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Net Neutrality: A Fast Lane to Understanding the Trade-offs

Shane Greenstein, Martin Peitz, and Tommaso Valletti

Imagine you want to watch a movie online in the United States. For example, you might be subscribing to Comcast, the country's largest cable and broadband provider, and watching a movie delivered to you by Netflix, the giant television and movie-streaming service. What would happen if Comcast asked Netflix to pay for faster and more reliable access to its subscribers? Would Netflix be likely to agree to this request? Would Netflix charge you more for the movie? Would Comcast raise its broadband subscription fee for this improved service? If such a deal was struck, in what ways would consumer or producer welfare change? Such a deal between Comcast and Netflix actually happened in 2014. It is an example of prioritization, a network management practice that is part of the more general debate on "net neutrality."

The term "network neutrality" was introduced in a widely cited law article by Wu (2003). The article discusses whether an internet service provider should be required to treat all data from all content providers in the same way, and generally argues that net neutrality is good for the internet. For example, if a

■ *Shane Greenstein is MBA Class of 1957 Professor of Business Administration, Harvard Business School, Harvard University, Cambridge, Massachusetts. Martin Peitz is Professor of Economics, University of Mannheim, and also Director of the Mannheim Centre for Competition and Innovation (MaCCI), both in Mannheim, Germany. Tommaso Valletti is Professor of Economics, Imperial College Business School, London, United Kingdom; Professor of Economics, University of Rome Tor Vergata, Rome, Italy; and a Fellow at the Centre for Economic Policy Research (CEPR), London, United Kingdom. Their email addresses are sgreenstein@hbs.edu, martin.peitz@googlemail.com, and t.valletti@imperial.ac.uk.*

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net neutrality requirement does not exist, internet service providers might in some cases "throttle" certain content, slowing down delivery of that content—or even blocking it—so that it would not cause congestion and hinder other kinds of service. Internet service providers also might sign contracts to provide preferential treatment to the services of some content providers, giving their data a "fast lane" to users, so that other traffic would receive a "slow lane" during moments of congestion and arrive later.

The last decade has seen a strident public debate about net neutrality. Every developed country has had a different regulatory experience with this topic (for examples, see Marcus, Nooren, Cave, and Carter 2011; Marcus 2014). In the United States, the topic has fallen under the purview of the Federal Communications Commission, whose attempts to write rules have generated heated arguments, opposing votes along party lines, and repeated court review. In Europe, some individual states, such as the Netherlands, have introduced their own pro-neutrality legislation. A first piece of explicit Europe-wide neutrality legislation was proposed by the European Parliament in April 2014, and passed in modified form in October 2015 by the European Parliament. The policy debate remains alive today.

However, exactly what is at stake in net neutrality policy debates can be unclear. Considerable discussion has ensued among legal scholars about the precise meaning and issues surrounding net neutrality, and no consensus has emerged (for example, Yoo 2005; Sidak 2006; Lee and Wu 2009; Zittrain 2008; van Schewick 2010; Frischmann 2012). Stakeholders also take vastly different positions. Many data carriers say that differentiating charges and treatment of data will allow them to manage congestion efficiently and to provide an ongoing incentive to invest in faster service and innovate. Many content providers argue that without net neutrality rules, they will have a harder time reaching end users, reducing the benefits that end users receive from their internet connection. They also argue that the absence of net neutrality rules will deter them from innovating.

This article will provide a guide to the literature analyzing the economic trade-offs shaping policy choices. Our principal contribution is to identify the economic dimensions of this debate, and show that many questions can be informed by simple economic models of the market for internet services. This framework is useful both in teaching students and in informing the public about the economics of these important policy matters.

We begin by discussing the features of the modern internet. We introduce the key players, with a focus on internet service providers, content providers, and customers. We then summarize the insights of some models of the treatment of internet traffic. The economic literature has focused on two definitions of net neutrality. The most basic definition of net neutrality is to prohibit payments from content providers to internet service providers; this situation we refer to as a one-sided pricing model, in contrast with a two-sided pricing model in which such payments are permitted. Net neutrality may also be defined as prohibiting prioritization of traffic, with or without compensation. The research program then is to explore how a net neutrality rule would alter the distribution of rents and the efficiency of outcomes.

The economic literature examining net neutrality is young, and it would be rash to conclude that researchers have spotted all the key economic trade-offs. So throughout we identify some of the important open questions in this topic. Moreover, as we survey the literature, we highlight one particular theme: There is little support for the bold and simplistic claims of the most vociferous supporters and detractors of net neutrality. The economic consequences of such policies depend crucially on the precise policy choice and how it is implemented. The consequences further depend on how long-run economic trade-offs play out; for some of them, there is relevant experience in other industries to draw upon, but for others there is no experience and no consensus forecast.

Public net neutrality debates tend to range widely, and this too causes confusion. Our discussion will remain focused on policy for (un)equal treatment of traffic from different content providers by the "last-mile" internet service provider to which an end user subscribes. In this article, "net neutrality" *does not* encompass debates about consumer protection, like what a firm means when it advertises "unlimited" service. It also does not cover the extent to which the policies of internet service providers affect freedom of speech, privacy, or security.

Internet Structure and the Net Neutrality Debate

The modern commercial internet grew after many firms and users voluntarily adopted a set of practices for "inter-networking"—that is, transferring data between geographically dispersed local area networks and computer clients operated by different organizations. The commercial internet began to provide many revenue-generating services in the early to mid-1990s, and the network grew as many more firms and users began to participate. As of this writing, this network supports services to over three billion users (as reported at http://www.internetlivestats.com/internet-users/), and continues to grow worldwide.

Three facets of the network shape the net neutrality policy debate and arise in any economic model of this setting: complementarity between inputs provided by different firms; the direction and size of the flow of traffic and the flow of payments; and potential market power by some firms—in particular, internet service providers. We discuss these in turn.

Complementarity among inputs is almost synonymous with how the internet works, because what defines the modern internet is that it sends data from many locations to many locations. A broadband connection without access to any content is as useless as an online application without any broadband connectivity. An end user needs both. Here we see the three main players that we will study in this article: internet service providers such as Comcast, Verizon, or Vodafone; content providers such as Amazon, Facebook, Google, Netflix, Skype; and end users. A device, such as a laptop or a smartphone, is also needed, but we will ignore their (largely competitive) supply conditions.

Most economic models take for granted that the technical issues with complementarity have been solved. That is because all firms involved with moving data on the internet use the same nonproprietary "protocols," which are standardized software commands that organize the procedures for moving data between routers, computers, and the various physical layers of the network. One design for protocols acts as the standard for today's network, a protocol known as *TCP/IP*, which stands for Transmission Control Protocol/Internet Protocol.[1]

A major source of confusion for the economics arises from the many uses of the internet. Four types of different uses employ essentially the same internet processes: 1) static web browsing and e-mail, which tend to employ low bandwidth and can tolerate some delay; 2) video downloading, which can employ high bandwidth and can tolerate some delay; 3) voice-over IP, video-talk, video streaming, and multi-player gaming, which tend to employ high bandwidth and whose quality declines with delay; and 4) peer-to-peer applications, which tend to use high bandwidth and can tolerate delay, but can impose delay on others (Ou 2008).

Over time, the growth of the latter three applications has changed the scale and flow of data traffic on the internet, and this brought the treatment of traffic to the fore. Electronic mail dominated the volumes of traffic over the internet in the early 1990s, and tended to support nearly symmetric data flows from all locations to all locations. Though electronic mail has grown, email and web browsing made up only one-sixteenth of household internet traffic in 2014, while video made up just under two-thirds (Cisco 2015, Tables 10-13). In most developed countries, traffic related to web browsing became the majority of traffic sometime in the mid to late 1990s, and peer-to-peer traffic became the majority in the middle of the 2000s. In the last few years, streaming traffic for video applications makes up the largest fraction of traffic. On the modern internet, the majority of streaming traffic is unidirectional—mainly from content providers to users.

Most economic models of the internet overlook the details about how firms coordinate the movement of data. A first common arrangement moves data from a content provider over "backbone lines" and then to local broadband data carriers—either broadband internet service providers using DSL or cable, or mobile broadband providers. This step requires coordinated investments between content providers, backbone providers, and internet service providers, particularly at the points of interconnection between them. A second common arrangement moves traffic to servers located geographically close to the users of a broadband internet service provider. Independent third parties called content delivery networks, such as Akamai and Limelight, operate and maintain these servers. A content delivery network charges a content provider for hosting their content on servers close to the "last-mile" internet service provider, so that packets arrive at this service provider ahead of other packets.

[1] TCP/IP defines the "headers" or labels at the beginning and end of a "packet" of information. Each packet is of limited size, and as part of initial processing, larger messages are divided into several packets. Those headers inform a computer processor how to reassemble the packets, reproducing what had been sent. Vint Cerf and Robert Kahn wrote the first version of TCP/IP, and over time a large community of researchers and practitioners improved it to accommodate large-scale deployment. Useful starting points for interested readers would include Abbate (1999), Leiner et al. (2003), and Waldrop (2001). The transition from the noncommercial to the commercial Internet is explained in Greenstein (2015).

A third arrangement involves direct contracts between content providers and internet service providers, where the content providers "co-locate" their own servers inside the network of an internet service provider. Sometimes these direct contracts involve no payments; sometimes they do. Only content providers with popular content and the largest volumes of traffic choose this last option, suggesting that scale is an important consideration. In all three cases, questions often arise about who pays for investment to raise capacity for carrying data traffic.

The fact that most households have a very limited choice of broadband internet service providers adds an additional element to the policy concerns about these arrangements, motivating questions about an internet service provider's use of its market power vis-à-vis end users and content providers. As part of its 2015 Broadband Progress report for the United States, for example, the Federal Communications Commission found that a limited percentage of US households had access to a provider of broadband at 25 Mbps or more, and 20 percent had no access (Singleton 2015). Thus, an internet service provider (ISP) may enjoy a strong position in contractual negotiations with content providers, as it provides exclusive access to consumers who seek high-bandwidth services.

Have internet service providers sought to take advantage of their market status? Several recent controversies have made this question especially salient.

The Case of Bit-Torrent and Comcast. Bit-Torrent is a content provider focused on peer-to-peer file-sharing, including sharing of large files. Claims of Comcast interference with Bit-Torrent traffic had been circulating for many months, but the issue came to the forefront in 2007 when the Associated Press published a report concluding that Comcast was "throttling" Bit-Torrent traffic (Svensson 2007). Comcast claimed that it was not blocking peer-to-peer traffic, but only practicing "reasonable network management" to ensure quality service for all its subscribers. The Federal Communications Commission (2008) issued an order to Comcast for not having a "protocol-agnostic" policy—that is, a policy that applied to all content providers, not just one. Comcast altered its policies for restricting users who consume too much bandwidth (not specifically Bit-Torrent traffic), and sued the Federal Communications Commission over the scope and application of its legal authority.

The Dispute and Deal Between Netflix and Large Internet Service Providers. To accommodate growth in its streaming service, in late 2010 Netflix moved away from using Akamai's servers as its primary content delivery firm. Instead, it began streaming data through another content delivery firm, Limelight, and a backbone firm, Level3, and eventually another, Cogent. Netflix also began a program to co-locate its own servers inside ISPs. Some small ISPs agreed, with no money changing hands, but several large ISPs asked for payment for actions that reduced delays delivering data to households, such as upgrades to equipment, and for transporting data to servers with propitious locations. Users at these large ISPs began to experience delays around the middle of 2013 (with some public dispute about when this started, and why). In February 2014, Netflix and Comcast came to a deal—terms not publically disclosed—in which Netflix paid Comcast to co-locate servers inside Comcast's network. A little later, Netflix announced a similar deal with other large ISPs. Some commentators said these events illustrate a business-as-usual environment in which firms end up negotiating who will pay for certain investments (for example, Rayburn 2014). However, soon after these deals, Reid Hastings (2014), the chief executive officer of Netflix, seemed to display buyer's regret, publically raising alarms about the bargaining power of large broadband ISPs.

Data Caps and Their Exceptions. In many countries, internet service providers have adopted tiered pricing structures, in which higher bandwidth (and thus speed) comes at higher monthly expense to a household. In addition, some ISPs have adopted limits on total data usage for all users with particular contracts, which are known as "data caps." The levels and practices vary across providers, and participants hold distinct views about the consequences of these practices (Open Internet Advisory Committee 2013). Some ISPs also have adopted policies that count traffic over the public internet against the cap, but not traffic for video-on-demand using the ISP's proprietary or affiliated services. For instance, T-Mobile, a cellular provider in the United States, announced in November 2015 that it would exempt some video services such as ESPN, Netflix, and HBO from its data caps (but not others like Facebook and YouTube, for instance); however, to do so T-Mobile will stream the videos at lower quality, via a plan called "BingeOn" to which all customers are automatically opted in. Among the unresolved policy issues is whether these practices represent efficiency gains, or whether they unfairly tip the competitive landscape, raise the cost of rival services, and provide a cause for regulatory intervention.

Zero-rating Platforms. Facebook launched Free Basics in 2014, a Facebook-sponsored program that gives people in the developing world free access to cellular data for certain online services—including Facebook and WhatsApp (which belongs to Facebook). In 2015, Free Basics was available in 36 different countries, but has been temporarily banned in India while the Telecom Regulatory Authority of India sifts through public comments and explores whether the program violates the principles of net neutrality. The economics are similar to those of data caps, with the added twist that a content provider is visible as advertising and managing this program. While a "free" service is clearly good for increasing digital penetration, especially in developing countries, the biggest objection to Facebook's initiative is that it offers only a select few services chosen and controlled by Facebook, so that the platform could end up acting as gate-keeper limiting access to certain websites.

Paying for Faster Service. Orange, the largest French internet service provider, announced in 2013 that it made Google pay to deliver its YouTube traffic, though no exact figure was disclosed. The French telecommunications regulator also investigated in the same year complaints of Orange throttling against YouTube, but found no evidence of discriminatory action.

A key difference between the US and European regulatory situations is the market structure for internet service providers. European networks tend to have less concentration of broadband internet service providers, as well as less vertical integration between ISPs and content: for example, so far there is no merger in Europe equivalent to the merger of Comcast and NBC-Universal. In addition, most dominant internet content firms are based in the United States, which adds noise to every dispute concerning these issues in Europe.

While each of these events generated discussion with many legal aspects, important aspects of these debates also lend themselves to economic analysis. This is where we concentrate the bulk of our attention.

Basic Economic Analysis of Net Neutrality

A Neutrality (of Net Neutrality) Result

Let us revisit the example at the outset of this article. What happens if Comcast is allowed to charge Netflix every time that we watch a movie? The first, possibly surprising, answer that we give is this: when Comcast charges Netflix, *nothing* happens. A simple model shows how this result can arise.

Imagine an end user pays p to subscribe to Comcast and the subscription fee f to Netflix. Denote by t the "termination fee" that Netflix is asked to pay to Comcast (it is called a "termination fee" because it is the fee for bringing the content to the terminal point, that is, to the user). In this setting, Comcast and Netflix make take-it-or-leave-it offers to users and offer two services that are perfect complements. We are thus elaborating on the old issue of pricing with complementary goods, as already analyzed by Cournot (1838), enriched by side payments between the two firms offering those goods. Because broadband and content are perfect complements, the demand for both depends on the total price that an end user will have to pay. Let $q(p + f)$ denote this demand. The profits of Comcast and of Netflix are respectively given by

$$\pi_{ISP} = (p + t - c_{ISP})q$$

$$\pi_{CP} = (f - t - c_{CP})q,$$

where c_{ISP} and c_{CP} denote the per-subscriber cost to Comcast and Netflix, respectively. The two firms are free to set whatever price or subscription fee they want to for final users.

In this setting, it turns out that the payment t that flows between Comcast and Netflix does not affect margins for the firms, but only how they are earned. Remember that users face only a single total price, and that one particular level of this particular price will maximize overall joint profit for the two firms. Now imagine that Comcast tries to increase its profits by raising the termination fee t that it charges to Netflix. Netflix reacts by raising the subscription fee f that it charges to consumers to cover this change. Comcast will then react by lowering its price p so that the combined price-plus-fee charged to consumers remains at the profit-maximizing level. Indeed, as can be shown more rigorously, in this case the two firms have a symmetric position and will end up splitting the profits in half.[2] Ultimately, alterations in the termination fee change neither the bills of end users nor the profits of Comcast and Netflix. Regulation of the termination fee t would have no real economic consequences. The intuition for this is ultimately simple: There is "one price too many" in this setting, as both the internet service provider and the content provider can charge the user directly, through p and f, which means that any changes in termination fees can be easily offset.

Toward a More Complex World

This first result is not meant to end the discussion; on the contrary, the first result actually tells us that the simple model is missing several elements central to important economics trade-offs. At least four have received attention: 1) some content providers do not charge users directly, but get their money from advertising (like Facebook and Google); 2) there is considerable heterogeneity among both users and content providers, whereas the simple model deals with one content provider and one representative user; 3) we completely bypassed the "fast versus slow lane" issue, but congestion, quality of service, and network investments matter, as does investment by content providers; and 4) in some markets, multiple internet service providers compete for end users. Trade-offs are going to arise because, by introducing externalities, asymmetric information, and several dimensions of heterogeneity, often there will rather be "one or several prices too few" instead of "one price too many." To identify these trade-offs, we turn to a richer setting, although still very streamlined, that describes the internet ecosystem.

We begin with definitions for "one-sided pricing" and "two-sided pricing." To illustrate, we focus on how a single internet service provider interacts with two content providers and two end users. In two-sided pricing, the ISP can charge a subscription fee p to users and a termination fee t to content providers for delivering their content. By contrast, in one-sided pricing, the ISP can only charge a subscription fee to users. A regulatory restriction can rule out two-sided pricing.

[2] Under standard regularity conditions of the demand function, equilibrium prices are given as the solution to the first-order conditions

$$(1)\ \frac{d\pi_{ISP}}{dp} = (p + t - c_{ISP})q' + q = 0$$

$$(2)\ \frac{d\pi_{CP}}{df} = (f - t - c_{CP})q' + q = 0.$$

By adding (1) and (2) we get

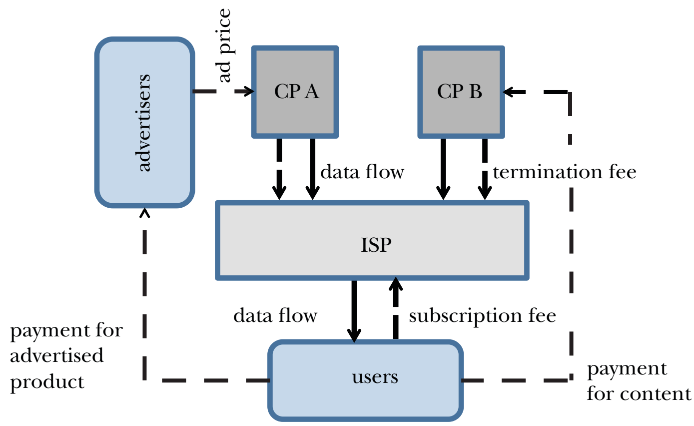
$$(3)\ (f + p - c_{ISP} - c_{CP})q' + 2q = 0,$$

which pins down uniquely the total price $p + f$ that the end user faces, together with the respective quantity q end user buys. Notice that this total price is *independent* of the per-subscriber transfer t between Comcast and Netflix. Moreover, rewriting the two first-order conditions (1) and (2), we obtain that Comcast and Netflix have the same margins,

$$p + t - c_{ISP} = f - t - c_{CP} = -q/q'.$$

Figure 1

The Interaction between Internet Service Providers, Content Providers (CPs), and Users



Source: Authors.

In this framing, net neutrality can be thought of as a requirement that the ISP provide the same service to all content providers and users, while charging a fee *only* to users.

The first-best social welfare outcome most likely involves having all content providers and end users "on board," which is to say that welfare is maximized when all content providers can contact all end users. This outcome is realistic when thinking about the internet, with its large network externalities and low marginal costs. It immediately follows that any situation which restricts participation either on the user side or on the content provider side will be inefficient, because of the decline in the size of network externalities. (This intuition also can support regulatory mandates that internet service providers must provide access to all legal content on the internet.)

Figure 1 illustrates the general situation. The internet service provider is shown as a platform that sits between users and content providers. Of course, this model is a simplification, in the sense that a more detailed diagram would show the data from the content provider moving to its own ISP, then to the "backbone" firms of the public internet, then to the end-user's ISP, and then on to the end users. The fuller picture could also include the use of content delivery networks. But this simplification helps in understanding the first-order effects. In this diagram, the dashed arrows represent the (typical) direction of payment flows; clearly, regulatory intervention may alter such flows. The content providers in this model can have differing business models. In this diagram, for instance, content provider *B* makes revenues from selling its content to end users, while content provider *A* does not charge end users, but makes revenues from advertising.

We now consider different simplified scenarios, each of which is meant to capture a different economic mechanism. The only monetary component present in every model we consider is the subscription fee p that is paid by end users to the internet service provider.

Price Structure and Rent-shifting between Content Providers and the Internet Service Provider

We first focus on the scenario that corresponds to the situation in which content providers are of type A, as depicted in Figure 1. Ad-financing of the content provider is the case, for instance, for Facebook, Google Search, YouTube, Twitter, and many other content providers who distribute "free" content. In this case, it turns out that net neutrality can affect the distribution of rents, and may therefore not be neutral in the long run, when content providers and internet service providers have to make investment decisions. Relatedly, this example supports the economic intuition that regulating termination directly shapes margins and profits for ISPs and content firms.

Consider two content providers, denoted as 1 and 2, who provide different value to end users, and both have the same ability to generate profits R per user from advertising. If the two end users have identical tastes, the user valuation of the service from an internet service provider depends on which content is available. Also we will assume that advertising does not affect the end users' utility.[3] Suppose that content provider 2 provides more interesting or higher-quality content than content provider 1. The value of content from content provider 1 is equal to 1 and the value of content by content provider 2 is equal to $v > 1$.

Now, contrast one-sided and two-sided pricing. If the internet service provider is restricted to using a one-sided pricing strategy, it sets $p = v + 1$ and extracts the full expected surplus on the user side. The outcome is efficient. In contrast, with two-sided pricing, the monopoly ISP continues to set $p = v + 1$ for users and, in addition, charges a termination fee $t = R$ from content providers, where R is the rent that content providers would have received under one-sided pricing. End user choice is not affected, and, in this simple example, the profits of content providers and ISPs change by equal amounts in opposite directions. In other words, two-sided pricing leads to a redistribution of rents between content providers and the ISP.

The "Waterbed Effect"

The ability of internet service providers to charge termination fees to content providers for delivering their content raises an important question for policy: does a positive termination fee lead to an equal reduction in prices to users? The economic

[3] To simplify the interaction between advertisers and users who buy the products advertised on the internet, we will assume that advertisers extract the full surplus in the advertiser–user relationship and that users are neutral to advertising. Thus, we do not need to introduce consumer surplus from the advertised products in the welfare analysis.

intuition resembles common arguments about "pass-through" and in this context goes by the label "the waterbed effect."

To illustrate, consider the situation in which the two content providers are identical, but users differ in their willingness to pay a subscription fee, which results in an elastic demand for access to the internet service provider. Thus, only some users may be willing to subscribe if the fee is high. When an ISP decides to charge a content provider for the (prioritized high-speed) traffic it generates, one may conjecture that the subscription fees paid by end users will decrease.

This result is obvious if the internet service provider is in a competitive setting, because its overall profits, from every source, are held to a normal level by the competitive process. However, the same result also holds for internet service providers with market power. If content providers are charged more, subscription fees will decrease because of the two-sided nature of the market. This will be to the advantage of end users, an aspect which is sometimes forgotten in the policy debate.

To develop some intuition for this result, consider the adjustment of prices on the user side with a monopoly internet service provider. Suppose that the two content providers are identical and can generate profits from advertising equal to R. Let the value of content for the first user be 1 for each content provider (and thus 2 overall). The corresponding value for the second user is denoted as $v > 1$ (note that 1 and v have now a different meaning than in the previous example). If the ISP is restricted to use a one-sided pricing strategy, it sets either $p = 2$ or $p = 2v$. In the former case, both users subscribe; in the latter case only the second user does so. It is profit-maximizing for the ISP to serve only the second user if $v > 2$, because the fee that it can charge to the second user more than compensates for the loss of the first user. The ISP uses its market power to raise the price such that some users (here user 1) prefer not to participate. In this case, the allocation is inefficient.

Now consider two-sided pricing. The internet service provider optimally charges the content provider a termination fee of $t = R$ to deliver content to each user. Thus, profits of the ISP on the content provider side are $4R$ if all content is delivered to all end users (since total transactions are 2 content providers × 2 users = 4 transactions) and $2R$ if all content is delivered to only one user. On the user side, the ISP again sets either $p = 2$ or $p = 2v$. In the former case, its overall profits are $4(1 + R)$ and in the latter $2(v + R)$. Thus, under two-sided pricing it is optimal for the ISP to set $p = 2$ and both users subscribe if $v \leq 2 + R$. Otherwise, $p = 2v$ and only user 2 subscribes.

Comparing one-sided to two-sided pricing, we see that users behave differently across the two regimes if $2 < v \leq 2 + R$. Here, a regulatory intervention to set $t = 0$ leads to a price *increase* on the user side from 2 to $2v$. This exemplifies a "waterbed effect," which refers to a situation in which pressure on one side of the market leads to a corresponding change in prices on the other side of the market—as when pushing on one side of a waterbed causes a bulge to appear elsewhere. In this case, a higher termination fee results in a lower subscription price p for end users. In the present example, restricting internet service providers to one-sided pricing reduces total welfare and reduces the surplus received by the user, while content providers benefit from this regulatory intervention.

What economic mechanism is at work in this example? Given the opportunity to charge the content provider for termination, the internet service provider is more willing to decrease the subscription fee to end users, precisely because more end users can be attracted to join the platform, resulting in more transactions with content providers that are profitable for the ISP too. Net neutrality, instead, cuts all profits from content providers for the ISP, which is therefore not interested in generating additional traffic from them. This generates inefficiencies when it is more profitable to make more money from fewer subscribers.[4]

This illustration about waterbed effects can also help us understand why two-sided pricing is not always superior to one-sided pricing. Consider a similar situation, with two identical end users, but now allow content providers to generate different levels of profits from advertising, as occurs when content providers differ in their ability to engage users. In particular, content provider 1 generates profits from advertising, while content provider 2 generates profits R_2, with $R_1 > R_2$. The willingness to pay for content is 1 for each user and any content. How do one-sided and two-sided pricing compare?

Under one-sided pricing, the internet service provider charges $p = 2$ to each user and the allocation is efficient. Under two-sided pricing, the ISP sets $p = 1$ and $t = R_1$ if $R_1 > 2R_2 + 1$; otherwise it sets $p = 2$ and $t = R_2$. In the former case, the ISP is willing to sacrifice the delivery of content by content provider 2 despite also obtaining less from users, because of the incentive to extract rents from the content provider that generates the largest advertising profits. The resulting allocation under two-sided pricing is inefficient, as one of the content providers is excluded.[5] Due to the heterogeneity among content providers, the ISP might actually find it attractive to restrict access of some content providers, as a way to extract more money from giving termination to those content providers with a higher willingness to pay.[6]

[4] Note that, if the ISP could price discriminate and offer them different prices, user 1 would pay $p_1 = 2$ and user 2 would pay a higher price $p_2 = 2v$, both with and without net neutrality. In that case, there would be no real economic effects. Once again, with sufficiently "many prices," we would have a neutrality (of net neutrality) result.

[5] A very similar result emerges if the two content providers are identical but their advertising profits depend on the number of active content providers. If $R(m)$ denotes profits from advertising when m content providers are active, competition for advertisers among content providers implies that $R(1) > R(2)$. The analysis then is in line with the one in the previous example $t = R(1)$ and under two-sided pricing if $R(1) > 2R(2) + 1$. As a result, two-sided pricing here leads to less content in equilibrium and an efficiency loss compared to one-sided pricing. For a formal analysis of exclusive access as a means to reduce competition among content providers for advertisers, see Kourandi, Krämer, and Valletti (2015).

[6] Also here, with sufficiently "many prices," the earlier "neutrality (of net neutrality)" result would be at work. If the monopolist could perfectly target each advertiser, it would set $t_1 = R_1$ for content provider 1 and a lower $t_2 = R_2$ for content provider 2. Everybody would be on board, reaching the same level of welfare with and without net neutrality.

The trade-off between charging more to content providers or users has a clear economic intuition: one-sided pricing is welfare-superior if heterogeneity among content providers is particularly pronounced, whereas two-sided pricing is welfare-superior if heterogeneity among end users is particularly pronounced. In the former case, one-sided pricing tends to lead to more content providers being active; in the latter case, two-sided pricing tends to lead to more users enjoying content. How the trade-off plays out for end users crucially depends on the size and incidence of the waterbed effect in the presence of market power—that is, how much would allowing or eliminating a termination fee affect the price charged to subscribers. This is an open empirical question.

In many respects, it is a familiar question for economists, potentially lending itself to empirical analysis of the "pass-through" between termination fees and user rates.[7] Pass-through analysis is common in empirical studies of international trade and taxation. However, that alone would not be sufficient to settle arguments about the trade-offs, and the lack of experience with use of termination fees in practice makes this more of a forecast than an estimate on past behavior.

When Content Providers Charge End Users

The economic modeling becomes more challenging when content providers have direct relationships with end users and charge them a subscription fee. This market practice is becoming common among streaming firms and providers of "over-the-top" services, such as Amazon Prime, Netflix, YouTube Red, and subscription television services. The economic insights in this situation are sufficiently ambiguous that economists should be wary of advocates making bold policy prescriptions in favor of two-sided pricing or one-sided pricing when content firms offer subscriptions.

In general, with both one-sided and two-sided pricing by the internet service provider, we should expect inefficient outcomes, as both content providers and the ISP want to charge users for the complementary services they offer.[8] Moreover, the extent of the (in)efficiency of two-sided pricing (in comparison to one-sided pricing) depends crucially on whether an ISP can charge distinct termination fees to different content providers, and whether content providers have an ability to pass on the termination fees charged by ISPs. When ISPs can tailor termination fees to each content firm, then they have an instrument for "taxing" every content firm and extracting surplus, which will be passed on to users if content firms can do so. Thus tailored termination fees tend to lead to more efficiency.

More realistically, without the ability of an internet service provider to tailor fees in this way, then inefficiencies will arise, as any termination fee will induce exits

[7] For a formal treatment, see Armstrong (2006) and Weyl and Fabinger (2013). Empirical evidence of the "waterbed" effect is provided by Genakos and Valletti (2011, 2015) in the context of cellular phones.
[8] This feature was already present in our baseline example; for example, as summarized by Equation 3 in footnote 2. An efficient outcome would imply that the total price should be equal to marginal costs $c_{ISP} + c_{CP}$; instead Equation 3 says that there is a mark-up above such costs. The relevant question is therefore whether this inefficiency is more severe with or without net neutrality.

(from content firms) that would not have arisen in one-sided pricing.[9] In that case, one-sided pricing can outperform two-sided pricing when content providers make their revenues from charging end users and users differ in their willingness to pay for content. The intuition appeared in prior discussion: if an ISP cannot perfectly price discriminate across its users, it does not have incentive to account for the additional gain to users from access to additional content.

Contracting with Externalities

Stepping back from the details, we can observe a pattern in the analysis so far. The cases above are examples of situations where parties are "contracting with externalities." An internet service provider may increase bandwidth to subscribers without taking into account the advertising revenues that will accrue to content providers, who deliver content to such subscribers. Similarly, a content provider may introduce new applications desired by subscribers without taking into account the effect this has on the rents the ISP can extract. With suitably many payments (and symmetric information) between the parties, mild forms of regulation would be neutral in this setting: that is, relative prices might change, but not total prices paid/received by the parties involved—and regulation has little or no impact on final allocations.

Certain forms of neutrality regulation can lead to real effects, namely, when they impose sufficiently binding constraints on the contracts between internet service providers, users, and content providers. For instance, when prices are required to be uniform or zero between two types of parties, then numerous inefficiencies arise, as we demonstrated with the examples in the previous section (see also Gans 2015).

It is an unresolved question which type of economic effect dominates in practice. The analysis indicates the challenge for addressing the issue. Which insights are most empirically relevant in an environment where content firms use a mix of advertising and subscription models for generating revenue? Moreover, if regulators do impose strong constraints on contracts between the players in internet access markets, it becomes difficult to learn what pricing structures would arise in an alternative situation, for example, if parties had been permitted to negotiate.

[9] Let us revisit the example with ad-financed content providers, in which content providers generate different values for users. Imagine the content providers commit to their fees before the monopoly ISP sets its prices. (However, content providers do anticipate the pricing by the ISP.) As we will see, from a welfare perspective, one-sided pricing now tends to outperform two-sided pricing. Suppose that the user's willingness to pay for content by content provider 1 is equal to 1 and the willingness to pay for content by content provider 2 is equal to $v > 1$. Then, content provider 1 optimally sets $f_1 = 1$ and content provider 2 sets $f_2 = v$ irrespective of whether the ISP is required to use one-sided pricing or is allowed to engage in two-sided pricing. With one-sided pricing, the ISP cannot make a positive profit and sets $p = 0$; the allocation is efficient as both content providers would be active. With two-sided pricing, the ISP either decides to set $t = 1$ and $p = 0$ or $t = v$ and $p = 0$. With the former strategy, its profit is equal to 4 and with the latter, $2v$. If $v > 2$, the ISP optimally uses the latter strategy, content provider 2 prefers not to participate, and the allocation becomes inefficient. This model assumes that the ISP must set a nondiscriminatory termination rate—that is, the same for both content providers—which makes participation of the low-quality content provider unattractive.

Broadening the Model: Congestion, Investment, Competition

The discussion to this point has been heavily focused on choices about price-setting in different sets of circumstances. However, several important economic trade-offs are missing. Price setting interacts with the quality of service when networks regularly suffer congestion, for example. Congestion can be exacerbated by lack of investment, or by the (presence or absence of) rules governing prioritization of traffic. When incorporating investments, long-term trade-offs come into play.

These long-term trade-offs depend on the competitive setting, both horizontal competition (between internet service providers) and vertical competition (between ISPs integrated into content and other content providers). While these long-term issues are standard issues in industrial organization, setting them in a data network gives rise to novel trade-offs and concerns.

Congestion: Static Effects

The presence of potential congestion can result in some internet traffic being delivered with delay, making it potentially valueless. Standard economics suggests a strong analogy here with pricing automobile traffic congestion. However, the discussion above suggested the potential for a missing price. Thus, in a world of second best, interesting economic trade-offs should arise.

To begin, recognize that some types of traffic lose their value with delay (like Skype calls) while other types do not (downloading large files with BitTorrent). Delaying the latter would cause little social cost, as the material is not very time-sensitive, and the principal cost of delay is inconvenience. Some form of time-of-day pricing could induce delaying traffic until nonpeak hours, although such congestion pricing would be at odds with the strictest net neutrality requirements. Appropriate peak pricing could give incentives to users (in particular, content providers) to reduce congestion, and this should be welfare-enhancing if capacity is provided with priority to high-value traffic.

Time-of-day pricing was common during the era of dial-up internet service providers, but it is not common in the broadband era. One puzzle is why broadband carriers have not initiated experiments with such programs, especially in the era prior to political lobbying for net neutrality regulation.

Because congestion tends to arise only during peak load hours, a more controversial question concerns treating content providers unequally during such hours. Some carriers have proposed keeping a "slow lane" for free, while allowing for a paid-for "fast lane."

There are still few contributions that consider the impact of net-neutrality policies on high-volume and time-sensitive traffic (exceptions include Choi, Jeon, and Kim 2015a, 2015b; Peitz and Schuett 2015). The potential for efficiency gains arises because rationing traffic could lead to better performance for time-sensitive traffic in times of congestion. Whether users are better off depends on whether those gains outweigh the potential distortions that arise. As with the discussion above, the distortions depend crucially on the ability and incentives of the content provider to pass on to users the price for prioritized delivery, and the incentives of the ISP to adjust the subscription fee on the user side.

A major policy concern for prioritization is whether internet service providers manipulate congestion in self-interested ways that lead to (un)desirable outcomes. For example, Choi and Kim (2010), using a queuing model for traffic, illustrate how prioritized access could serve as a rent-extraction device.[10] In other words, the ISP engages in "menu pricing" (or second-degree price discrimination) by offering a choice between price plans, which lets content providers sort themselves by their choices. Prioritization then gives a "too large" market share to the content provider that opts for priority, while it would be socially preferable to have more equal shares and more content provision.

Economides and Hermalin (2012), considering a fixed pipe for time-sensitive traffic transmitted in times of congestion, find that charges for prioritized access can serve as a price-discrimination device. In their setting, the internet service provider extracts considerable surplus, which may lead to too little content provision. The analysis is reminiscent of the properties of third-degree price discrimination, insofar as welfare increases under the regime that allows a greater amount of content to be consumed.

Investment and the Dirt Road

Public debate has expressed a concern that, in the absence of net neutrality, an internet service provider might benefit from strategically degrading the quality of the nonpriority lane in order to drive traffic to a paid-for prioritized lane. In popular discussion, this possibility sometimes goes under the heading "fast lane versus the dirt road."

Economic analysis acknowledges distinct policy concerns. One set of concerns about the dirt road builds on a standard model of endogenous quality selection from a monopolist provider. When internet service providers offer multiple tiers of services and prices, a monopolist ISP could face incentives to shade the quality of lower-quality products in order to give incentives to users to upgrade to higher margins for the higher-quality products (Mussa and Rosen 1978). This incentive could manifest itself as lower investment in the capacity of lower-tier service, which users would experience as constrained capacity. Importantly, most practical net neutrality proposals permit tiered services to users, and, therefore, do not alter this incentive.

Additional policy concerns arise from selling prioritization to content providers for delivering data to users. Because monopoly providers of access to users may be the only channel through which content providers can reach users, internet service providers have incentives to invest in ways that raise the value of the prioritization

[10] Specifically, they employ the so-called M/M/1 queuing system, which is also used in other studies like Krämer and Wiewiorra (2012) and Bourreau, Kourandi, and Valletti (2015). This queuing system is considered a good proxy for actual congestion: 1) the total number of Internet users is large; 2) each user has a small impact on congestion; and 3) all Internet users can be assumed as independent. In reality, packets move through a complex network of routers, but economic models have abstracted from this.

sold to content providers. For example, Choi and Kim (2010) argue that the ISP may have *less* incentive to invest in network expansion in a regime with prioritization, because by doing so it can create scarcity that makes content providers more desperate to obtain priority. An ISP might benefit from strategically degrading (at least in relative terms) the quality of the nonpriority lane in order to extract higher profits from the priority lane. Bourreau, Kourandi, and Valletti (2015) argue that this risk of fast lane/dirt road is present even with competing ISPs.

Innovation introduces an additional dimension into this debate. A certain level of "quality of service" (performance of the network), may be needed to make innovative services by content providers feasible: for example, guaranteed delivery quality may be a key factor to make socially valuable major innovations in interactive e-learning, e-health care services, and e-mobility in the form of autonomous vehicles. In that case, a regime of fast and slow lanes allows internet service providers to extract additional revenues from content providers through priority fees. It is possible that innovation in content provider services will also increase: some highly congestion-sensitive applications, which were left out of the market under net neutrality, would enter when applications can make deals for high-priority lanes (Bourreau, Kourandi, Valletti 2015; Krämer and Wiewiorra 2012).[11]

One additional policy implication deserves to be mentioned: initiative by a regulatory authority to monitor traffic quality can help avoid the fast lane/dirt road problems by enforcing a minimally required floor. On a related note, if regulation of traffic quality is too complex or costly for the regulatory authority to monitor, a net neutrality regime might be a useful policy to avoid quality degradation of the traffic for nonpriority content providers.

Economic analyses on investment and network neutrality have mainly focused on the expansion of network capacity by internet service providers. However, an expansion of capacity by ISPs is not the only solution to resolving congestion problems. Major content providers such as Google, Netflix, and Amazon have developed other measures, such as advanced compression technologies, to ensure a sufficient quality-of-service. They have also deployed or rented content delivery networks. That raises the question of whether prioritized delivery and other investments in quality-of-service are substitutes or complements, which remains an important unresolved question. Choi, Jeon, and Kim (2014) take first steps in addressing it, by showing how the result depends on whether the ISP has a large or small installed network capacity.

One often hears the concern that strict net neutrality rules would help small innovative firms because large content providers are better able to pay for

[11] As noted by several writers, however, the opportunity cost of such services may be the underinvestment in public access networks, discouraging investment brought by entrepreneurial services that use the public network (Bourreau et al. 2015). The question then is the following: if the internet service provider can charge on the content side, and earns greater total profit by doing so, will it invest more in equilibrium (because it can appropriate a greater share of the surplus generated by the investment) or invest less (because the content side invests less)? According to Reggiani and Valletti (2016), there is a complementarity between investment by ISPs and total investments on the content provider side.

prioritization. However, as large content providers have other means to deal with the congestion issue, it may instead be the small innovative firms which need the possibility of prioritized access, because it does not require larger forms of up-front investments which they can ill afford.

Competition and Bottlenecks

It is often argued that spurring competition between internet service providers can remove the need for a regulatory approach to net neutrality. For example, the European Commission (2011) stated that "the significance of the types of problems arising in the net-neutrality debate is correlated to the degree of competition existing in the market." In the United States, the Federal Communications Commission in a 2010 ruling exempted mobile networks from most of the net neutrality rules, on the grounds that they face stronger capacity constraints than fixed networks, and that competition at least mitigates any negative effects of a departure from net neutrality.

Would introducing more competition eliminate the need for net neutrality regulation? This is an open question because few models address how bargaining between internet service providers and content providers changes when some of an ISP's users face competitive alternatives. For example, is the threat by some users to move between ISPs sufficient to alter an ISP's pricing and investment activity? What is the biggest competitive consequence from an ISP becoming larger through merger? Does it hamper the prospects of potential entrants or does it increase its strength when negotiating with content providers?

Recent theory contributions generally support the idea that lifting net neutrality regulation on competing platforms is welfare-increasing (Krämer and Wiewiorra 2012; Bourreau, Kourandi, and Valletti 2015). However, this outcome does not arise because competition reduces the incentives of ISPs to discriminate between content providers. In these models, each ISP has a unilateral incentive to introduce a priority lane, no matter what its rival does. Thus, price discrimination on the content provider side continues to be present. What then is the reason for the welfare gain? In a situation where end users subscribe to only one ISP (that is, they "single-home"), there is fierce competition for end users among ISPs when the ISP is allowed to charge content providers. The overall effect of more competition tends to be a better deal for users and lower overall price distortions. An increase in competition makes the ISP's firm-specific demand on the user side more elastic, but does not make much difference to the ISP's firm-specific demand on the content side (which is inelastic so long as end users single-home).

The exercise of monopoly power over content providers arises independent of competition for end users under two-sided pricing. This "termination bottleneck" problem is common in traditional telephony regulation (see also Economides and Tåg 2012). The problem is less pronounced if the content provider can reach some users on multiple platforms (that is, if some end-users "multi-home") or if the content provider has bargaining power so that it can negotiate its termination fees with the internet service provider (Armstrong 2002).

Competition and Vertical Issues

Internet service providers can decide to integrate into services other than delivery of data, like video on demand. There are two key questions for economic analysis of net neutrality. First, under what condition does vertical integration reflect some efficiency rationale, thus improving the experience of users? Second, in which circumstances does it lead to harm to the competitive process because users cannot access alternative content providers, who compete on an "uneven playing field?"[12] Once again, the economics of this topic depends mostly on speculative forecasts about carrier behavior, user elasticities, and content provider incentives, and not much in the way of regulatory case experience.

The economic arguments for efficiency in this setting are not unique to the net neutrality debate. At least in theory, when content providers and internet service providers offer complements, vertical integration may reduce prices, as absent integration neither party internalizes the profit loss inflicted on the other party by raising its price. Also, vertical integration may reduce the underinvestment that arises with independent parties, as the investment generates benefits for the firm producing the complementary product. The magnitude of these gains in practice is unclear, but the empirical literature from other industries identifies many examples of efficiency gains from vertical integration (Lafontaine and Slade 2007).

Anticompetitive concerns arise because an internet service provider may offer its own services and charge termination fees for competing content providers, potentially leading to partial or full exclusion. For example, Netflix's customers may use Comcast's network to download videos from Netflix, while Comcast also sells video services delivered through cable television. Similarly, both telecom and cable ISPs provide their own phone services that are also supplied by independent voice-over-IP providers such as Skype or Vonage. Without network neutrality rules (or interventions based on general competition law), ISPs may favor their own services and use price and possibly nonprice instruments to reduce competition.

A related concern about "uneven playing fields" arises in situations where internet service providers impose data caps on use. As stressed in the earlier discussion, caps arise as part of tiered pricing.[13] Data caps also shape competition between content providers. Data caps create an artificial scarcity, making users perceive different digital products from different content providers as substitutes (for scarce space within the cap). Thus, the cap "heightens" the degree of competition

[12] A notable example is the case regarding Madison River, a small telephone company accused of blocking ports used for voice-over-internet (VoIP) applications, thereby affecting customers' ability to use VoIP through one or more VoIP service providers. See "In the Matter of Madison River Communications, LLC and affiliated companies" (FCC 2005).

[13] For an economic estimate of the behavioral consequences of such caps, see Nevo, Turner, and Williams (forthcoming). They show that caps imposed on end users have important allocative effects. However data limitations do not allow them to consider unequal treatment of traffic from different sources, which remains an important area for further research (for a first step see Nurski, 2014, using UK data). See also Jullien and Sand-Zantman (2016) for a formal treatment.

experienced by content providers, who might otherwise have been able to differentiate from competitors satisfying heterogeneous user tastes (Economides and Hermalin 2015). If the ISP is allowed to charge the content provider directly for a priority lane, then an ISP may be able to raise its profits further with the "heightened" competitive setting, inducing content providers to bid more for the fast lane than they otherwise would have done in the absence of a cap.

One other concern with caps is their scope. Some internet service providers have adopted policies to exempt traffic for their own services in a policy known as "zero-rating." Simple general conclusions are hard to state because of the variety of situations. As one example, in 2012 Comcast exempted Xfinity app use from its data cap when watching through Xbox (Open Internet Advisory Committee 2013, Appendix 1, pp. 35–38). Other content providers raised questions about whether exemption of some traffic created an uneven playing field, while carriers claimed the practice generated efficiency gains. As a second example from a very different setting, some carriers have considered supplying a free bundled service to a wireless broadband subscription, such as a Spotify Premium for subscribers to T-Mobile. If a carrier cannot exempt its own service, is it permitted to do so with a business partner? A third example also raises issues about universal service. Zero pricing may seem to offer "free" services—often in the context of free access to a limited version of the internet for the poor. Does expansion of use provide a benefit that merits less concern about the competitive effects, or not?

Conclusion

Net neutrality has been on the agenda of policymakers and in the news in recent years. The Federal Communications Commission (2010) adopted is first order on this subject in November 2010. Its most recent order came in early 2015 (available at https://www.fcc.gov/document/protecting-and-promoting-open-internet-nprm). It covers three distinct areas of the behavior of a broadband internet service provider: rules to limit the right to block traffic; rules defining minimal transparency requirements for internet service providers; and rules for limiting discriminatory treatment of traffic. Both the precise meaning and the legal status of the 2015 order remain unsettled. Many regulators around the globe continue to debate how to implement these rules.

Economics has always had much to bring to the debate involving the provision of services that require high fixed costs and result in prices above variable expenses, so economic analysis on net neutrality can build on prior thinking. There are, however, a number of open research questions in this setting because the situation involves multiple participants in complementary economic relationships where they share the costs and benefits of actions, and users benefit from improvement and investment. It should come as no surprise, therefore, that the thrust of the conclusions from economic analysis tilt against simplistic declarations in favor or against net neutrality. This suggests that bold and sweeping recommendations and interventions, given the current state of empirical knowledge, have a substantial chance of being misguided.

■ *None of the authors has any financial stake in matters related to net neutrality policy. Greenstein served on the Open Internet Advisory Committee in 2013, and in 2014–1015 as special economic consultant to the Federal Communications Commission in the Comcast/TWC merger. Peitz has served as an economic expert for the German Federal Ministry of Economic Affairs on net neutrality from 2010 to 2012 and on a regulatory framework for the digital economy since 2015. We thank Jonathan Baker, Jay Pil Choi, Joshua Gans, Jan Krämer, Florian Schuett, and the editors for comments. We especially thank Timothy Taylor for very useful and detailed suggestions. The opinions are our own, and we are responsible for all remaining errors.*

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