lukas Wiewiorra), weinhardt@kit.edu (Christof Weinhardt)

Internet is the abbreviation of the term internetwork, which describes the connection between computer networks all around the world on the basis of the same set of communication protocols. At its start in the 1960s, the Internet was a closed research network between just a few universities, intended to transmit text messages. The architectural design of the Internet was guided by two fundamental design principles: Messages are fragmented into data packets that are routed through the network autonomously (end-to-end principle) and as fast as possible (best-effort (BE) principle). This entails that intermediate nodes, so-called routers, do not differentiate packets based on their content or source. Rather, routers maintain routing tables in which they store the next node that lies on the supposedly shortest path to the packet's destination address. However, as each router acts autonomously along when deciding the path along which it sends a packet, no router has end-to-end control over which path the packet is send from sender to receiver. Moreover, it is possible, even likely, that packets from the same message flow may take different routes through the network. Packets are stored in a router's queue if they arrive at a faster rate than the rate at which the router can send out packets. If the router's queue is full, the package is deleted (dropped) and must be resent by the source node. Full router queues are the main reason for congestion on the Internet. However, no matter how important a data packet may be, routers would always process their queue according to the first-in-first-out principle.

These fundamental principles always were (and remain in the context of the NN debate) key elements of the open Internet spirit. Essentially, they establish that all data packets sent to the network are treated equally and that no intermediate node can exercise control over the network as a whole. In the context of the NN debate this has become known as a *non-discrimination rule* (see, e.g., Schuett, 2010). However, this historic and romantic view of the Internet neglects that Quality of Service (QoS) has always been an issue for the network of networks. Over and beyond the sending of mere text messages, there is a desire for reliable transmission of information that is time critical (low latency), or for which it is desired that data packets are received at a steady rate and in a particular order (low jitter). Voice communication, for example, requires both, low latency and low jitter. This desire for QoS was manifested in the architecture of the Internet as early as January 1, 1983, when the Internet was switched over to the Transmission Control Protocol / Internet Protocol (TCP/IP). In particular, the Internet protocol version 4 (IPv4), which constitutes the nuts and bolts of the Internet since then, already contains a type of service (TOS) field in its header by which routers could prioritize packets in their queues and thereby establish QoS. However, a general agreement on how to handle data with different TOS entries was never reached and thus the TOS field was not used accordingly. Consequently, in telecommunications engineering, research on new protocols and mechanisms to enable QoS in the Internet has spurred ever since, long before the NN debate came to life. Among the more prominent examples are Frame Relay [RFC 3202], ATM [RFC 2386], DiffServ [RFC 2474] or Token Bucket [RFC 2698]. Also the current Internet protocol version 6 (IPv6), which was standardized in 1998, contains header information

on the traffic class as well as a flow label, which facilitates QoS for real-time applications. In addition, data packets can even be differentiated solely based on what type of data they are carrying, without the need for an explicit marking in the protocol header. This is possible by means of so-called Deep Packet Inspection (DPI). All of these features are currently deployed in the Internet as we know it, and many of them have been deployed for decades. The NN debate, however, sometimes questions the existence and use of QoS mechanisms in the Internet and argues that the success of the Internet was only possible due to the BE principle. While the vision of an Internet that is based purely on the BE principle is certainly not true, some of these claims nevertheless deserve credit and will be discussed in detail.

Another far-reaching event was the steady commercialization of the Internet in the 1990s. At about the same time, the disruptive innovation of content visualization and linkage via the Hyper Text Markup Language (HTML), the so called World Wide Web (WWW) made the Internet a global success. Private firms began to heavily invest in backbone infrastructure and commercial ISPs provided access to the Internet, at first predominately by dial up connections. The average data traffic per household severely increased with the availability of broadband and rich media content (Bauer et al., 2009). According to the Minnesota Internet Traffic Studies (Odlyzko et al., 2012) Internet traffic in the US is growing annually by about 50 percent. The increase in network traffic is the consequence of the ongoing transition of the Internet to a fundamental universal access technology. Media consumption using traditional platforms such as broadcasting and cable is declining and content is instead consumed via the Internet. Today the commercial Internet ecosystem consists of several players. Internet users (IUs) are connected to the network by their local access provider (ISP), while content and service providers (CSPs) offer a wide range of applications and content to the mass of potential consumers. All of these actors are spread around the world and interconnect with each other over the Internet's backbone, which is under the control of an oligopoly of big network providers (Economides, 2005). The Internet has become a trillion dollar industry (Pélissié du Rausas et al., 2011) and has emerged from a mere *network of networks* to the *market of markets*. Much of the NN debate is devoted to the question whether the market for Internet access should be a free market, or whether it should be regulated in the sense that some feasible revenue flows are to be prohibited.

This survey on the emerging NN literature is thus organized along the following two central questions of the debate: How will different types of QoS management techniques and business models affect the Internet ecosystem? And which types of revenue streams in the Internet, if any, should be prohibited? It can be said in advance that the present article will not conclude with a definite answer to these questions. Rather, the article is meant as a progress report that summarizes the arguments for and against different types of NN regulation and provides a policy guideline for the decision whether a NN regulation should be adopted or not. Furthermore, the article provides an outlook beyond the NN debate and discusses how the concept of 'neutrality' could be adopted to other

parts of the Internet ecosystem. In particular, it is likely that soon other gatekeepers up and down the information value chain may be pushed to center stage when the debate concentrates on issues like *device neutrality* (e.g., with Apple being the gatekeeper) or *search neutrality* (here, Google is the gatekeeper).

The remainder of this article is structured as follows. In the next section, a working definition for NN as well as the fundamentals of the NN debate are introduced. In Section 3 the different non-net neutrality (NNN) scenarios that have been discussed in the literature are evaluated with respect to their opportunities and threats for the future of the Internet, as well with respect to possible remedies that could alleviate these threats. Where appropriate, the current state of NN regulation in different countries is summarized. In the light of these results, policy guidelines for NN regulation are derived in Section 4. Thereafter, other forms of neutrality in the Internet ecosystem are considered in Section 5. Finally, the article concludes with a brief summary and open research questions.

2. Fundamentals of net neutrality

The term 'net neutrality' was coined by law professor Tim Wu (2003), although the idea of Internet neutrality can be traced back to the open access movement that was lead by Lawrence Lessig (2001, p.168–175). The debate on NN centers around the potential consequences of network owners exercising additional control over the data traffic in their networks. In this context, the meaning of 'control' is often ambiguous and can mean anything from blocking certain types of undesired or unaffiliated traffic (Wu, 2007), to termination fees (Lee & Wu, 2009), to offering differentiated services and taking measures of network management (Hahn & Wallsten, 2006). To date, there is no generally accepted definition of NN. In this article, a strict definition of NN is adopted that has, among others, beens put forth by consumer rights groups:[1]

Definition 1 (Strict net neutrality). *Net neutrality prohibits Internet service providers from speeding up, slowing down or blocking Internet traffic based on its source, ownership or destination.*

As mentioned above, the techniques necessary to differentiate certain types of traffic are by and large already implemented in the networks. However, what has caused the debate is that ISPs have implicitly and overtly signaled that they intend to use these techniques to generate extra revenues. In this context, proponents of NN envision several particular deviations from NN which, as they say, endanger the 'openness' of the Internet that has been instrumental for generating innovations. In the remainder of this section, each concern and corresponding NNN scenario is considered in turn:

[1] See, e.g., Save the Internet (2012). There are also more fine grained definitions of NN, which, however, require additional insights that are yet to be developed in this paper. For now, it is useful to adopt a definition of NN that is strict enough to encompass all possible concerns of NN proponents. Other definitions will be presented later where they fit.

2.1. Exercising market power in the customer access network

The debate was particularly stimulated in 2005 after a blunt statement by Ed Whitacre, at the time the Chief Executive Officer of ATT, who said: "Now what [content providers] would like to do is use my pipes free, but I ain't going to let them do that because we have spent this capital and we have to have a return on it" (O'Connell, 2005). Similar statements have been released by major European network operators since then (Lambert, 2010; Schneibel & Farivar, 2010).

To understand what the ISPs are implying here, consider Figure 1. From an economic point of view ISPs are the operators of a two-sided market platform (Rochet & Tirole, 2006; Armstrong, 2006; Hagiu, 2006) that connects the suppliers of content and services (CSPs) with the consumers (IUs) that demand these services. In a two-sided market, each side prefers to have many partners on the other side of the market. Thus, CSPs prefer to have access to many IUs, because these create advertisement revenues. Likewise IUs prefer the variety that is created by many CSPs. Suppose for a minute that there would only be one ISP in the world which connects CSPs with IUs. This ISP would consider these cross-side externalities and select a payment scheme for each side that maximizes its revenues. Instead of demanding the same payment from both sides, the classic result is that the platform operator chooses a lower fee from the side that is valued the most. In this vein, entry is stimulated and the added valuation can be monetized. There are several real world examples that demonstrate this practice: Credit card companies levy fees on merchants, not customers. Dating platforms offer free subscriptions to women, not men. Sometimes even a zero payment seems not enough to stimulate entry by the side that is valued the most. Then, the platform operator may consider to pay for entry (e.g., offer free drinks to women in a club).

Such two-sided pricing is currently not employed in the Internet. One of the reasons is that CSPs and IUs are usually not connected to the same ISP, as depicted in Figure 1. The *core* of the Internet is comprised by several ISPs that perform different roles. More precisely, the core can be separated into (i) the *customer access network:* the physical connection to each household, (ii) the *backhaul network*, which aggregates the traffic from all connected households of a single ISP and (iii) the *backbone network:* the network that delivers the aggregated traffic from and to different ISPs. IUs are connected to a so-called access ISP which provides them with general access to the Internet. In most cases, IUs are subscribed to only one access ISP (known as single-homing) and cannot switch ISPs arbitrarily, either because they are bound by a long-term contract, or because they simply do not have a choice of ISPs in the region where they live. Conversely CSPs are usually subscribed to more than one backbone ISP (known as multi-homing), and sometimes, like in the case of Google, even maintain their own backbone network. This limits the extent of market power that each backbone ISP can exercise on the connected CSPs severely (Economides, 2005). The important message is that currently CSPs and IUs only pay the ISP through which they connect to the Internet. Interconnection between the backbone and access ISPs is warranted by a set of mutual agreements that

are either based on bill-and-keep arrangements (peering) or volume-based tariffs (transit). In case of transit, the access ISP has to pay the backbone ISP, and not the other way around.

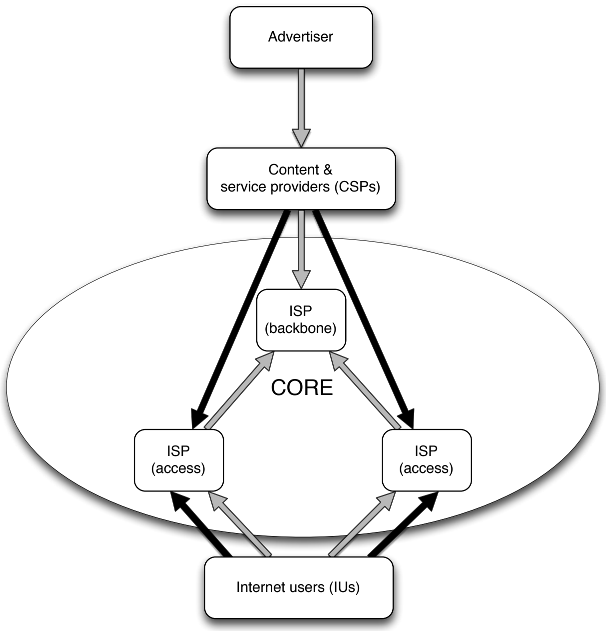

Figure 1: Current (gray) and prospective (black) revenue streams in the Internet ecosystem

Consequently, the IUs subscription fee is currently the main revenue source for access ISPs. Moreover, in many countries customers predominantly pay flat fees for their access to the Internet, and thus they are not sensitive with respect to how much traffic they are generating. Moreover, due to competition or fixed-mobile substitution, prices for Internet access have dropped throughout the years. Currently, it seems unlikely that access ISPs can evade from this *flat rate trap*. For example, in 2010 the big Canadian ISPs tried to return to a metered pricing scheme by imposing usage based billing on their wholesale products. As a consequence, smaller ISPs that rely on resale and wholesale products of the big Canadian ISPs would not be able to offer *real* flat rates anymore. With the whole country in jeopardy to loose unlimited Internet access, tremendous public protest arose and finally regulators decided to stop the larger telecommunications providers from pursuing such plans (Openmedia.ca, 2011).

At the same time Internet traffic has increased, a trend that is often created by an increasing number of quality demanding services. One prominent example for this development is the company Netflix. Netflix offers video on demand streaming of many TV shows and movies for a monthly subscription fee. According to Sandvine (2010, p.14), already 20.6 percent of all peak period bytes

downloaded on fixed access networks in North America are due to Netflix. In total, approximately 45 percent of downstream traffic on North American fixed and mobile access networks is attributable to real-time entertainment (Sandvine, 2010, p.12).

In an effort to prepare for the *exaflood*[2] ISPs were and are forced to invest heavily in their networks.[3] Such investments are always lumpy and thus periodically cause an overprovisioning of bandwidth, which, however, is soon filled up again with new content. This is the vicious circle that network operators are trying to escape from. However, it is important to emphasize that transportation network equipment providers like Cisco, Alcatel Lucent and Huawei are constantly improving the efficiency of their products (e.g., by making use of new sophisticated multiplexing methods) such that the costs per unit of bandwidth are decreasing. This partially offsets the costs that ISPs worry about.

In summary, ISPs claim that their investments in the network are hardly counter-balanced by new revenues from IUs. In reverse, CSPs benefit from the increased bandwidth of the customer access networks, which enables them to offer even more bandwidth demanding services, which in turn leads to a re-congestion of the network and a new need for infrastructure investments.

In this context, it is clear what led Ed Whitacre to the above cited statement, and what he thinks access ISPs should do about it: In the absence of additional profit prospects on the user side, access ISPs could generate extra revenue from CSPs, who are in part causing the necessity for infrastructure investments, by exercising their market power on the installed subscriber base in the sense of a two-sided market. CSPs have a high valuation for customers, consequently, the terminating access ISP demands an extra fee (over and beyond the access fee to the backbone ISP they are connected to) from the CSP for delivering its data to the IUs. This new revenue stream (the black arrows in Figure 1) would clearly be considered as a violation of NN according to the strict definition above, but also of less strict definitions. Hahn & Wallsten (2006), for example, define NN as follows:

Definition 2 (Hahn & Wallsten). *"Net neutrality usually means that broadband service providers charge consumers only once for Internet access, do not favor one content provider over another, and do not charge content providers for sending information over broadband lines to end users."*

[2]The term exaflood was introduced by Bret Swanson of the Discovery Institute in 2001. In Swanson & Gilder (2008) he draws the picture of the presumably impending flood of exabytes (10^{18} bytes) that is caused by increasing media consumption and will eventually lead to the congestive breakdown of the Internet.

[3]The largest share of the cost is due to the civil engineering that is necessary to upgrade the customer access network with fiber. In Europe, for example, 60-80 percent of the overall investments costs into last mile fiber access network are due to civil works (Analysys Mason, 2008). Mobile operators, on the other hand, are constrained by the limited availability of spectrum as well as by the increasing amount of electromagnetic interference that is caused by a more widespread availability and usage of wireless services.

When CSPs are charged extra, just to be able to transmit their data to the access ISP's customers, but without any additional benefits in return, then these payments are simply termination fees, which are common practice in the fixed and mobile market for voice communications. In the remainder of this article this deviation of NN is called the *termination fee model*. The related academic literature is discussed in Section 3.3.

However, instead of blocking the traffic of those CSPs that do not pay the termination fee, ISPs may also offer CSPs faster access lanes to its customers in return for an additional fee. Such pay for priority arrangements seem less obtrusive, yet, given a fixed amount of bandwidth, speeding up some CSPs' traffic will inevitably lead to a slowing down of those CSPs that do not pay the priority fee. The introduction of pay for priority arrangements is probably the most controversial issue of the NN debate, and consequently, many economic papers have been devoted to it. We denote this as the *CSP tiering model* and discuss its implications in Section 3.4.

2.2. Applying traffic management

A second major concern of the NN movement addresses the ISPs' possibility to apply traffic management techniques (i.e., the technical possibilities to prioritize or degrade certain traffic flows) in order to distort downstream competition or to limit undesired or unprofitable traffic. In this way, revenues can be generated by avoidance of opportunity cost. Two scenarios are likely and have in fact already been subject to legal disputes.

First, with the availability of QoS techniques ISPs may be tempted to prioritize affiliated content or, conversely, to degrade or block content that is harmful to the ISPs other revenue streams. This argument applies mostly to ISPs that are vertically integrated with a large CSP (like in the case of Comcast and NBC Universal) or that originated from a telecommunications company (like most DSL-based operators). The threat of abuse of market power by vertically integrated ISPs is a strong concern in the United States (US) where cable, which tends to be vertically integrated more than telephone companies, served 54.9 % of the retail market in June 2011. Although this concern has been articulated in academic articles (e.g., van Schewick, 2007) no actual case is known so far. By contrast, there exist several examples of ISPs that have blocked voice over IP (VoIP) traffic which is in competition to their regular telephone service. The most prominent example is that of Madison River Communications, which was subject to an investigation by the FCC in 2005 for exactly such practice. The case was settled under the old common carrier powers of the FCC, which applied at that point in time to DSL service (c.f. FCC, 2011).

Some ISPs in Europe, especially those that offer mobile Internet access, currently prohibit VoIP traffic in their networks by means of their terms and conditions, unless the IU pays extra for it.

Second, traffic management techniques may be used by the ISP to avoid or limit traffic that, in their view, generates nothing but costs. Here, the most prominent example is that of Comcast, the largest cable company in the US, which was subject to scrutiny by the FCC in 2008 because it had restricted

the flow of peer-to-peer (P2P) traffic. The FCC issued a cease or desist order against Comcast in 2008, which was overturned by the US Court of Appeals in 2010, because it was found that the FCC "has failed to tie its assertion of regulatory authority to an actual law enacted by Congress" (McCullagh, 2010). P2P traffic usually accounts for a large share of the total traffic that is sent in the customer access network. However, because it is generated and consumed by the end users, the ISPs can hardly monetize this traffic. It is therefore still a common, but since the Comcast case less pronounced practice by ISPs around the world to 'manage' P2P and related traffic. For example, in 2010, Georg Merdian, director of the infrastructure regulation devision of Kabel Deutschland, Germany's largest cable company, said in an interview that the cable network currently is sufficient for the data traffic generated by the customers, but "we anticipate we will soon have to use some kind of management techniques"(O'Brien, 2010). Interestingly, Kabel Deutschland was already using traffic management procedures on a large scale at the time Georg Merdian was interviewed. Table 1 reports the amount of DPI that is performed by the largest German ISPs. The table was compiled using data from the Glasnost project (Dischinger et al., 2010), a research project at the Max Planck Institute for Software Systems, which developed an online tool that enables IUs to check if their ISP is actually interfering with their data transmissions. The table reports the number of performed DPI tests by voluntarily participating IUs and the share of tests that showed indications of DPI interference by the respective ISP. They found that on average at least 10% of users experienced degradation in P2P traffic and, contrary to the arguments of ISPs, throughout the day and not only at peak times. Even higher numbers of DPI were observed by Mueller & Asghari (2012) for the US market.

Operators Name	**Tests**	**DPI**
Kabel Deutschland	250	39%
Deutsche Telekom	205	3%
Vodafone Germany	116	4%
HanseNet Telekommunikation	112	7%
Telefonica O2 Germany	50	2%
Kabel BW	27	7%
Unitymedia	26	4%
NetCologne	18	11%
Versatel Communications	18	6%

Table 1: DPI of German ISPs based on Glasnost data in Q4/2009 (Source: Mueller et al., 2009)

Thus, traffic management constitutes the current *status quo* of the Internet. The implications of this status quo are discussed in more detail in Section 3.1.

2.3. *Offering differentiated Internet access*

Finally, QoS techniques may also be employed to provide tiered Internet access to IUs (as opposed to CSP tiering), or to manage the traffic of certain IUs (as opposed to certain protocols). Two scenarios, or combinations of these, are feasible.

First, light users could be offered limited access to the Internet in return for a discount to the current flat rate price for unlimited access. This means that access to websites or services that are not included in the selected Internet access package would be denied, or cost extra. At the same time, the cost for an unlimited Internet access is likely to increase, because it is no longer cross-subsidized by the light users. This is not merely a vision, but has already been pursued in mobile communications, where walled-garden Internet access, like iMode, was common a decade ago (Olla & Patel, 2002). However, with respect to fixed-line Internet access, proponents of NN fear that such practice may lead to a fragmentation of the Internet.

The second scenario would allow users to opt for different QoS classes when selecting their Internet access. Power users could then, for example, choose between a BE flat rate or a QoS flat rate for Internet access, the latter of course at an increased price. Likewise, it could be possible to buy QoS just for particular services (like VoIP) and to be otherwise content with an BE access to the Internet. Particularly mobile communications providers envision to offer such practices. The current mobile communications standard Long Term Evolution (LTE) allows exactly for such QoS requests on demand. Some fixed-line ISPs already offer quality-tailored Internet access solutions. The British ISP Plusnet, for instance, offers three service classes to its customers. To explain and justify this procedure the provider clarifies: "With traffic management we can do lots of clever things to make sure everyone gets a good, fair online experience" (Plusnet, 2011). Offering different QoS classes to users is commonly known as *user tiering*. According to the strict definition, it is a violation of NN and thus also under scrutiny by some NN proponents. However, even strict NN activists would acknowledge that some kind of differentiation in users' Internet access can be useful. Currently, this differentiation is usually achieved by offering Internet access with different bandwidths. Such capacity-based discrimination is generally accepted by NN proponents because no particular traffic is prioritized or degraded. Thus, it is in line with the strict definition of NN. This article will therefore focus on the case of user tiering which is believed to generate extra revenues for ISPs (denoted by the additional black arrows in Figure 1) and discussed in Section 3.5.

2.4. *Content Delivery Networks*

Finally, it is worth to draw attention to content distribution networks (CDNs) which have, so far, not been the focus of the NN debate. Classic CDNs like Akamai, Level3 and Limelight are paid by big CSPs to improve the Quality of Experience (QoE) in a BE Internet. They achieve this by building additional infrastructure that bypasses congested routes on the public Internet and

by caching frequently downloaded content closer to respective customer access networks. Often, CDNs even pay ISPs in order to be able to locate their servers directly in the ISPs' customer access network.

It is evident that the implications of CDNs are very similar to those of QoS mechanisms and, thus, they should be mentioned here. CSPs are usually considered to be the primary proponents of NN and clearly, under a termination fee model, all CSPs are definitely worse off. However, under CSP tiering this is not clear at all. As mentioned before, CSPs generate revenues predominantly by advertisements. The advertisement revenues increase with the number of users of a service. Therefore, the revenues of CSPs are obviously somehow related to the value and the performance of the content or the services. If consumers experience a bad service quality due to congestion in the network they will probably not visit this CSP again because they attribute the bad quality directly to the CSP. For this reason CSPs are eager to improve their Quality of Experience (QoE) for the customer. QoE is not the same as QoS. This is exemplified by Figure 2, which shows that the QoE of a service is influenced by three major dimensions: (i) the CSP's requirements with respect to to QoS, (ii) the actual QoS that is delivered by the network and (iii) the IUs' preferences and expectations about the service experience. In this framework, the QoS

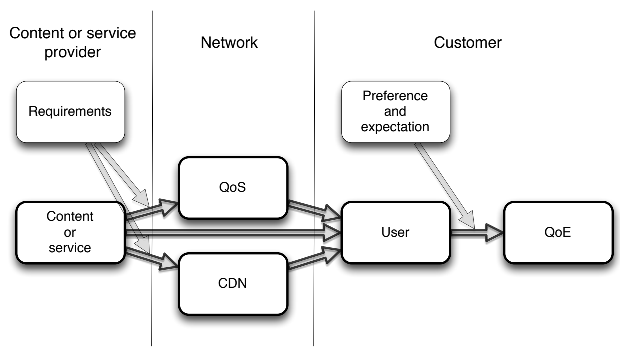

Figure 2: Quality of experience (inspired by Kilkki, 2008)

mechanisms that have been discussed above are only one possible means of achieving QoE. Another possibility is to employ a CDN, and in the absence of global QoS standards, CDNs already are a very important part of today's Internet infrastructure. In Section 5 the role of CDNs in a 'neutral' Internet will therefore be discussed in more detail.

3. Opportunities, concerns and remedies in possible non-net neutrality scenarios

To the best of our knowledge, there are only three notable papers which structure the NN debate and the related literature. Schuett (2010) provided the first review that focuses narrowly on the presentation of the theoretical

economic literature. In particular, Schuett distinguishes between NN as a *zero pricing rule* and as a *non-discrimination rule*. Faulhaber (2011) gives a more general introduction to the debate and also discusses the relevant literature that has emerged in the post Schuett (2010)-era. He also analyzes the new FCC rules and draws the clear-cut conclusion that no evidence or academic result would justify ex ante NN regulation. Similarly, Bauer (2007) identifies three possible governance structures that could deal with potential NNN threats: Relying fully on anti-trust law, non-discrimination rules and full NN regulation. His policy implications inspired parts of the structured policy decision process that is presented in Section 4.

This section presents a new framework to structure the NN debate that combines and extends previous approaches. In particular, two general dimensions are identified that form all possible NNN scenarios. The scheme allows categorizing the economic literature but can also accommodate contributions from the law and engineering domain. Especially in the engineering domain network management and prioritization mechanisms were studied long before the NN debate emerged.

From the previous discussion, it is obvious that (preferential) access to customers is the key to the NN debate. The academic NN debate centers around the question whether the potential outcome of possible NNN scenarios constitutes such a grave threat to the freedom of the Internet ecosystem and welfare, that ex ante NN regulation is necessary and appropriate. Over the last years the question about neutrality in Internet access has therefore grown from a mere dispute between policy makers and network owners to a debate about the potential pitfalls of ex ante regulation in contrast to a laissez-faire approach with respect to the long term effects on innovation, content variety and network investments. With this survey, we do not intend to engage in this policy debate. We rather evaluate possible NNN scenarios on the basis of the extent literature by taking a normative stands that is based on maximizing welfare and especially consumer's surplus.

		Pricing regime	
		One-sided	**Two-sided**
Network regime	**Quality of service**	User tiering (IUs choose priority class.)	Content and service provider tiering (CSPs and/or IUs choose priority class.)
	Managed network	Status quo (Best effort network with traffic engineering and/or managed services.)	Termination fee (Additional fee for CSPs to terminate traffic at access ISP.)
	Capacity only	Strict net neutrality (No discrimination based on source, destination or content.)	

Figure 3: Non-net neutrality framework

Our survey of the academic debate is structured along the NNN framework that is depicted in Figure 3. NNN scenarios can be categorized along two dimensions: The network regime and the pricing regime. The pricing regime

denotes whether an access ISP employs one-sided pricing (as is traditionally the case) or two-sided pricing (as described above). The network regime refers to the QoS mechanisms and corresponding business models that are in place. Under strict NN, which prohibits any prioritization or degradation of data flows, only capacity-based differentiation is allowed. This means that CSPs or IUs may acquire Internet connections with different bandwidth, however, all data packets that are sent over these connections are handled according to the BE principle, and thus, if the network becomes congested, they are all equally worse off. In a managed network, QoS mechanisms are employed, e.g., to ensure QoE in the customer access network. However, thereby no new revenue streams are generated for the access ISP. Finally, the network regime may allow for pay for priority arrangements, such that CSPs or IUs can self-select whether and to what degree they prefer a preferential treatment of their data packets. In this survey, as is also the case for the extant literature, it is assumed that QoS can be acquired on a non-discriminatory basis, such that first-degree price discrimination, which would clearly be anti-competitive, is ruled out.

The different NNN scenarios described in the previous section can be categorized along these two dimensions as shown by Figure 3. For example, the current status quo is constituted by a managed network with one-sided pricing. Consequently, according to the strict definition of NN, this is already a NNN scenario. In the following, for each scenario of the NNN framework, the opportunities, concerns and possible remedies to counteract these concerns that are unique to each scenario (over and beyond the status quo) are discussed.

3.1. Status quo

As outlined before, prioritization mechanisms for data packets are by and large readily implemented in the network infrastructure of access ISPs today. Based on these techniques the ISP can decide how to handle the identified data packets. Without going into too much technical details, one can distinguish between two possible outcomes that are of the concern to NN proponents: First, packets of certain applications, services or content are not delivered to the requesting customer (*blocking*). Second, the experience while using or consuming certain applications, services or content is reduced, beyond the level that would be achieved under BE (*degradation*).

Blocking is evidently the strongest form of interference. In the public NN debate it is often related to the fear that ISPs may be in the position to limit the freedom of speech. ISPs could block access to politically controversial (but legal) information, or shut down websites of unwanted organizations (e.g., the websites of labor associations to prevent an assembly of workers (Austen, 2005)). Evidence of such practices is anecdotal, however, not at least because it evokes almost certainly a loss of reputation for the ISPs. It seems obvious that such limitations of freedom of speech should be addressable by constitutional law of the respective country. However, we are aware that there exist remarkable differences in the legal basis for preserving free speech online, which we cannot discuss in detail here. Depending on the country, there might be special circumstances that warrant a net neutrality law with respect to free online speech.

For continental Europe at least, Holznagel & Nüßing (2011) conclude that the existing constitutional law already offers sufficient protection in this regard.

On the contrary, the practice of degradation of certain protocols or traffic flows is commonplace. The cases of Madison River Communications and Comcast, as well as the results of the Glasnost project provide ample evidence. However, the prioritization of certain protocols and services (e.g., Internet Protocol television (IPTV)), which may be exercised by the ISP for justifiable reasons (e.g., to ensure QoE) will inevitably also result in the degradation of non-prioritized traffic during peak times. ISPs have the strongest incentive to prioritize those services that provide them with additional revenue streams.

The fine line between reasonable network management, which may be to the benefit of all consumers, and distortion of downstream competition has particularly been discussed by legal scholars, and constituted the kick-off to the NN debate. In his seminal article, Wu (2003) discusses in detail the differences between necessary network management and harmful degradation and proposes a NN law called *Forbidding Broadband Discrimination*. He emphasizes the right to reasonably use the Internet connection, but also accounts for the necessity to ensure the quality of the Broadband service for the better part of the customers. Christopher Yoo (2005), also a law professor, can be seen as his dogmatic counterpart. While Wu is concerned with the gatekeeper position and anti competitive behavior of ISPs, Yoo highlights the efficiency gains of QoS and the advantages of more intense infrastructure competition under differentiated services. In his view differentiation facilitates the survival of more ISPs and therefore more alternatives in local Internet access exist. Both authors also differ in their assessment about innovation in the Internet ecosystem. While Wu argues that innovation at the edge of the network is more important and cannot be compensated by innovation in the core and new local access products, Yoo concludes that the natural monopoly theory has led to the false premise that competition in the service layer is more important than competition in the infrastructure layer. In his eyes NN is a matter between the big CSPs and big ISPs.

While Wu and Yoo focus on the aspect of traffic management, QoS and price discrimination, van Schewick (2007) analyzes the incentive of ISPs to discriminate against unaffiliated CSPs of complementary products in detail. She concludes that NN regulation is necessary to protect independent producers, but acknowledges that this does not come without social costs. Van Schewick sees a direct trade-off between innovation at the network level (core) and innovation at the application level (edge). In her analysis, the reduction of innovation incentives of a high number of potential innovators cannot be compensated by the higher innovation of a few network providers. In addition, she reasons that centralized innovators, like ISPs, cannot successfully replicate the innovative potential of a large number of independent developers with their own services. In other words, she sees applications and services as the main driver of the Internet economy and therefore innovation at the edge of the network is more important than innovation at the core. Consequently, she argues that NN regulation is needed to foster innovation. The paper has received much attention, however,

at the same time its conclusion also seems to be an assumption, namely that innovation at the edge is more important than innovation at the core. In addition, antitrust law (i.e., ex post regulation in contrast to ex ante regulation) should already be able to deal with distortions of downstream competition (see Section 4).

Remedies. In order to counteract these alleged threats of the status quo, two remedies seem particularly promising: Transparency and competition.

One of the main concerns with network management is that it is intransparent to the public which network management techniques are employed and which content is subject to it. Therefore, establishing transparency about the ISPs' network management practices could alleviate these concerns and empower users to make an informed decision when they choose an access ISP. Transparency can be established bottom-up or top-down. In the bottom-up approach, users are enabled to detect whether their ISPs discriminates certain types of traffic. This is done by the Glasnost project, for example. The top-down approach would require the ISPs to make their network management practices publicly available. This is currently not (satisfactorily) done and would potentially require ex ante NN rules. The usefulness of transparency in the context of NN is discussed in detail by Faulhaber (2010) and Sluijs et al. (2010). Faulhaber emphasizes that information has to be easily accessible and understandable to be helpful in the NN context. He draws a comparison to nutrition information on groceries and claims that there has to be information available on the product, otherwise consumers incur unnecessary search costs. If the information is accessible, but complex and difficult to understand, the information does not help consumers to make a more informed decision. In addition, the information should be verifiable. In contrast to this qualitative approach, Sluijs et al. (2010) use an economic laboratory experiment to study the impact of transparency. They simulate a market with two ISPs and a potential customer base with human participants and vary the information about the delivered service quality available to the customers. Their most important result is that already a fraction of informed users can help the whole market to achieve a welfare-superior outcome. This suggests that a few informed entitites (e.g., IT experts who publish a consumer review) might be enough to ensure that all customers can make an informed choice when selecting their access ISP. This is likely to discipline ISPs and to increase welfare.

The aspect of transparency is closely related to the aspect of competition between access ISPs. Transparency is essentially useless if IUs cannot act upon it by choosing an alternative ISP. A sufficient level of competition, however, will not materialize in many cases. In rural areas (especially in the US) often a maximum of two ISPs is available. Usually one of them is the local telecommunications provider, while the other is the local cable company. Opponents of NN regulation argue that abuse of network management as well as other deviations from the status quo are unproblematic in the face of competition. However, it is far from obvious that competition will alleviate the concerns of NN proponents. Wu (2007), for example, analyzes the US mobile phone market with

respect to NN and finds many examples of non neutral behavior (e.g., crippled products and degradation) although this market is considered as highly competitive. He explains the interplay of competition and transparency as follows: "To say that competition can then be a reason not to examine industry practices and mandate as much disclosure as possible is exactly backward. For it is such information that is necessary to make competition work in the first place" (Wu, 2007, p.423). Also Kocsis & Bijl (2007) argue that competition may not always be beneficial in the context of NNN scenarios. They argue that termination fees and exclusive deals with CSPs can lead to more horizontal differentiation of ISPs and consequently to higher mark-ups. This conversely would result in less intense competition between the ISPs in the market.

Legislation and regulation. Since 2005, the Federal Communications Commission (FCC) has worked towards a codification of principles that ensure the "open and interconnected character of the Internet", a circumscription to avoid the biased term NN. By and large, the FCC seeks to maintain the current status quo and has followed the views presented in this section. In its final Report & Order from December 2010 the FCC adopted the following NN framework.

Definition 3 (FCC). *"A person engaged in the provision of fixed broadband Internet access service, insofar as such person is so engaged, shall[...]"*

1. *Transparency*
   "[...]publicly disclose accurate information regarding the network management practices, performance, and commercial terms[...]."(FCC, 2010, Sec. 54)
2. *No Blocking*
   "[...]not block lawful content, applications, services, or non-harmful devices, subject to reasonable network management."(FCC, 2010, Sec. 63)
3. *No Unreasonable Discrimination*
   '[...]not unreasonable discriminate in transmitting lawful network traffic over a consumer's broadband Internet access service."(FCC, 2010, Sec. 68)[4]

The FCC acknowledges the usefulness of "reasonable network management", but also concludes that pay for priority arrangements would "raise significant cause for concern" (FCC, 2010, Sec. 76). Likewise, transparency and competition are considered to be the main remedies to ensure NN. It is important to highlight

[4]"A network management practice is reasonable if it is appropriate and tailored to achieving a legitimate network management purpose, taking into account the particular network architecture and technology of the broadband Internet access service "(FCC, 2010, Sec. 82). "Legitimate network management purposes include: ensuring network security and integrity, including by addressing traffic that is harmful to the network; addressing traffic that is unwanted by end users (including by premise operators), such as by providing services or capabilities consistent with an end user's choices regarding parental controls or security capabilities; and reducing or mitigating the effects of congestion on the network" (FCC, 2010, p.17952).

that wireless network services are *not* subject to restrictions of network management. The main reason for this differentiation lies in the alleged competition between wireless network operators. Because the effect of competition is yet unclear, it will be interesting to see whether the FCC's NN ruling, which took effect on November 20, 2011, will lead to different developments of the fixed and wireless networks in the US.

3.2. Strict NN model

It should be clear by now that strict NN would imply taking a step backwards from the current status quo of the Internet towards a network regime where any network management practice would be forbidden. Such regulated technical disarming could lead to congestion problems in peak times, which could only be counteracted by overprovisioning of network capacity. In any case, ISPs' revenues would be reduced because business models that rely on managed services, like IPTV, could not be reliably offered anymore. The likely result of this strict interpretation of NN would be that consumer prices for (full) Internet access increase, or that the rate of investments in network infrastructure is reduced.

A related problem is that strict NN prohibits offering limited Internet access for a lower price. This could mean anything from access to the 'full' Internet with lower priority in the backhaul of the ISP, to unhampered access to only a subset of content or services for a lower price. This line of argumentation is also acknowledged by vice-president of the European commission Neelie Kroes who said that "requiring operators to provide only 'full internet' could kill innovative new offers [...] Even worse, it could mean higher prices for those consumers with more limited needs who were ready to accept a cheaper, limited package" (Meyer, 2011).

3.3. Termination fee model

In this NNN scenario access ISPs understand themselves as two-sided market operators, connecting CSPs with the IUs via their network. Under this regime, ISPs could use their monopoly over the last mile to charge the CSPs additional fees for terminating their traffic to the installed customer base. Under the termination fee model these fees would accrue independently of how a CSP's data traffic is handled by the ISPs and thus they are merely an additional financial burden for CSPs, without any immediate reward.

First, it is important to understand that the termination fee model, as well as all other NNN models discussed in this paper, will generally pose the same concerns as the current status quo. In other words, if ISPs have an incentive to block or degrade costly traffic flows or heavy users under a managed network regime, why should this incentive not prevail under any other NNN scenario? The same logic applies to concerns about freedom of speech. If ISPs would indeed want to block disliked websites, why should they do not so under another network regime? Finally, also the concerns that an integrated ISP abuses its control over the network to artificially degrade or block rival content persist under all NNN scenarios. If ISPs indeed want to pursue such goals, the network

regime is not of importance to this matter, as long as the network technology offers the possibility to differentiate data packets, which holds true for all scenarios except strict NN. Therefore, the discussion of the status quo will not be repeated for each NNN model. Rather it is noted that these opportunities, concerns and remedies apply more generally to all NNN scenarios. In the following, only new or unique issues of the NNN scenario in question are presented.

With respect to the termination fee model, and any other model of NNN that employs two-sided pricing, the main concern of NN proponents is that the additional termination fee causes CSPs to cease or to be discouraged from ever offering their services. It is therefore argued that two-sided pricing reduces innovation in the Internet.

Economides & Tåg (2012) study the termination fee scenario in a formal two-sided market model, where CSPs pay a lump-sum to connect to the IUs. The essential assumption in the model is that CSPs value an additional IU more than IUs an additional CSP. The first working paper version of the article was available in 2007 and many things changed in the process of refining the model. The main finding in the published version of the paper is that IUs and ISPs are better off with NNN. Regulators, who are often most concerned with consumer welfare, should therefore be considerate before imposing mandatory NN. This result is a direct consequence of the above assumption and fully in line with the extant two-sided market literature: The more consumers can be attracted, the more profit can be generated with additional fees on the CSP side of the market. Consequently, consumers enjoy a lower subscription price as under NNN and ISPs are allowed to extract additional revenues from the CSPs. This rebalancing of the tariff to IUs is known as the waterbed effect (Genakos & Valletti, 2012). Under monopoly NN is only welfare enhancing if the differentiation between the consumers is relatively high. In other words, this would mean that IUs have a very strong brand preference for a particular ISP compared to their valuation of access to and content in the network. This is a very questionable case in the context of a homogeneous product like Internet access. Therefore, in their model only CSPs would profit undoubtedly from NN regulation. Although the results of the preliminary version of the paper supported the need for NN regulation, the results of the published version are therefore rather tipped in favor of NNN. The authors themselves conclude that the welfare results are ambiguous. Nevertheless, the published version remains to be written in a very NN orientated manner.

Njoroge et al. (2010) follow a similar approach but add the platform investment decision and interconnection between two ISPs to the picture. Both platforms charge flat access charges to CSPs and IUs. Under NN the platforms differentiate maximally resulting in a high and low quality platform. They show that welfare in their model is generally higher in the NNN regime because the NNN regime leads to higher infrastructure investments by the low quality ISP. In their model, the same argument as for the model of Economides & Tåg (2012) holds true with respect to consumer surplus and CSPs revenues. CSPs revenues increase through higher advertising revenues, overcompensating for the higher price for access. Even though the welfare results in Njoroge et al. (2010) are

unambiguously pro NN, it is interesting that the high quality ISP prefers the NN regime. This is due to the fact that under the NNN regime the low quality ISP can catch up through additional investments in the network infrastructure, resulting in fiercer competition and lower revenues.

Musacchio et al. (2009) also incorporate investment costs into their model, but mainly add to the debate by exploring the effect of multiple ISPs charging for access. The ISPs in their model are assumed to have regional monopolies and are therefore not in direct competition with each other. Their interest is the price charging behavior in this situation. The authors show that two-sided pricing is preferable if the ratio of advertising rates to price sensitivity is extreme. However, otherwise a situation similar to the tragedy of the commons may arise in equilibrium. ISPs tend to ignore their own negative effect of overcharging on the investments of the CSPs and consequently on the revenue of all other ISPs. This negative effect becomes more prominent as the number of ISPs increases and therefore NN becomes more attractive in this case.

Hermalin & Katz (2007), mainly interested in studying product line restrictions, apply their model to the NN debate. They analyze a monopolistic ISP which offers a menu of qualities (i.e., transmission classes with different QoS) to CSPs. In a special case of their model, they also look into the enforcement of the zero-price rule for CSPs. They find that the ISP would only produce one quality in this case, but that this quality would be even lower than the quality that would result from a termination fee model. Thus, their findings are in favor of this NNN scenario.

Lee & Wu (2009) also discuss two-sided pricing, but argue in favor of a zero-price rule for CSPs for several reasons. First, they highlight the important fact that all IU are potential future CSPs and that a zero-price rule ensures cheap market entry. Moreover, a zero-price rule ensures that no one has to ask for permission to reach the installed base of ISPs. In addition to that they make the point that access ISPs are actually already compensated for traffic by peering and transit agreements. Because these contracts are negotiable and voluntarily, there is no reason why higher infrastructure costs could not be supported by more favorable agreements. A zero-price rule would also eliminate costs, because two-sided pricing makes new billing and accounting infrastructure for CSPs necessary and thereby introduces a new form of transaction costs. The most striking argument in the paper deals with the potential fragmentation of the Internet ecosystem. Interconnection will depend on the number of ISP and its agreements with CSPs, but given the number of ISPs and CSPs worldwide it seems inevitable that IUs would have only access to a fraction of the CSPs they have today.

Yoo (2005) argues that the burden of proof that NNN is indeed worse than NN is on the side of those who want to regulate. He therefore calls for a wait-and-see approach. In particular, Yoo doubts that the presumption that bandwidth increases faster than demand is correct. In his opinion, overprovisioning is more likely to be welfare-inferior than management or diversification of the network.

Remedies. In light of these many arguments for and against a termination fee model, the policy conclusion is not obvious. However, it is the opinion of the authors that there exist remedies (besides the enforcement of strict NN) which can alleviate most of the concerns of NN proponents (see Section 4).

One important piece of the puzzle seems to be the issue of price discrimination. With very few exceptions, there is consensus among academics that price discrimination techniques which are not beneficial to the IU side of the market, should also not be allowed on the CSP side of the market. This applies in particular to first degree price discrimination. Therefore, even many opponents of NN vote for some kind of *non-discriminatory surcharge* rule in pricing. However, different forms of non-discriminatory access are feasible. For instance, ISPs could charge all services using the same protocol (e.g., Session Internet Protocol (SIP)) or that are in the same group of services (e.g., VoIP) the same fees for data transportation, but services in another class (e.g., IPTV) a different price. Because services in the respective classes are not in direct competition with each other, and because the quality expectations of consumers may differ between the two types of services,[5] such price discrimination could be considered as non discriminatory (Wyatt, 2010). Clearly, the most undisputed price discrimination scheme would be to charge the same fee to all CSPs that want to connect to the network of an access ISP. As long as ISPs would be allowed to engage in price discrimination (e.g., by auctioning off access as is considered by Choi & Kim, 2010), financially strong CSPs have an indisputable advantage. Therefore, a non discriminatory surcharge may be one regulatory tool to ensure a level playing field for all CSPs (that are in the same class of services).

Even a non discriminatory surcharge would not alleviate the problem that young start-up companies with a constrained budget, but innovative ideas and services, may be excluded from entry. However, this is not solely a problem that is related to NN. Start-ups have to raise money for all other aspects of their business (e.g., hardware, personnel), and thus it is hard to believe that a great service may not make it to the Internet market just because of termination fees. Nevertheless, one viable way to overcome such problems would be to enforce that promising companies are granted access to the network free of charge.[6] NN proponents would counter that then somebody would have to judge the idea and business plan of the start-up ex ante, possible denying support for 'promising' ideas. They would continue that the Internet is only what it is because it did not have such gatekeepers. Therefore, another option could be to offer some kind of non-discriminatory revenue sharing. Start-up companies could commit to pay a fixed share (for a limited time) of all potential revenues to the ISP. This would not hinder access to the network for anyone, but allow the ISP to generate additional revenues in the case the business idea becomes

[5] IUs usually expect more reliability and quality with real time communication services than with streaming media, where buffering of data can already account for temporary quality reduction due to network congestion.

[6] Likewise, under a QoS regime, access to the the priority lane could be granted free for a limited time.

successful. This construct would allow all possible ideas to be introduced to the market and fees are only imposed if the innovation becomes successful. Consequently, the key underlying question is whether Internet start-ups should be treated differently than traditional start-ups.

3.4. CSP tiering model

Many critics of NN refer to the argument that the current BE Internet cannot be considered as 'neutral' since different types of data and applications have different requirements for network quality. Consider for instance an application like Skype.[7] If the network is congested, the resulting delay of data packages of the Skype service has a highly detrimental effect on the usability of the service. In comparison, the detrimental effect on an email service is negligible. According to this logic, congestion-sensitive services could be better off if they were allowed to pay for priority, whereas the detrimental effect of a worsening in congestion to the remaining BE class could be less severe, because only congestion-insensitive CSPs remain in this class.

Although all pricing schemes that are compatible with two-sided pricing are feasible, the most relevant scenario for this CSP tiering model is that only the CSPs that opt for the priority lane have to pay extra. CSPs that remain in the BE class must not pay additional termination fees. Hence, in contrast to the pure termination fee model, CSPs get priority in return for their payment and thus the overall effect of CSP tiering on welfare is more likely to be positive than under the termination fee model.

However, CSP tiering also bears one additional risk compared to the termination fee scenario: If the ISP makes more money from the sales of priority access, then it may have the incentive to artificially degrade the quality of the BE class in order to force more CSPs into the costly priority lane. In effect, when the quality of the BE is such that all CSPs are required to buy priority, the ISP would establish a termination fee model through the backdoor. This is known as the *dirty road fallacy* in the context of the NN debate (Sidak & Teece, 2010).

The economic literature on QoS tiering on the CSP side is very young, but many papers have been published in recent years. Many theoretical models rely on assumptions about the network industry, that may influence the results. First, there are differences about the nature of Internet service quality. Some authors view data transportation quality as a complement to quality of the delivered content, while others see it as substitutes. Jamison & Hauge (2008), for example, focus on this issue. They assume that the current network capacity will increase with the introduction of CSP tiering, such that the transmission quality of the BE class is not affected. In this special case, they find that CSP tiering has an beneficial effect on content variety. This result is possible, because CSPs with a lower content value can now compensate by buying priority access.

[7]Skype offers a VoIP service that allows free calls between all connected users.

Economides & Hermalin (2012) focus in their formal analysis on the so-called *re-congestion effect*, which describes the assumption that those CSPs that are prioritized under a QoS tiering regime will receive even more consumer requests (high value content) and thus generate more traffic than under NN, which in turn re-congests the network. This assumption contrast this model to previous work by Hermalin & Katz (2007) and leads, by construction, to a welfare loss under CSP tiering. In addition, much of the analysis is now based on the implicit assumption that content variety is exogenous and equal under NN and CSP tiering. This leads to the result that NN is superior in the short-run. However, this assumption neglects possible positive effects on content and service variety through the provision of higher quality that would not be delivered under NN. In case the re-congestion effect is not too strong CSP tiering is the more efficient regime, because it provides higher investment incentives (i.e., investments are not overcompensated by increase in demand).

Hermalin & Katz (2007), from which a special case has been discussed in the context of the termination fee model, rests otherwise on the same principal modeling assumptions as Economides & Hermalin (2012). The authors analyze CSP tiering by a monopolistic ISP and also in a duopoly when the ISP is free to offer a menu of qualities (NNN) and when it is restricted to offer one quality (NN). One obvious result of NN is that all CSPs with a lower valuation for quality are driven out of the market, while CSPs with a high valuation for quality are suffering from the underprovisioning of quality. By contrast, under CSP tiering there are some CSPs with a medium valuation for quality that are now receiving a better quality than under NN.

Cheng et al. (2011) and Choi & Kim (2010) were the first to employ a queuing model to formalize the relationship between priority and BE traffic. This can be exemplified formally by means of the $M/M/1$ queuing model (Kleinrock, 1976). Essentially, the model assumes that there exists a single router in the Internet with an infinite queue (i.e., no packets are dropped) and at which data packets arrive with rate λ according to a Poisson process (i.e., each pair of consecutive arrivals has an exponential distribution and each of these inter-arrival times is assumed to be independent of other inter-arrival times). The router can handle the arriving data packets at rate μ, which can be interpreted as the capacity of the network. In a BE Internet, at which the arriving data packets are handled by the router according to the first-in-first-out principle, the classical result is that the average waiting time of a packet, which can be interpreted as the level of congestion in the network, is $w_{NN} = 1/(\mu-\lambda)$. However, now consider a tiered system in which the data packets of some CSPs are handled with priority, i.e., these packets are always enqueued ahead of the BE packets. Let x denote the share of CSPs that have bought priority access, then the waiting times are $w_P = 1/(\mu-x\lambda)$ and $w_{BE} = \mu/(\mu-\lambda)\, w_P$ for the priority and best-effort class, respectively. It is easy to see that the relation $w_P < w_{NN} < w_{BE}$ holds, assuming an equal transmission capacity in both regimes and assuming that not all CSPs buy priority access. Otherwise, when all CSPs are in the priority class, the model trivially collapses to $w_P = w_{NN}$, which amounts again to a termination fee model. Both papers investigate the effect of

CSP tiering on competition among CSPs and on the ISP's investment incentives. In both models, which are strikingly similar, exactly two CSPs compete for customers that dislike congestion and visit one of the two CSPs exclusively. CSPs can improve their competitive position by purchasing priority access from a monopolistic ISP. This alleviates customers of the respective service from some of the network's congestion. Choi & Kim, in contrast to Cheng et al., assume that the ISP sells priority access to only one of the two CSPs exclusively in order to exclude a possible prisoners' dilemma situation. More specifically, Cheng et al. (2011) find that when the difference in profit margins between the two content providers is rather small, both will individually buy priority access. In this situation, neither CSP gains an advantage and the price paid for priority access is forfeited. Therefore, Choi & Kim make the restrictive assumption that the ISP will auction off the priority lane (discriminatory surcharge). As discussed before, this can be considered as the worst case pricing scenario for CSP tiering. Cheng et al. (2011) and Choi & Kim (2010) show for a large range of parameters that the ISP's incentive to invest in infrastructure is higher under NN, whereas CSP tiering is generally welfare enhancing in the short run.

Krämer & Wiewiorra (2012) model the main arguments of the NN debate in a two-sided market framework with network congestion sensitive CSPs and IUs on each side, respectively. The platform is controlled by a monopolistic ISP offering CSPs prioritized access to its customers for a non discriminatory surcharge. The CSPs are not in direct competition to each other, but the model allows for entry of new CSPs and can therefore also account for the impact of CSP tiering on content variety. CSP tiering functions as a means to allocate congestion away from the congestion sensitive and to the congestion insensitive CSPs. Krämer & Wiewiorra find that CSP tiering may be the more efficient regime in the short run. In the long run, it provides higher incentives for broadband investments, because the entry by new, congestion sensitive CSPs creates additional demand for the priority service and consequently additional revenues for the ISP. However, the long run welfare results depend on the distribution of congestion sensitivity on the CSP side of the market. If the mass of congestion sensitive CSPs is very large, an effect that is similar to the re-congestion effect of Economides & Hermalin (2012) can be observed. This shows how dependent the welfare results of formal models are with respect to underlying assumptions about the development of Internet traffic.

Reggiani & Valletti (2012) extend this approach by adding a single big CSP (e.g., Google) to the picture. The big CSP can offer different services simultaneously, while a continuum of small CSPs ('the fringe') can offer only a single service per CSP. Reggiani & Valletti find that NN is likely to hinder investment at the core, but fosters innovation at the fringe. Moreover, they show that the content variety of the big CSP is reduced. Like in Krämer & Wiewiorra (2012), CSP tiering leads to a better allocation of network resources and is consequently welfare enhancing. Nevertheless, CSP tiering may eventually be more beneficial to the big players on the CSPs side of the Internet ecosystem.

It is still an open question how competition between access ISPs will affect the welfare implications of CSP tiering. To date only two papers exist that

consider the issue of ISP competition and NN in a formal model. Bourreau et al. (2012) extend the framework of Krämer & Wiewiorra (2012) by allowing by competition between ISPs. Their results are remarkably similar to those of Krämer & Wiewiorra (2012), which suggests that competition will not push the Internet access market towards NN. A different outcome is obtained with respect to the ISPs surplus, however. Although each ISPs unilaterally prefers to introduce a CSP tiering regime, there might exist situations in which the ISPs do not benefit from this deviation from NN, because competition is intensified. A similar result with respect to consumers' surplus is obtained by Choi et al. (2011), who focus on the interconnection agreement between competing ISPs in a static model of CSP tiering (i.e., without investments). They find that the competition for IUs is stronger under under a CSP tiering regime if ISPs have some monopoly power over the CSPs. In conclusion, this preliminary evidence suggests that, from a regulatory perspective, the case for CSP tiering might even be strengthend if there exists competition between access ISPs.

Remedies. The general tone of the economic literature on CSP tiering is that this practice is likely to be welfare enhancing if the dirt road fallacy can be avoided. In order to deal with this issue, regulators could implement a minimum quality standard (MQS) policy that warrants a sufficient transmission quality to the BE class. However, under certain circumstances, as Krämer & Wiewiorra (2012) show, an MQS could also be detrimental to welfare because it forces the ISP to invest too much into the network (overprovisioning). Brennan (2011) argues in favor of a MQS and shows that this regulatory tool may have far less negative impact than NN. It can mitigate not only QoS related concerns, but also traffic management related concerns that relate to the artificial degradation of rival content or costly traffic flows. However, he also notes that an MQS could also be abused by the industry. Incumbents could vote for a high quality standard in order to foreclose the market for (low quality) entrants.

Legislation and regulation. In contrast to the FCC's order (FCC, 2010), the current European legal framework on electronic communications networks and services (specifically, EU Directive 2009/136/EC from November 25, 2009) has no general objections against CSP tiering. However, it already takes precaution by allowing the national regulatory agencies to set a minimum quality of service requirement (Article 22, 3) in order to "prevent the degradation of service and the hindering or slowing down of traffic over networks". In addition, the European framework contains similar rules to the FCC's order with respect to transparency and blocking. Beyond that, a specific NN law is currently only effective on two other countries. First, Chile enacted a NN law in 2010, which was finally implemented in May 2011 (Art.24Ha/Ley 20.453). In its initally proposed version, the law was considered to be the first implementation of strict NN in the world. However, the finally adopted version of the law merely states that ISPs cannot "arbitrarily block, interfere, discriminate, hinder or restrict" the use of the Internet. Thus, the law does not prevent a tiered system per se. In this respect the final law is in fact a compromise between NN proponents

and opponents, rather than a codification of strict NN. Second, the Netherlands enacted a NN law in 2011 that forbids network operators to degrade certain applications or to charge extra fees from customers. The law was suggested after the announcement of mobile network operators to charge extra for certain VoIP and messaging applications. In contrast to the USA, where mobile markets are to some degree exempt from NN regulation, the Dutch law specifically targets the mobile markets (O'Brien, 2011). The law became effective on May 8, 2012. Other countries are currently considering whether to impose NN regulation and the body of European regulators (BEREC), issued a series of discussion papers for consultation on the topic of net neutrality. Moreover, for example in Germany the government commissioned a committee of inquiry (partially comprised by politicians and partially by experts) on different issues of the digital economy, among which was also the issue of NN. In its final report, which is also intended as guidance to the national regulatory authority, the committee did not come to a consensus with respect to CSP tiering. However, similar to the FCC's order, it acknowledges that reasonable network management is welfare-enhancing.

3.5. User tiering model

The strict definition of NN does not only apply to QoS tiering on the CSP side, but also to QoS tiering on the IU side. Therefore IU tiering, i.e., when some IU pay for the prioritized transmission of their data packets, would also constitute a violation of NN. However, IU tiering adheres to the current one-sided pricing paradigm of the Internet and thus no additional fees are collected from CSPs. Therefore, one of the NN proponents' main concerns, namely the negative effect of NNN on innovation, does not hold here. Moreover, IU tiering is different from CSP tiering in that the users themselves decide about which service is being prioritized or degraded. Therefore, the need for transparency and the fear that downstream competition is distorted are lessened. Nevertheless, it should be clear that network management may be exercised on top of IU tiering arrangements. Furthermore, it is obvious that upgrading some users will inevitably downgrade others. Therefore, in general the same arguments as for CSP tiering and the status quo also apply here.

In an article that preceded the NN debate, Reitman (1991) looks into endogenous quality differentiation in congested markets. He distinguishes between impatient and patient consumers and finds that in an competitive equilibrium firms will always choose prices and capacities to differentiate themselves from each other. With many firms in the market, all of them are choosing the same level of capacity and differentiate each other solely by prices. This result is similar to the idea of Paris Metro Pricing (see, e.g., Chau et al., 2010). Until the mid 1980s the Paris Metro service was operated with first and second class cars. The cars in both classes were absolutely identical, but first class tickets cost twice as much as second class tickets. With respect to access ISPs, Paris Metro Pricing would mean that the available bandwidth is split up in a portion for priority services and a portion for BE services. This has in fact been proposed by Odlyzko (1999). The consequence of splitting up capacity and differentiating

prices is that more revenue is generated compared to a single network with two times the capacity.

In the spirit of Paris Metro Pricing, Schwartz et al. (2008) investigate the investment and capacity division decision of competing ISPs. They find, that two service classes together are socially beneficial. Moreover, the proportion of consumers that is worse off than with a single service class is decreasing in the number of ISPs in the market. If there are only a few ISPs with market power, too much capacity would be provided for the premium service and thus a larger share of consumers would be forced into this service class, resulting in a welfare loss. Therefore, the authors conclude that capacity regulation (i.e., the assignment of a predefined share of capacity to the standard service), would be welfare enhancing. This regulation would be similar to a MQS regulation. The authors assume that users could otherwise boycott the transition to a new QoS regime. Ex ante MQS regulation can consequently build reputation for a QoS regime and increases the probability that the transition to a new tiered system successfully takes place. With respect to the NN debate, the authors interpret the current regime as a voluntary abandonment of QoS (i.e., the ISPs assign all capacity to one service class).

Bandyopadhyay & Cheng (2006) study the effect of IU tiering in a theoretical model that incorporates queuing theory. In their model, users are able to decide for preferential treatment of their data on the fly during an Internet session. They find that this pricing scheme would increase the revenues of ISPs without significant costs to introduce the service. Nevertheless, the authors identify a potential problem: The monopolistic ISP might want to serve only customers with a high valuation for this service, excluding other customer groups. This could make regulatory intervention necessary if Internet access is politically classified as an universal access technology.

Remedies. As mentioned above, IU tiering is currently only employed by very few ISPs. Therefore, it is interesting to ask why ISPs lobby so intensely for the introduction of differentiated services on the CSP side, but still hesitate to offer differentiated service to the IUs. Evidently, given the backup of the above academic papers and the less heated arguments of NN proponents, IU tiering would be a much less scrutinized business strategy. For some observers of the NN debate, IU tiering would not even be an issue of NN. For example, Tim Berners Lee, Director and Founder of the World Wide Web Foundation, said once in an interview: “While we may pay for different service levels, e.g., we pay more for a higher bandwidth, the important thing about the Net is that if we both pay for a certain level of service, then we can communicate at that level no matter who we are. We pay to be able to connect to a certain bandwidth and that’s all we have to do. It’s up to our ISPs to ensure that the interconnection is done. This is how it has always been done” (Powell, 2006, p.3).

One potential reason for this puzzle might be that ISPs are afraid of the IUs reaction to such price discrimination (i.e., differentiated services). In particular, end users’ perception of fairness seems to play a very important role in this context. In contrast to CSPs, the IUs’ perception of the fairness of pricing

schemes is generally more prone to psychological and social influence factors (Bolton et al., 2003). This effect becomes even more prevalent if the good is scarce and has to be allocated between all users (Xia et al., 2004). Consequently, ISPs, who are in competition for IUs, are reluctant to offer pricing schemes that trigger such emotions. In fact, the NN debate shows in an impressive way to what size the complaint of Internet activists can grow.

4. Policy conclusions

The debate on net neutrality rests on two fundamental assumptions. First, the belief that Internet traffic will increase at a rate which cannot be handled by the current technology and traffic management techniques and which will therefore result in a severe and persistent congestion problem (exaflood). Second, the ISPs' claim they cannot bear the costs for the necessary network infrastructure investments without tapping additional revenue streams, yielding a NNN scenario. If regulators deem that both assumptions are probably true, a switch to a NNN model should not be prohibited ex ante. In fact, the previous survey of the academic literature has shown that deviations from NN are generally welfare enhancing if the appropriate remedies are applied.

In the spirit of Jordan & Ghosh (2009), Figure 4 shows a flow chart that can guide policy makers through the potential threats that are associated with the different NNN scenarios. The chart is clustered into those threats that are specific to a tiered QoS system (CSP tiering or IU tiering model), two-sided pricing (termination fee model) or a managed network (status quo). For each threat, a remedy is suggested that can potentially deal with it. For the sake of clearness, we have simplified the flow chart with respect to the binary nature of the decision whether a remedy is considered to have solved the threat at hand or not. Of course, we acknowledge that in reality the conclusion may be more fine grained and result in a 'rather yes' or 'rather no'.

The most prevalent concern in a NNN scenario that entails QoS tiering is the dirt road fallacy. It may be counteracted by an appropriate MQS policy, as for example, foreseen in the current European regulatory framework. Only if this measure is, for whatever reason, not considered to be suitable, a more specific NN is warranted.

The same logic applies to the concerns that are related to two-sided pricing. First, if ISPs engage in discriminatory pricing, a non discriminatory surcharge could be demanded. Second, reduced innovation at the edge, which results from the existence of positive termination fees that cannot be raised by smaller CSPs, could be alleviated by innovation funds (venture capital) or revenue sharing agreements, as described in Section 3.4.

Third, there may be a threat of fragmentation of the Internet, which results from the concern that ISPs and CSPs cannot reach an agreement on the payment of a termination fee. As Lee & Wu (2009) point out, this may be due to the ISP's desire to differentiate itself through exclusive content. A possible remedy, that is well known from the telecommunications industry, would be to instantiate

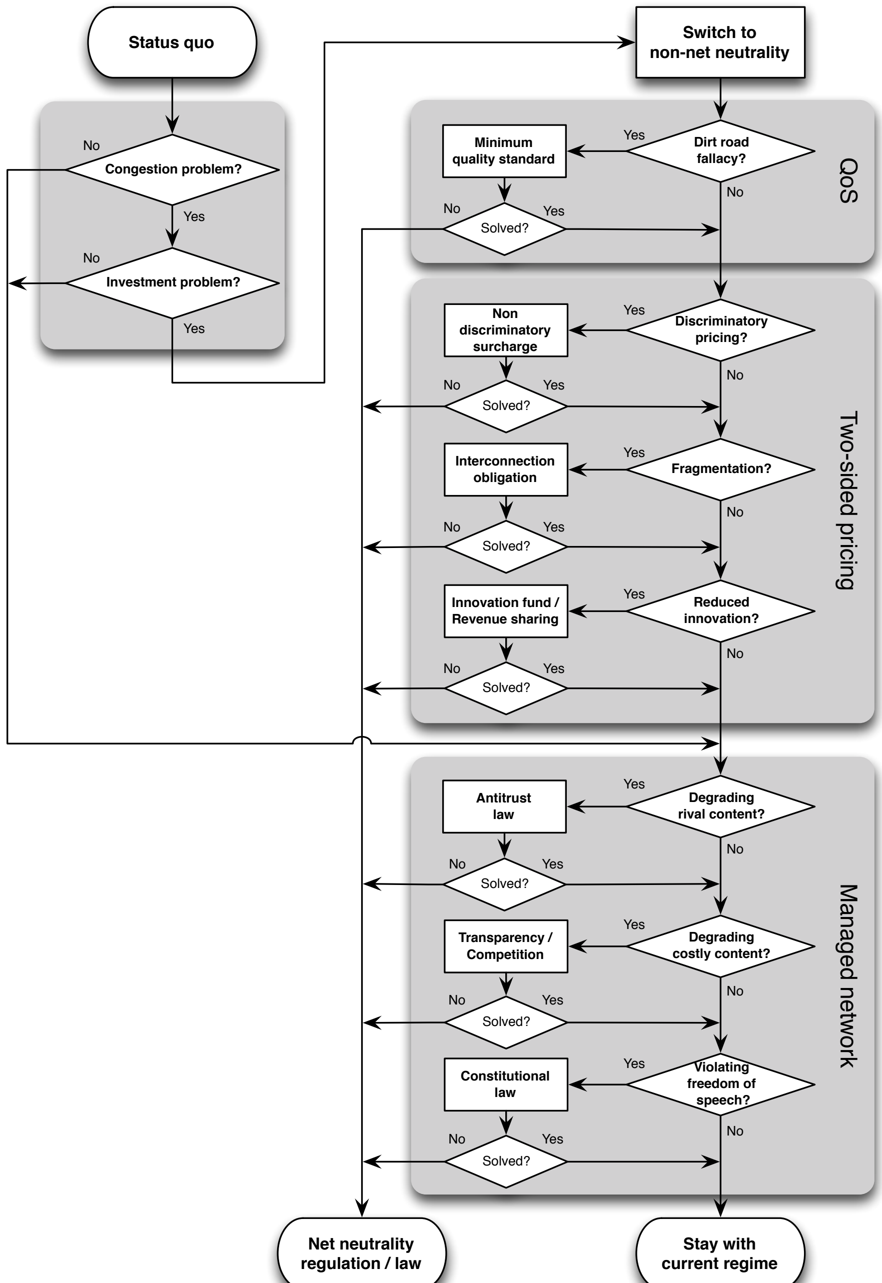

Figure 4: Proposed net neutrality policy decision process

interconnection obligations. Only if one of these measures fails to solve the problem at hand, stricter NN seems justified.

The final set of concerns and remedies is related to practices that can already be employed by access ISPs in the current status quo, i.e., in a managed network. Distortion of downstream competition (degradation of rival content, e.g., VoIP) can readily be addressed ex post by antitrust law. Likewise, violations of freedom of speech could already be subject to constitutional law. Furthermore, if an ISP engages in degradation of certain users, content or protocols due to cost considerations, a mix of transparency obligations and competition is currently considered to be the right regulatory response. Again, only if these measures cannot address the concerns adequately, stricter NN regulation should be taken into consideration.

In summary, it is evident that the case for strict net neutrality regulation is viable only if many, if not all of the proposed remedies are believed to fail. Additionally, such regulation would only be supported by the assumption that the conjectured congestion and investment problems are not real and that the prospective efficiency gains under NNN would not be realized. In all other cases, it seems that policy makers have appropriate options at hand, most of which constitute undisputed legal or regulatory pillars (constitutional & antitrust law, interconnection), or which can be outsourced to the market, as in the case of innovation funds and revenue sharing.

5. Outlook: Neutrality in the Internet ecosystem

In the end, the NN debate may only be the onset of a larger debate on neutrality in the Internet ecosystem. Renda (2010), for example, points out that the Internet ecosystem is affected by competition up and down the Internet value chain, which exerts pressure on the network layer by taking over revenue sources historically exploited by ISPs. In other words, while the NN debate is currently focused on ISPs as the gatekeepers of the customer access network, other gatekeepers of the information society may soon enter center stage on other forms of neutrality. This is exemplified by Figure 5.

First, the concept of neutrality may be applied to content and services, i.e., upstream the network layer. Second, neutrality may become an issue downstream the network layer, i.e., with respect to the devices through which end-users access the network. Third, the NN debate may spill over to other players in the network layer, specifically CDNs. Each issue is discussed in turn.

5.1. Net neutrality and CDNs

The role of CDNs has already been introduced in Section 2. In the context of the NN debate, the relationship between CDNs and CSP tiering is obvious. CDNs are paid by CSPs in order to be able to provide QoE to IUs (see Figure 2) and employ sophisticated mechanisms in order to circumvent congestion in the network. Thus, CDNs can be considered as a network management technique. Nevertheless, from a technical perspective, it is arguable whether CDNs violate

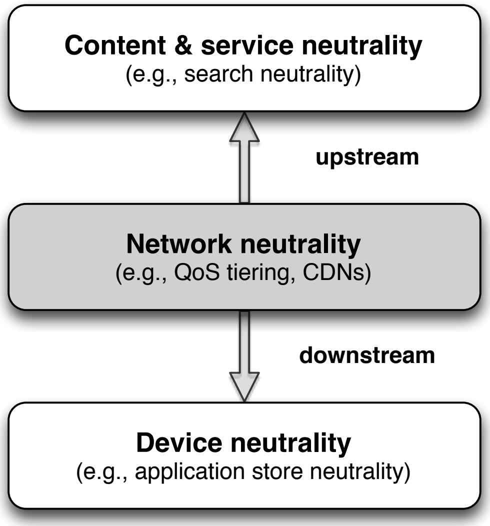

Figure 5: Neutrality in the Internet ecosystem

the strict definition of NN because the data packets of CDNs are sent with BE, although not over the same paths as other traffic. In any case, the fact remains that only big CSPs can afford to employ a CDN and thus, the same arguments with respect to openness and insurance of fair competition between CSPs as in the case of CSP tiering apply (Wu & Yoo, 2007). Interestingly, the NN debate seems to have bypassed CDNs, possibly because some proponents of NN view CDNs as less harmful. This is mainly because the market for CDNs is considered to be competitive. Consequently, it is argued that CDNs cannot be seen as gatekeepers for delivering quality in the public Internet.

However, the CDN market is dominated by Akamai, who invented this business and who has more than 60% market share (Rice, 2010). In many cases this would be considered a dominant position by a regulatory authority. Therefore, large CDNs should be considered as gatekeepers in the Internet economy. Moreover, in recent years access ISPs have begun to cooperate with CDNs in order to increase the QoE for their customers or simply to reduce costs from transit (see, e.g., Rayburn, 2009). Latest with this development in mind, the differences between CDNs and access ISPs finally vanish.

5.2. Device neutrality

With the tremendous success of smart phones and tablet computers, mobile device manufacturers (such as Apple) and owners of mobile operating systems (such as Google) are exerting more and more control over the content and services that are consumed on this class of devices. In times when predominantly

feature phones were sold, (mobile) network operators were in control of the software and services that were preinstalled on the subsidized devices. This power structure has changed dramatically. More recently the network operators' own affiliated services (e.g., SMS, MMS, video telephony) are steadily replaced by applications that rely only on Internet connectivity, and not on special protocols that are under the network operator's control. Additionally, device manufacturers are opposing the demands of network owners to control the technological capabilities of their handsets. According to Hahn et al. (2007, p.424), these include the requirement that the handset (i) must be sold by the operator (or its agent), (ii) cannot be used in a rival network, (iii) is free of call timers, or (iv) provides limited or not connectivity to open access networks (e.g., Bluetooth or WiFi).

This development was again turned over by Apple. With the iPhone, Apple essentially took over full control over the end user experience and software, including all wireless functionalities. Apple decides which software is allowed on their devices, both indirectly (e.g., no support of flash media) as well as directly through its centralized approval process for the AppStore. Thereby, Apple as well as other mobile operating systems providers (such as Google or Microsoft) are in the position of a gatekeeper that controls the content and functionality of end-user devices. The similarity to NN is immediate and thus, it is not surprising that this development is also of concern to some NN activists. For example, Wu (2007) discusses related problems under the umbrella term 'Wireless net neutrality'. In particular, he surveys extensively the practices of mobile network operators by which they attempt to exert as much control over their network as possible (see list above) and calls for regulation that would impose the right to connect any non-harmful device to the network ('Wireless Carterfone'). Moreover, Wu demands to regulate handset subsidies and to enact strict rules to prevent crippled products, e.g., phones with disabled Bluetooth functionality. Wallsten (2007) responds to Wu paper with a short note, because he thinks that many of his arguments are flawed, especially in the light that there is enough competition in the mobile communications industry. Among others, he provides several counterexamples. Hahn et al. (2007), finally, call for a more moderate approach with respect to wireless NN. They conclude with the somewhat tautological recommendation that regulatory intervention is only necessary if there is a definite market failure and if the proposed interventions lead to a better outcome as the status quo. Nevertheless, wireless NN, or as it is called more intuitively here, device neutrality, seems to be an issue that deserves more academic attention in the future.

5.3. Content and service neutrality

A similar line of argumentation may apply upstream the Internet value chain. Big CSPs, such as Google, certainly have significant market power in the Internet ecosystem and may therefore also abuse their dominant position. A particular concern addresses Google's power to report search results in a non-neutral way. For many people, Google's search engine is the first place to go when they look for information in the WWW. However, it is not publicly

known how Google's algorithm derives the order of the search results. Google has just revealed the set of measures that are taken into account, but there is no information about how important a single measure is for the final 'page rank'. This provides ample ground for suspicion with respect to the neutrality (non-discrimination) of Google's search results.

Odlyzko (2009), for example, argues that even the founders of Google, Sergey Brin and Larry Page, once thought that advertisement funded search engines have an incentive to bias search results in favor of their paying advertisers. The problem becomes even more evident if one considers other well known gatekeepers in the modern Internet ecosystem. Social network providers (e.g., Facebook), for instance, own the information about the so-called social graph (the aggregate information about all links of each participant of the social network with other participants of the network and the related personal information). With this information search engines can personalize search results even more, based on personal preferences, social affiliation and browsing history.

In this context, Grimmelmann (2010, p.438) analyzes eight principles for search neutrality: (1) *Equality:* Search engines should not differentiate between websites. (2) *Objectivity:* There are correct search results and incorrect ones, so search engines should return only the correct ones. (3) *Bias:* Search engines should not distort the information landscape. (4) *Traffic:* Websites that depend on a flow of visitors should not be cut off by search engines. (5) *Relevance:* Search engines should maximize users' satisfaction with search results. (6) *Self-interest:* Search engines should not trade on their own account. (7) *Transparency:* Search engines should disclose the algorithms they use to rank web pages. (8) *Manipulation:* Search engines should rank sites only according to general rules, rather than promoting and demoting sites on an individual basis.

Of course, each of the principles is disputable. However, it is also obvious that Google's search results have a tremendous impact on the success of a new CSP. Therefore, the debate on search neutrality is akin to that of net neutrality and consequently, the same general concerns (e.g., with respect to manipulation or transparency) are addressed. Interestingly, Grimmelmann finds that all of the above principles of search neutrality are inappropriate for any possible form of regulation. However, he also comes to a conclusion that is similar to the herein proposed decision process for NN regulation: "Just because search neutrality is incoherent, it doesn't follow that search engines deserve a free pass under antitrust, intellectual property, privacy, or other well-established bodies of law. Nor is search-specific legal oversight out of the question. Search engines are capable of doing dastardly things[...]"(Grimmelmann, 2010, p.438).

6. Conclusions

The NN has received much attention by Internet enthusiasts, policy-makers and academics alike. However, much of the public debate, and even some parts of the academic debate, were driven by emotionality, rather than facts. This article is an attempt to provide a comprehensive introduction as well as a survey

of the academic state of the art on the issue of net neutrality. In particular, the concerns, benefits and remedies of different NNN scenarios are discussed along a framework that characterize these scenarios by the QoS regime and the pricing regime that is employed.

Irrespective of the regime, the majority of the papers that conduct an economic analysis find that strict NN regulation is warranted only under very special circumstances. The main assumptions that drive pro NN results are that (i) innovation at the edge is more important than innovation at the core (e.g., van Schewick, 2007), (ii) the introduction of QoS tiering will inevitably lead to a re-congestion effect (e.g., Economides & Hermalin, 2012) and that (iii) CSPs have less market power than ISPs. With respect to the latter, the extant literature that models the Internet as a two-sided market has thus far ruled out that large CSPs may also be the recipient of additional revenues in a termination fee model (e.g., Economides & Tåg, 2012), because no access ISP would be able to attract customers without access to these CSPs. Likewise, the effect of competition between access ISPs is currently not sufficiently researched. First evidence suggests, however, that the results from monopoly considerations carry over to a large extent. Moreover, the empirical evidence from the mobile communications industry, which is usually considered as sufficiently competitive, also demonstrates that operators remain in the position to exert market power due to their (temporary) termination monopoly over their current customers. Thus, there is currently little reason to believe that sufficient competition between access CSPs will warrant NN. Consequently, an exemption from NN obligations, if it is considered necessary in the first place, for wireless networks based on the argument of competition does not seem to be justified. By contrast, the problem of network congestion, which is one of the main drivers for a deviation from NN, is likely to be more pronounced in wireless networks. In any case, the economics of NN should be the same for wireless and wired networks.

In conclusion, while there is consensus on some parts of the NN debate (e.g., allowing reasonable network management (Faulhaber, 2011)), there is also still considerable disagreement that necessitates further research (e.g., with respect to the effect of competition). In the future, it would also be desirable to see more empirical papers on the topic that could either confirm or reject some of the assumptions that drive the results of the analytical models. Finally, it is also likely that the debate on neutrality will intensify in the future, extending to related topics such as content and service neutrality as well as device neutrality. However, with respect to many of the underlying questions, society will have to acknowledge that the Internet "is evolving to permit more sophisticated forms of pricing and cost recovery, a perhaps painful requirement in this commercial world" (Leiner et al., 2011).

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