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The Welfare Impacts of Broadband Network Management: Can Broadband Service Providers be Trusted?

George S. Ford, PhD
Thomas M. Koutsky, Esq.
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The Welfare Impacts of Broadband Network Management: Can Broadband Service Providers be Trusted?

George S. Ford, PhD†
Thomas M. Koutsky, Esq.*
Lawrence J. Spiwak, Esq.‡

Abstract: The extent to which broadband Internet service providers can engage in "reasonable traffic management" when faced with potentially congestion-causing applications like BitTorrent or other file-sharing applications is currently the subject of heated debate. This PAPER provides a formal economic analysis of the likely welfare consequences of broadband Internet network management that is directed at controlling network congestion. We show that it is socially desirable to charge a congestion premium or utilize other traffic management techniques when congestion-causing applications impose a congestion externality and degrade the experience of other users. The most efficient traffic management actions would be targeted at applications that cause congestion externalities and not upon all applications generally. The model also suggests congestion externalities caused by applications may vary depending upon network capacity constraints and protocols. As a result, assessment of the reasonableness of network management practices is most logical on a case-by-case basis rather than imposition of a single "bright-line" test. Instead, our model indicates that if it is shown that a congestion externality is present and that a traffic management tool directly remedies that externality, it is appropriate to presume that this type of traffic management by a private firm is legitimate and welfare enhancing.

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† Chief Economist, Phoenix Center for Advanced Legal & Economic Public Policy Studies.

* Resident Scholar, Phoenix Center for Advanced Legal & Economic Public Policy Studies.

‡ President, Phoenix Center for Advanced Legal & Economic Public Policy Studies.

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I. Introduction

A core principle of the regulatory concept of Network Neutrality is the idea that consumers of broadband Internet service should have unimpeded access to Internet content. In a POLICY STATEMENT released in 2005, the Federal Communications Commission ("FCC") embraced this idea, stating that "consumers are entitled to access the lawful Internet content of their choice."[1] Significantly, this liberal access is not unfettered, since the agency limits its policy to "legal content" and, more critically, specifically allows broadband service providers to engage in "reasonable network management."[2] To this end, the purpose of this PAPER is to provide a formal economic analysis of the likely welfare consequences of network management that is designed to control network congestion. Our focus is upon the presence of *congestion externalities*—that is, the use of applications by some users that reduce the value of broadband service to other users on the broadband network, without compensation, by causing delays or other service quality problems.

The theoretical model presented in this PAPER reveals that in the presence of a congestion externality, network management—including, but not limited to, the differential treatment of particular applications—is welfare enhancing. This finding is hardly revolutionary, as targeted solutions to congestion have been a staple of transportation economics for decades and were proposed for the

1 POLICY STATEMENT, Federal Communications Commission, FCC-05-151 (Sep. 23, 2005) ("POLICY STATEMENT").

2 *Id.* at n. 15.

Internet a decade ago.[3] Where our analysis contributes most significantly to the "reasonable network management" debate is the formal recognition that congestion imposes a *negative* externality on Internet subscribers. Linking congestion to externalities is noteworthy, since it is well known from economic theory that private firms may respond inadequately to externalities.[4]

Externalities are, in fact, the logical basis for many governmental interventions into markets, including environmental regulation, zoning laws, and education policy. Indeed, with regard to broadband networks, many organizations and individuals that have called for the regulation and subsidization of broadband deployment argue that private firms will fail to incorporate the full social benefits of broadband (i.e., "positive" externalities) into their investment calculus.[5] That is, so their argument goes, government intervention is required because private investment decisions are based only on what benefits can be turned into profits and do not fully consider the social welfare benefits of those investments.[6] The same argument has been the basis for

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3 Nobel Prize-winning economist William Vickery of Columbia pioneered the field of congestion pricing for transportation, having first proposed it for the New York Subway system in 1955, and also established the welfare benefits of responsive pricing by public utilities. *See generally,* R. Arnott, K. Arrow, A.B. Atkinson, and H.D. Jacques, eds., PUBLIC ECONOMICS: SELECTED PAPERS BY WILLIAM VICKERY (1996), ch. 14-16. For application of these principles in the context of the Internet, *see* R. Bohn, H. W. Braun, and S. Wolff, *Mitigating the Coming Internet Crunch*, San Diego Super Computer Centre (SDSC) (1993) (available at: ftp://ftp.sdsc.edu/pub/sdsc/anr/papers/precedence.ps.Z); J. K. MacKie-Mason, L. Murphy, and J. Murphy, *Responsive Pricing in the Internet*, In Bailey, J. P. & McKnight, L. W. (eds.) INTERNET ECONOMICS (1997).

4 This point is discussed in most general economics texts. *See, e.g.,* D. W. Carlton and J. M. Perloff, MODERN INDUSTRIAL ORGANIZATION (2005) at 82-3; P. R. G. Layard and A. A. Walters, MICROECONOMIC THEORY (1978) at 189-95; R. J. Carbaugh, CONTEMPORARY ECONOMICS: AN APPLICATIONS APPROACH (2006) at 188-91.

5 *See, e.g.,* L. Lessig, *Why Your Broadband Sucks*, WIRED (Mar. 12, 2005); R. D. Atkinson, *Framing a National Broadband Policy*, 16 COMMLAW CONSPECTUS 146 (2007); Florida Municipal Electric Association, *The Case for Municipal Broadband in Florida*, White Paper (Undated)(available at: http://www.baller.com/pdfs/fmea_white_paper.pdf).

6 We present evidence of this underinvestment in G. S. Ford, T. M. Koutsky and L. J. Spiwak, *The Efficiency Risk of Network Neutrality Rules*, PHOENIX CENTER POLICY BULLETIN NO. 16 (May 2006) at 9 ("… the hurdle for beneficial investment to the firm is higher than the hurdle for beneficial investment for consumers and society. Thus, the model indicates that, if anything, the firm's incentive to invest in cost-reducing intelligence is too low from a consumer and social perspective. As such, policymakers should be more concerned with the prospect for too little and not too much investment in cost-reducing network intelligence.").

billions of dollars in subsidies for Research and Development in the U.S. and abroad.[7]

If firms do not respond adequately to positive externalities, however, then would not the same be true of negative externalities? We show in this PAPER that similar to the positive externality case, when viewed from a social welfare perspective, firms do too little to reduce the harmful effects of negative externalities caused by network congestion.[8] Accordingly, those who argue that the FCC needs to impose *per se* prohibitions against network management practices because broadband providers will always be "too aggressive" in clamping down on uses of their network have it precisely backward, their error being a direct consequence of failing to recognize that congestion imposes an externality on users.[9] Furthermore, when we observe private firms engage in highly aggressive network management practices to alleviate the impact of congestion—whether via price or other measures—the congestion externality in question is, in fact, larger than society would prefer. As a result, once it is shown that a congestion externality is present and that the traffic management technique alleviates that congestion, it would be appropriate to presume that this type of traffic management by a private firm is legitimate and welfare enhancing.[10]

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7 For research and development, the argument dates back (at least) to K. Arrow, *Economic Welfare and the Allocation of Resources for Invention*, in THE RATE AND DIRECTION OF INVENTIVE ACTIVITY (1962) at 609-25.

8 By "too little" we mean that a right-minded regulator (one that maximizes social welfare) would respond more aggressively to congestion than do profit-maximizing firms.

9 For example, Free Press *et al.* have asked that the FCC affirmatively declare that "discriminating against applications is not reasonable network management." Reply Comments of Free Press, Public Knowledge, *et al.*, WC Docket No. 07-52, CS Docket No. 97-80 (Feb. 28, 2008) ("Free Press Reply Comments") at 4. This position is non-categorical and seeks to outlaw all traffic management tools that directed at any particular application.

10 This failure to recognize that congestion imposes an externality on users is consistently found in those proponents of network neutrality who argue that broadband providers are too aggressive in the management of congestion and call for *per se* prohibitions against all network management practices. For example, in their petition to the FCC regarding Comcast's treatment of BitTorrent traffic, Free Press and others assert that "no economic argument supports the notion that degrading applications is reasonable network management." In particular, Free Press asserts that "the transaction costs" of metered Internet usage "must not be prohibitively high" because bandwidth use is metered in Australia. As a result, Free Press states that blocking or degrading applications should be prohibited that that network providers simply rely on other options—such as setting "dynamic quotas" on bandwidth for end users, "charge by usage," "provide more

(Footnote Continued. . . .)

Our PAPER is organized as follows. Section II focuses upon the impact of *congestion externalities* upon broadband networks. We demonstrate that when a congestion externality is present—that is, if one's use of the broadband network (like a file-sharing application) adversely impacts the value of the network to other users—consumer and social welfare can be increased if those congestion-causing applications or users are assessed a *congestion premium* designed to reduce the use of such applications.[11] Logically, such actions are more likely to enhance welfare if the congestion premium is directed towards the specific application or users that cause the congestion externality; as a result, differential treatment of certain applications or uses is socially desirable when there is congestion.[12]

In Section III, we outline some policy implications of our approach and conclusions. Because of the impact of congestion externalities, our analysis shows that the most welfare enhancing traffic management tools may be those that are most targeted at those externalities. In addition, congestion externalities may vary considerably by application, and they may be particularly large on certain networks or particular network architectures. As a result, what constitutes "reasonable" network management is apt to vary depending upon the application at issue and also across networks. As a result, assessment of

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bandwidth to all users," or "actually offer high symmetric bandwidth speeds." Free Press, Public Knowledge *et al.* Petition for Declaratory Ruling, CC Docket Nos. 02-33, 01-337, 95-20, 98-10, GN Docket No. 00-185, CS Docket No. 02-52, WC Docket No. 07-52 (filed Nov. 1, 2007) (hereinafter "Free Press Petition") at 29-32. *See also*, R. Frieden, *Wireless Carterfone: A Long Overdue Policy Promoting Consumer Choice and Competition*, Working Paper, New America Foundation (2008) (available at: http://www.newamerica.net/files/Wireless_Carterfone_Frieden.pdf); C. Holohan, *Time Warner's Pricing Paradox: Proposed Changes in the Cable Provider's Fees for Web Use Could Crimp Demand for Download Services and Hurt Net Innovation*, BUSINESS WEEK (Jan. 28, 2008).

11 A "congestion premium" can be one of several network management actions, ranging from imposing a specific additional price to run a particular application (which me model here) to more aggressive actions like traffic shaping.

12 Indeed, one study of Internet traffic patterns in Japan has shown that 10% of all users account for 60-90% of all traffic by means of peer-to-peer applications, and that of that set of "P2P" users, only 10% account for 60% of all P2P traffic. *See* H. Saito, *Network Management Issues in Japan* (Feb. 29, 2008) (available at: http://igrowthglobal.org/data/images/saito%20networkmgmt.pdf) at 6. Even though use of congestion-causing applications and bandwidth by consumers is widely disproportionate, many argue that broadband service providers should be prohibited from application or user-specific responses. *See, e.g.*, Comments of Free Press *et al.* in WC Docket No. 07-52 (Feb. 13, 2008) (available at: http://fjallfoss.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6519841216) at 42 ("All discrimination, not just anticompetitive discrimination, is prohibited").

network management practices is best suited to a case-by-case scrutiny rather than the imposition of a "bright-line" rule.[13]

We believe our analysis provides significant policy guidance and helps form expectations regarding the evolution of network management practices. However, our analysis is not a complete assessment of all broadband service provider traffic management practices. We stress that our analysis is limited to cases where congestion is established to be a problem. As a result, our work does not address situations where these congestion externalities are not present and network management may be motivated by other concerns. Further, our analysis is positive rather than normative. So, while can say something about what "is," our approach does little to limit those that argue about what "should be" based on their own personal preferences.

II. A Model of Congestion Externalities and Bandwidth Pricing

Our economic model has the following framework. First, we divide the population of consumers into two groups: (1) consumers that use congestion-causing applications (e.g., certain P2P applications like BitTorrent); and (2) consumers that do not. In our model, we assume that consumers using congestion-causing applications impose a congestion externality on all users. There is ample support for this assumption.[14] These negative externalities can be present even when a broadband network offers substantial bandwidth to consumers. For example, in Japan, which is reputed to boast some of the highest

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[13] This observation is consistent with other aspects of "network neutrality" that we have explored. *See generally* T. R. Beard, G. S. Ford, T. M. Koutsky and L. J. Spiwak, *Network Neutrality and Industry Structure*, 29 HASTINGS COMMUNICATIONS AND ENTERTAINMENT LAW JOURNAL 149 (2007); G. S. Ford, T. M. Koutsky and L. J. Spiwak, *Network Neutrality and Foreclosing Market Exchange: A Transaction Cost Analysis*, PHOENIX CENTER POLICY PAPER NO. 28 (Mar. 2007); G. S. Ford, T. M. Koutsky and L. J. Spiwak, *The Burden of Network Neutrality Mandates on Rural Broadband Deployment*, PHOENIX CENTER POLICY PAPER NO. 25 (Jul. 2006).

[14] *See generally* J. J. Martin and J. M. Westall, *Assessing the Impact of BitTorrent on DOCSIS Networks*, PROCEEDINGS OF IEEE BROADNETS 2007, Fourth International Conference on Broadband Communications, Networks and Systems (Raleigh, NC 2007); Comments of the Information Technology and Innovation Foundation in WC Docket No 07-52 (Feb. 13, 2008) (available at: http://fjallfoss.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6519841052); Letter from Richard Bennett to Marlene H. Dortch, Secretary, Federal Communications Commission, in WC Docket No. 07-52 (Feb. 9, 2008) (available at: http://bennett.com/FCC_Submission_All.pdf); Comments of George Ou in WC Docket No 07-52 (Feb. 13, 2008) (available at: http://fjallfoss.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6519841072).

broadband speeds in the world, a small number of users and P2P applications consume the vast majority of bandwidth available, to the point that some Japanese Internet service providers curb or restrict P2P traffic.[15]

Formally, an externality exists whenever (a) some individual A's utility or production relationships include real variables (i.e., non-monetary), whose values are chosen by others without particular attention to the effects on A's welfare; and (b) the decision maker, whose activity affects other's utility levels or enters their production functions, does not receive or pay in compensation for this activity an amount equal in value to the resulting benefits or costs to others.[16] This concept is applicable with regard to Internet usage. Varian and Mackie-Mason (1995) have observed that when users access content on the Internet, "they presumably take into account their own costs and benefits from usage, but ignore the congestion, delay, or exclusion costs that they impose on other users. Economists refer to this phenomenon as a 'congestion externality.'"[17] Thus, a congestion externality arises when one set of Internet users engages in activities that result in the degradation of service for others in the form of delay or other serious quality problems (without compensation). The concept of "congestion externality" is not original to this work, but has been studies in transportation economics for many decades and there are many papers analyzing such externalities on the Internet.[18]

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15 *See* Saito, *supra* n. 12 at 11; Martin and Westall, *id.* (finding that while Bit-Torrent applications contribute to the demand for high speed broadband access, they also contribute to the undesirable 80/20 effect wherein 80% of the bandwidth is consumed by 20% of the users); *see also* A. Schatz, D. Searcey and V. Kumar, *Officials Step Up Net-Neutrality Efforts, House Bill Aims To Ensure Providers Route Traffic Fairly*, WALL STREET JOURNAL (February 13, 2008)(reporting that Time Warner estimates that 5% of its users account for 50% of the bandwidth usage in many parts of its network).

16 W. J. Baumol and W. E. Oates, THE THEORY OF ENVIRONMENTAL POLICY (1988), at 17-8.

17 H. R. Varian and J. MacKie-Mason, *Pricing Congestible Network Resources*, 13 IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS 1141 (1995).

18 On Internet congestion, *see* Varian and MacKie-Mason, *id.*, and P. Baake and K. Mitusch, *Competition with Congestible Network*, 2 JOURNAL OF ECONOMICS 151 (2007); T. Heikkinen, *On Congestion Pricing in a Wireless Network*, 8 WIRELESS NETWORKS 347 (2002); and C. Courcoubetis, F. Kelly, V. Siris, and R. Weber, *A Study of Simple Usage-Based Charging Schemes for Broadband Networks*, 15 TELECOMMUNICATIONS SYSTEMS 323 (2000). Early contributions to transport economics include A. Walters, *The Theory and Measurement of Private and Social Cost of Highway Congestion*, 29 ECONOMETRICA 676 (1961); W.S. Vickrey, *Congestion Theory and Transport Investment*, 59 AMERICAN ECONOMIC REVIEW: PAPERS AND PROCEEDINGS 251 (1969); R. Arnott, *Unpriced Transport Congestion*, 2 JOURNAL OF ECONOMIC Theory 294 (1979). The literature in this area is vast.

Within this setup, we evaluate the decision of both a private, profit maximizing firm and a welfare maximizing regulator in an effort to assess whether the two would make different decisions with regard to traffic management. In our model, the decision maker, whether firm or regulator, sets prices with the congestion externality in mind. We find, as does the previous literature, that in the presence of a congestion externality, the firm will apply a price premium on the congestion-causing application, use, or user in an effort to reduce congestion.[19] Likewise, the right-minded regulator also will apply a congestion premium, but it is important to understand that the behavior of the firm (whose goal is to maximize profits) and the regulator (whose goal is to maximize welfare) are not identical. The differences are important because they show that when private firms undertake such actions, the congestion externality must be substantially and sufficiently large enough to warrant that intervention, more so than would warrant intervention by a welfare maximizing agent like a regulator.

A. *Model Framework*

In our model we have two types of customers: (a) consumers that use congestion-causing applications and (b) users that do not. For expositional convenience, we often refer to these users as "large" or "small" users, or represent them by the subscripts "L" or "S".[20] We assume that the large users impose a negative externality on the small users in the form of network congestion, and this congestion reduces the value of the network not only to small but also large users. That is, the online activity of large users creates network congestion for all users, thereby diminishing the value of broadband services to all users.[21]

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19 *See generally* Courcoubetis, *et al.*, *id*.

20 In practice, congestion is not so binary, but can occur at different times of the day and be caused by a variety of user types. We divide users into these two groups to simplify the model. Modeling more complex settings should not alter the primary findings of the analysis.

21 Notably, the congestion externality and peak load pricing problems appear very similar. However, in peak load pricing problems, the high-usage consumers impose a cost on the provider, and the price they pay therefore optimally includes this capacity cost. In contrast, in the congestion pricing problem, the high-usage consumers impose a cost on other users. This externality does, of course, impact the provider, since it reduces her ability to extract payments, but only indirectly so. However, because low-usage consumers are not able to impose a charge to induce the high-usage consumers to behave optimally, they must rely on the network operator to do so.

Formally, the net value of broadband service (NV) to each customer group is

$$NV_L = v_L - P_L - c\lambda Q_L\,, \tag{1}$$

$$NV_S = v_S - P_S - c\lambda Q_L\,, \tag{2}$$

where the net value is equal to the gross value of broadband service (v_L or v_S), which is uniformly distributed on the interval $U[0, V]$ with V being the highest reservation price (the choke price), less the price paid for broadband service (P_L or P_S), less the value of the congestion externality ($c\lambda Q_L$). As shown in the equations, only the large users (Q_L) cause the congestion externality, and the cost of the externality is c per large user. The parameter λ denotes the relative sizes of the large to small user populations.[22]

The demand systems are implicitly defined by:

$$Q_L = V - P_L - c\lambda Q_L\,, \tag{3}$$

$$Q_S = V - P_S - c\lambda Q_L\,, \tag{4}$$

where V is the highest reservation price for broadband service (as noted above). Solving Equations (3) and (4) yields:

$$Q_L = \frac{V - P_L}{(1 + c\lambda)}\,, \tag{5}$$

$$Q_S = \frac{V - P_S + c\lambda(P_L - P_S)}{(1 + c\lambda)}\,. \tag{6}$$

We can now turn to the question of optimal pricing of access to a particular application if that particular application creates a congestion externality.

B. *Pricing by Private Network Operator*

First, we consider the pricing decisions of private network operator, which we assume for modeling purposes to be a hypothetical monopolist. Of course, broadband service in the United States is not provided under monopoly conditions, but this approach serves as a useful starting point. Often, the forms

22 The equations are normalized by the population of small users (N_S), so that $\lambda = N_L/N_S$, where N_L is the population of large users.

of the pricing rules are similar in monopoly and oligopoly, with competition simply rendering lower prices.[23] This approach informs us as to when a network operator acting solely on the basis of a profit motive will engage in traffic management techniques like bandwidth pricing and we then can explore the welfare effects of that activity. While we limit our analysis to pricing, in some cases alternative measures may be taken in place of a pricing solution. Here, our model assumes that pricing (such as a congestion premium) can be used to resolve the problem, but other methods may be either more efficient or effective than pricing.[24] Therefore, while we model price, one could think of price as including a broad range of tools designed to control congestion that have an impact upon the purchasing decisions and value of the service to end users. Of these tools, we expect that the firm will use the most effective and efficient available.

With the cost of production normalized to zero, the firm's profit function is:

$$\pi = \frac{\lambda P_L(V - P_L)}{(1 + c\lambda)} + \frac{P_S(V - P_S + c\lambda(P_L - P_S))}{(1 + c\lambda)}. \tag{7}$$

From the first order conditions of Equation (7), we can solve for the prices for the firm's unrestricted maximization problem:

$$P_S^* = \alpha_S V , \tag{8}$$

$$P_L^* = \alpha_L V , \tag{9}$$

where

$$\alpha_S = \min\left\{\frac{1}{2}, \left[2 + c\lambda\left(\frac{2-c}{2+c\lambda}\right)\right]^{-1}\right\}, \tag{10}$$

$$\alpha_L = \min\left\{1, \frac{1 + c\alpha_S}{2}\right\}, \tag{11}$$

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23 For example, in a symmetric Cournot oligopoly, the price-cost margin is $1/N\varepsilon$, where N is the number of firms and ε is the own-price elasticity of market demand. *See, e.g.*, S. Martin, ADVANCED INDUSTRIAL ECONOMICS (1993) at 21.

24 For a discussion related to Internet pricing, *see, e.g.*, C. Yoo, *Network Neutrality and the Economics of Congestion*, 94 GEORGETOWN LAW JOURNAL 1847 (2006).

and

$$(P_L^* - P_S^*) = \frac{c(1+\lambda)}{(2+c\lambda)} P_S^* . \tag{12}$$

From Equation (12), we see that the difference between P_L and P_S is non-negative and increasing in both c and λ; the higher the cost of congestion or the larger the relative size of the group creating it, the higher the price to large users. Thus, with a congestion externality ($c > 0$), a private network operator will charge a large user a congestion premium (i.e., $P_L^* > P_S^*$) as defined in Equation (12).

The congestion premium charged to congestion-causing applications or users indicates that the firm's pricing behavior does, to some extent, internalize the congestion externality that is caused by an application or use that imposes that congestion externality.[25] Congestion reduces the demand for the firm's service, so reducing congestion (by reducing the number of large users through higher prices) increases profits by increasing demand. While the use of the congestion premium is motivated solely by the impact of congestion on profits, it is possible to show that the use of the congestion premium by the monopolist increases both consumer and social surplus.[26]

25 "Internalizing" the externality means that the firm is able to price access to its network in a manner that completely aligns consumption of congestion-causing applications with the full effects of those applications upon the network and other users of the network.

26 This finding starkly contrasts with points raised by those opposed to targeted management practices. For example, Free Press has contended that "discriminating against applications is not reasonable network management . . . even when providers claim to have bandwidth issues." Free Press Reply Comments, *supra* n. 9 at 4.

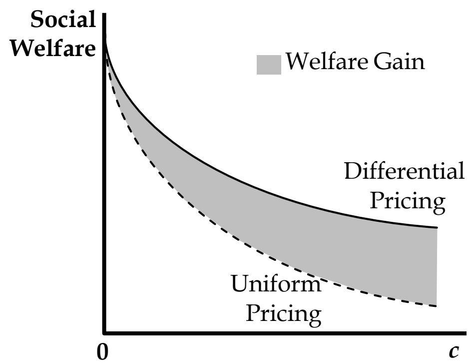

Figure 1. Pricing and Social Welfare

Figure 1 illustrates the relationship between social welfare and congestion costs under differential and uniform pricing. On the vertical axis is social welfare, while congestion costs are on the horizontal. The figure is created by fixing λ (arbitrarily) and numerically solving for welfare at various values of c.[27] As shown in the figure, social welfare is always larger in the absence of a uniform pricing constraint as long as $c > 0$. Thus, with congestion, a congestion premium is welfare enhancing.

C. *Pricing by a Welfare Maximizing Regulator*

We saw above that a profit maximizing monopolist would charge a congestion premium for congestion-causing applications or uses when such applications or uses create a congestion externality. The model demonstrates that in such circumstances, a congestion pricing scheme increases social welfare (both consumer and producer surplus). Here, we evaluate the pricing decision of a social planner (which we call a welfare maximizing regulator) to see how the pricing decisions differ from the profit maximizing case. This comparison is important because it should help us identify to what extent the decisions of a profit-maximizing firm are consistent with those of a welfare maximizing regulator. (For a pedagogical discussion of the difference in incentives between the firm and regulator, see Section II.F infra.)

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[27] The shape of the curves differs across values of λ, but social welfare always improves with differential pricing as long as $c > 0$.

Recall that in our model, small users do not impose a congestion externality and the marginal cost of production is normalized to zero. Hence, the welfare maximizing price P_S is zero. In order to determine the socially optimal price for large users, we need to choose P_L in order to maximize the following welfare function:

$$Welfare(P_S = 0, P_L) = \left\{ \frac{Q_S(P_S = 0)^2}{2} + \frac{\lambda Q_L^2}{2} + \lambda P_L Q_L \right\}. \quad (13)$$

Denoting the welfare maximizing price by P_L^W, the first-order condition yields:

$$c\lambda(V + c\lambda P_L^W) - \lambda(V - P_L^W) + \lambda(1 + c\lambda)(V - 2P_L^W) = 0, \quad (14)$$

so that the welfare maximizing price is

$$P_L^W = \left[\frac{c(1+\lambda)}{1 + c(2-c)\lambda} \right] V. \quad (15)$$

Clearly, as long as $c > 0$, the optimal price to the large user is positive. The social planner likewise charges a congestion premium to large users in the presence of a congestion externality. With congestion, the private firm's pricing decisions are directionally consistent with those of a social planner (price rises in both c and λ), though not identical.

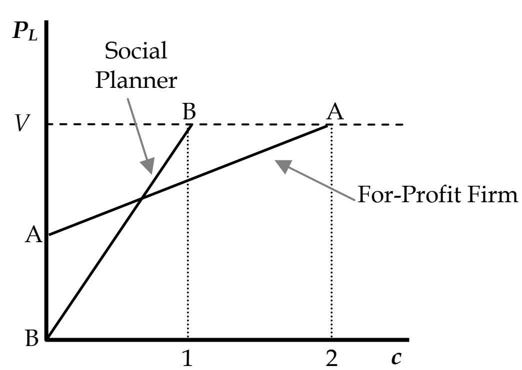

Figure 2. Congestion Costs and Pricing

As shown in Equations (12) and (15), the congestion premium is increasing in congestion costs c for both the firm and the regulator. Figure 2 illustrates the difference between the pricing behavior of the monopolist and the regulator as c

rises. In the figure, the vertical axis measures the price to the large user (P_L), whereas the horizontal axis measures the cost of the congestion externality (c). The line labeled AA illustrates the pricing decision of the firm; the line BB the pricing decision of the regulator.[28] Since the marginal cost is normalized to zero, when the congestion cost is zero the regulator sets the price to the large user at zero, but the firm sets a positive price (equal to ½V). But, as the size of the congestion externality increases, the firm fails to internalize the entire burden of the congestion, so that *the social welfare maximizing regulator actually behaves more aggressively towards increases in congestion than does the for-profit firm*, increasing price at a faster rate in response to increases in congestion costs (c).

D. *Zero-Use Pricing by Firms*

As shown in Figure 2, the price to the large user increases until it reaches V, where V is the choke price for the large users (i.e., the highest price someone is willing to pay). When price reaches V, then, no large user finds it worthwhile to use the congestion-causing application. In essence, the large user is unwilling to pay the social cost she imposes on other users in the form of a price premium, so the application is not used (during times when the application causes congestion).

From Equation (10) we see that when $c \geq 2$, the firm's premium on the congestion-causing application is higher than large users are willing to pay. That is, when $c = 2$, we have $\alpha_L = 1$, $\alpha_S = ½$, $Q_L^* = 0$, and $Q_S^* = \frac{1}{2}V$. The market outcome of zero usage of the congestion-causing application may seem extreme and, to some, undesirable, but the outcome is welfare improving. With differential pricing and $c \geq 2$ (so there is zero use), consumer surplus and profit are $CS_D = \frac{1}{8}V^2$ and $\pi_D = \frac{1}{4}V^2$. Under a uniform pricing constraint, we have

$$CS_U = \frac{1}{8}\left[\frac{(1+\lambda)}{(1+c\lambda)^2}\right]V^2 \tag{16}$$

$$\pi_U = \frac{1}{4}\left[\frac{(1+\lambda)}{(1+c\lambda)}\right]V^2 . \tag{17}$$

28 The curves are drawn as linear but actually have a slight non-linear shape.

When $c \geq 2$, it is clear that $CS_D > CS_U$ and $\pi_D > \pi_U$.[29] Consequently, zero-use pricing is surplus increasing for both consumers and firms, and total surplus rises. Importantly, consumers, on whole, are better off with zero-use pricing (when $c > 0$), so the arguments of the opponents of network management are not clearly based on consumer welfare grounds.

E. *Zero-Use Pricing by a Welfare Maximizing Regulator*

As noted above, the regulator behaves more aggressively toward increases in congestion than does the for-profit firm. From Equation (15) we see that when $c \geq 1$, we have $P_L^W > V$ and there is zero use of the congestion-causing application. So, the regulator implements zero-use pricing when $c \geq 1$. This results is also shown in Figure 2, with line BB intersecting V at $c = 1$ and AA intersection V at $c = 2$. Since zero use occurs at $c \geq 2$ for the for-profit firm, the regulator is shown again to respond more aggressively to congestion than does the firm. Since zero-use pricing is analogous to blocking the congestion-causing application, our analysis implies that the aggressive treatment of congestion should not be prohibited by government.

F. *The Difference in Incentives*

We have described in the previous analysis how a welfare maximizing regulator would take more aggressive steps to curtail congestion than a profit-maximizing firm would take. To the economist, this difference in behavior is expected in the presence of externalities, but to the layman the lower tolerance for congestion may seem peculiar at first glance. For pedagogical reasons, we present a graphical illustration of the difference in incentives.

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29 When $c \geq 2$, both terms in brackets in Expressions (16) and (17) are less than 1.

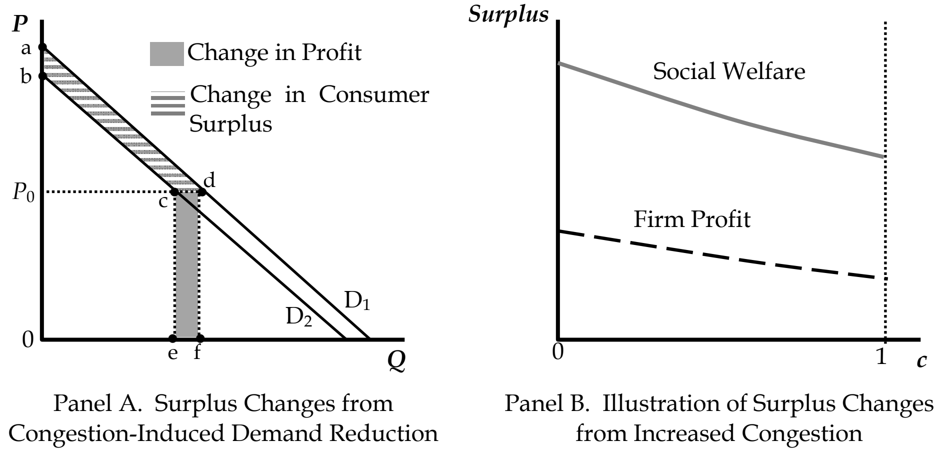

Figure 3. For-Profit Monopoly versus Welfare-Maximizing Regulator

Figure 3 shows the difference between the incentives of the for-profit firm and welfare maximizing regulator with regard to congestion. In both figures, the welfare effects are computed holding price constant. Assume that one use of the network causes a congestion externality so that the value of the network is diminished for other users and applications—this would reduce demand for the network, represented in Panel A by a reduction in demand from D_1 to D_2. When this happens, and if price is held constant, profits will fall by the shaded rectangle **cdef** below the price P_0. This reduction in profit is what motivates a firm to undertake traffic management techniques (e.g., pricing premiums). These techniques are designed to attenuate congestion so that demand for the broadband service does not decrease from D_1 to D_2 (or decrease by as much).[30] While this profit change is relevant to the welfare-maximizing regulator, the regulator is *also* concerned about the loss of consumer surplus marked as the hatched area **abcd** above P_0. Clearly, the negative effects of congestion are larger for the regulator than for the firm by the amount **abcd**. As a result, we once again see that the social welfare maximizing regulator will respond more aggressively to increases in congestion than a for-profit firm would respond.

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[30] While comical, the quote attributed to Yogi Berra about a popular restaurant—"Nobody goes there no more, it's too crowded"—has some truth to it. A restaurant with a reputation for being crowded all the time will indeed have trouble attracting new patrons.

Panel B illustrates the change in welfare as the size of the congestion externality increases. As the size of the congestion externality increases, both social welfare and firm profit declines. Observe that not only is social welfare larger than firm profit (since it includes consumer surplus too), but the slope of the social welfare curve is steeper than the profit curve, since social welfare includes not only the decline in profits but also the fall in consumer surplus. This larger marginal effect of congestion implies the regulator always has a greater incentive to curb incremental congestion than does the for-profit firm. The implication being that firms may be too soft—not too aggressive—in protecting consumers from the adverse effects of network congestion cause by particular applications and other users.

III. Policy Implications and Conclusion

Broadband service providers have a litany of traffic management tools at their disposal, but the use of some of these tools with regard to particular applications has been challenged by proponents of network neutrality. This PAPER explores the welfare effects of broadband network management in the presence of congestion externalities. Our analysis shows that when faced with legitimate examples of congestion, consumer surplus and total social welfare can rise when network operators use traffic management tools such as differential pricing, traffic prioritization, or traffic shaping. Our model also shows because a for-profit service provider may not fully internalize the cost to society of a negative externality, that provider will respond to these congestion externalities less aggressively than a welfare maximizing regulator.

This analysis has important policy implications. First, it is socially desirable to charge a congestion premium when congestion-causing applications are used on a broadband network—especially one that targets a particular congestion-causing application. The objective of such charges is to attenuate congestion by requiring users of bandwidth-greedy applications to consider more fully the congestion costs imposed on others. Alleviating congestion is the target, so the more targeted such charges are, the more likely they are efficient.[31] Indeed, if such charges are *not* targeted and are instead generally applied to all applications

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31 An application-specific action may be justified if a particular application is designed to circumvent common congestion control protocols. For example, Internet protocols already include numerous algorithms—such as Slow Start, Congestion Avoidance, Fast Recovery—that are designed to curb congestion, and that some applications like BitTorrent attempt to circumvent some of these congestion-reducing algorithms.

(such as a simple "price-per-bit" scheme[32]), then the price premiums may not achieve their desired purpose.[33] In fact, the most efficient traffic management actions would be targeted, to the greatest extent possible, at applications that cause congestion externalities and not upon all applications generally. Consequently, the fact that a broadband service provider operator may engage in application-specific traffic management techniques should not necessarily be viewed by a policymaker as evidence of illicit anticompetitive intent.

Second, our model also suggests that different networks may have different network management practices, because capacity constraints and network protocols may not be the same across networks. For example, congestion is more likely to occur in shared media networks, such as wireless broadband networks. In wireless networks, all users share the common pool of spectrum capacity that is used to provide such services. Given a higher relative potential for costly congestion in shared media network, we might expect network management practices to arise in these networks first.[34] Diligence in managing traffic is an engineering reality, and the tools needed to can be expected to vary across network architectures. Because networks are diverse, different applications might impact congestion differently. As a result, judging the appropriateness of a particular traffic management technique is perhaps best undertaken on a case-by-case basis rather than prescriptive, *ex ante* regulations and prohibitions.

Finally, our finding that a private network operator would be much more forgiving to congestion-causing applications that would social welfare maximizing regulator is important to bear in mind when judging whether a private firm's traffic management practices are proper. To the extent that public policy seeks to address network management practices from a positive (rather than normative) analytical perspective, laws and regulations should be designed with full recognition that for-profit firms will tend to do less than is socially

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32 *See* Free Press Petition, *supra* n. 10.

33 For example, a general charge applied to all users based on the bandwidth they consume may be less efficient than a charge directed at particular high bandwidth applications because not all bandwidth heavy applications create a congestion externality—an email with a 5 MB attachment imposes a very different network demand than a 5 MB stream of real-time video. Some bandwidth-heavy applications, such as online backup services, may operate mostly during periods of low Internet use, thereby limiting their contribution to congestion.

34 We have already seen some attack on the differential treatment of P2P traffic by wireless carriers. *See, e.g.,* T. Wu, *Wireless Carterfone*, 1 INTERNATIONAL JOURNAL OF COMMUNICATION 389 (2007).

optimal to curb congestion. To get a for-profit firm to act to curb congestion, the negative externality caused by congestion must be substantial enough so as to impact profits and that action will certainly have a significant impact on social welfare.

Our approach provides a possible framework for analyzing disputes over whether a particular network management technique is reasonable. As stated above, because congestion externalities can differ among applications and networks, a case-by-case approach is preferable to broad, *ex ante* prohibitions. As a result, our approach indicates that one can presume that when congestion externalities are present, actions taken by a private, broadband service provider to alleviate that negative externality will enhance social welfare.

Applying this presumption could simplify the FCC's review of complaints regarding network management practices. Free Press has argued before the FCC that the legal standard for enjoining unreasonable network management practices "should be low,"[35] but our analysis shows quite the opposite. Because when a private firm employs a specific traffic tool to remedy actual congestion externalities, our model indicates that it is appropriate to presume that such activity is welfare enhancing and the burden of proof should be laid upon those that dispute the reasonableness of that tool. Of course, before applying such a presumption, policymakers should require evidence that the targeted application or use creates a congestion externality and that the particular traffic management tool utilized by the broadband network operator does in fact alleviate that congestion.

We would like to stress again that our analysis is limited to situations in which a particular application, use, or user causes network congestion that harms other users of the network. Our analysis is not intended to be a complete assessment of network management practices, and we do not consider the role that disclosure of traffic management policies might have upon consumer and social welfare. Nevertheless, we believe that our approach properly places the focus of attention upon whether congestion externalities are present and the extent to which it may vary by application, use, user, and even network. The complexity of this issue indicates that specific, prescriptive rules that ban entire categories of traffic management techniques across all network architectures and topologies can result in sub-optimal outcomes.

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35 Free Press Reply Comments, *supra* n. 9 at 4.