

Dumbing Down the Net: A Further Look at the Net Neutrality Debate

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I. Introduction

It is commonplace for sellers of goods and services to enhance the value of their products by paying extra for premium delivery service. For example package delivery services such as Federal Express and the U.S. Postal Service offer shippers a variety of delivery speeds and insurance programs. Web content providers such as Yahoo! and MSN Live Earth can purchase web-enhancing services from companies such as Akamai to speed the delivery of their web content to customers.¹

Recently there has been concern over the desires of some Internet Service Providers (ISPs) such as AT&T and Verizon to offer Internet content providers faster, premium delivery of content and services to end user customers and to charge the content providers for the superior transmission. This is part of what has been termed the net neutrality issue, which is actually a loose collection of issues that vary in their mixture and meaning over time.² However, the provision of and charging for premium transmission speed of Internet packets consistently appear in the public debate.³ Proponents of net neutrality argue that the network itself is simply infrastructure that should not add value to the service, and thus innovation should occur only at the edges of the network.⁴ Net neutrality advocates also hold that the network should be a commons that broadband users are allowed to use in ways that are not illegal and that do not harm the network and that networks should not discriminate between uses, users, and content. In contrast, network providers such as AT&T argue that offering premium transmission

¹ http://www.akamai.com/html/customers/customer_list.html, downloaded July 1, 2008.

² See Wu (2004) for an explanation of the various issues included under the general name of net neutrality.

³ See Hahn and Wallsten (2006).

⁴ Net neutrality proponents have pressed their case at the Federal Communications Commission and, as of the time of this writing, are seeking federal legislation to impose mandatory net neutrality. See <http://www.google.com/help/netneutrality.html>, downloaded July 5, 2008.

services will improve customer choice and that ISPs would not degrade service to content providers not purchasing the premium transmission speed.⁵

In order to analyze the potential effects of policy proposals to ensure net neutrality, it is important to consider positively (rather than normatively) conditions under which the various hypothesized outcomes might occur. In this chapter, we focus on the findings of analytical research on the effects of networks offering and charging for premium transmission service, and on the effect of regulation on network providers' offerings. In Section II we provide background on the Internet and on the net neutrality debate. Section III considers how premium transmission is provided and priced, and how content providers provide their services. Section IV addresses how the offering and provision of premium transmission affects network innovation, network subscription, and incentives for the network provider to hinder rivals. Section V is the conclusion.

II. Background

Net neutrality became part of the public debate over the roles of networks in 2003 with the Supreme Court reversal of the Ninth Circuit court ruling in *Brand X Internet Services v. FCC*.⁶ The decision upheld the Federal Communications Commission's (FCC's) conclusion that cable modems, as an information service, are not subject to the regulation as telecommunications carriers.⁷ This decision resulted in asymmetric regulatory treatment of two substitutable services: Internet access via cable modems and Internet access via DSL (digital subscriber line), which is offered by telephone

⁵ See Whitacre (2006).

⁶ Case filed October 6, 2003.

⁷ National Cable & Telecommunications Assn. V. Brand X Internet Services (04-277) 345 F.3d 1120. The Supreme Court stated that the FCC had the authority, under its Title I jurisdiction, to impose regulation on the Internet industry in the future, if necessary.

companies. This led to intense lobbying on the part of telephone companies to have DSL treated in a manner similar to cable access. The FCC issued a ruling in 2005⁸ that exempted DSL from the “statutory access requirements applied to traditional telephone [service]”.⁹ This effectively deregulated methods of Internet access in the United States, at least with respect to traditional telecommunications regulation.

Currently ISPs and Internet backbone providers carry traffic on a best effort basis, which in general means that the first packets into a switching point are the first packets out. Net neutrality proponents see this best-effort approach as central principle for an application-blind Internet, which they apparently believe is important for content development and innovation. They fear that network providers might exercise market power to “pick and choose” what Internet users would “be able to see and do on the Internet.”¹⁰ Recent quotes by telephone company executives have provided fuel for this fear: Verizon CEO Ivan Seidenberg stated, “We have to make sure that they [application providers] don’t sit on our network and chew up bandwidth... We need to pay for the pipe.”¹¹ The FCC under Chairman Powell and Chairman Martin has believed that it is doing an adequate job of overseeing and promoting competition among ISPs,¹² but net neutrality proponents believe that the FCC and the federal courts will not exercise rigorous oversight of ISPs absent legislation.¹³ They believe that the FCC’s actions to

⁸ See *Appropriate Framework for Broadband Access to the Internet over Wireline Facilities, Report and Order and Notice of Proposed Rulemaking*, 20 FCCR 14853.

⁹ Yoo (2006), pg. 1858.

¹⁰ See statement of Google CEO Eric Schmidt, http://www.google.com/help/netneutrality_letter.html, downloaded July 5, 2008.

¹¹ Quoted on arstechnica.com website, January 6, 2006.

¹² See *High-Speed Services for Internet Access: Status as of June 30, 2006* available at www.fcc.gov/wcb/stats for data supporting the FCC assertion that the broadband market is competitive.

¹³ For a more detailed discussion of the lack of oversight from the federal courts and FCC see Prepared Statement of Earl W. Comstock for United States House of Representatives Committee on the Judiciary Telecommunications and Antitrust Task Force, submitted 25 April 2006. See also the testimony of Paul

date are inadequate, and they fear that without legislative or regulatory safeguards the phone companies will determine which content providers are to be successful and which are not.

The broader debate is over what regulations if any are to be imposed on the Internet industry. Content providers (such as Google and Microsoft) are concerned about ISPs offering preferred delivery of data. Such offerings would be designed so that for a fee, the ISPs would guarantee “head of the line” privileges for a customer’s data,¹⁴ even though there is some doubt as to the technical feasibility of such a plan if it were implemented.¹⁵ From these content providers’ perspectives, there are two basic implications: (1) Any content provider that did not pay the extra fee might have the quality of service for its data degraded;¹⁶ and (2) ISPs that are vertically integrated into the content business might give their own packets priority service or otherwise deliberately disadvantage their content rivals. Said another way, priority delivery of content could be a means by which ISPs could use price discrimination to earn higher profits while compelling content providers to pay the additional fee or risk degradation of service. Furthermore, network neutrality proponents believe that such an exercise of market power in infrastructure would stifle application-level innovation and harm consumers. Proponents of net neutrality use the case of Madison River Communications to illustrate their point. Madison River Communications is a rural telecommunications

Misener, Earl W. Comstock and Timothy Wu before United States House of Representatives Committee on the Judiciary Telecommunications and Antitrust Task Force, 26 April 2006.

¹⁴ As we explain below, “head of the line” is reference to one approach to providing some packets with premium transmission. There are other approaches as well.

¹⁵ See testimony of Gary R. Bachula, Vice President, Internet2 before the United States Senate Committee on Commerce, Science and Transportation. Testimony given 7 February 2006.

¹⁶ See Paul Misener’s testimony before the United States House of Representatives Committee on the Judiciary Telecommunications and Antitrust Task Force, 26 April 2006.

company that blocked its DSL customers from accessing VoIP¹⁷ service. After these actions were brought to regulators' attention, the FCC issued an order directing Madison River to allow its DSL customers to access VoIP service.¹⁸

The FCC also responded more broadly to concerns about net neutrality in other proceedings. Even though the FCC does not apply traditional telephone-like regulation to Internet access providers, it does retain some ancillary authority over Internet providers under its current statutes. Using that authority, the FCC recently adopted a set of policy principles applicable to Internet providers, namely:

- “To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to access the lawful Internet content of their choice.
- To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to run applications and use services of their choice, subject to the needs of law enforcement.
- To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to connect their choice of legal devices that do not harm the network.
- To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to competition among network providers, application and service providers, and content providers.”¹⁹

The FCC did note that these principles are “...subject to reasonable network management,”²⁰ which means that the principles did not necessarily bind the FCC to agree with net neutrality proponents.

¹⁷ VoIP is the acronym for Voice over Internet Protocol. VoIP allows people to use the Internet for telephone calls by sending voice data using IP (Internet Protocol) technology rather than via the traditional (copper wire) method of telecommunications.

¹⁸ See *Madison River Communications* Order FCC 4295 (2005).

¹⁹ *Policy Statement*, FCC 05-151, released September 23, 2005

²⁰ *Policy Statement*, p. 3, footnote 15

However, the FCC's policy statement may produce more questions than clarity.²¹ Consider the controversy over Comcast's management of P2P (peer to peer) traffic. Vuze, a company providing a platform for the downloading of high quality video (e.g., from National Geographic and PBS), has filed a petition for rulemaking requesting the FCC to prevent broadband network operators from degrading or blocking Internet content, a practice Vuze calls "throttling".²² Specifically, Vuze alleges that Comcast, a large cable operator, was throttling bandwidth-intensive traffic such as video distribution. Comcast used deep packet analysis to identify bandwidth-intensive applications, and then used that information to 'shape' or manage network traffic by delaying or disrupting those applications.²³ Comcast defended the practice, stating that it only delayed P2P traffic where the end user's computer was being used only for uploads even when the user was not present, and that this was done only when the network traffic reached specified levels of congestion.²⁴ Comcast also pointed out that its actions protected the quality of other consumer applications, such as VoIP and Internet gaming.

In support of their position, the ISPs also argue that that under the status quo they have no incentive to upgrade their networks, and limited ability to recoup costs of initial investments in the Internet. Conversely, if ISPs are able to offer (and charge for) premium transmission, the incentive and ability to invest in the network would be greater. Although these arguments may be overstated, we explain below that offering premium transmission improves overall network performance.

²¹ Jamison and Sichtler (2008).

²² Vuze Petition for Rulemaking, November 14, 2007.

²³ A coalition of parties, including Free Press and the Consumer Federation of America filed a Petition for Declaratory Ruling on November 1, 2007, requesting the FCC to rule that Comcast's practices violated the Commission's Policy Principles.

²⁴ Comments of Comcast, FCC WC Docket 07-52, February 12, 2008.

Thus far much of the net neutrality debate has been more rhetorical than rigorous. Relying upon the analytical research that does exist, we consider in the following sections the implications of net neutrality policies on network capacity, innovation, network subscription, and incentives for the network provider to hinder rivals.

III. Provision of Transmission and Content

A. Transmission Speed

In this section we describe how network providers can provide premium transmission services alongside standard transmission services. Consider what happens when consumers visit web sites. Each visit or hit triggers the delivery of the site's content to the consumer. The speed with which the content's packets transverse the network is determined by the physical speeds of the transmission and switching facilities of the network and by the amount of congestion that the packets encounter. Congestion occurs when more packets enter a point in the network during a given period of time than the point can process. With current technologies, the physical speeds are barely consequential; however, packets do encounter congestion in the network.

The amount of time that a packet takes to clear a point of congestion, called the wait time, is determined by the capacity of the network at that point, the number of packets that are trying to pass through that point, and the priorities given to the packets that are in the queue waiting to be processed. The capacity of the network at a particular point is defined as the number of packets the point can process during a unit of time. In some sense the net neutrality debate is about what happens at these congestion points or in their associated queues.

To understand this aspect of the debate, consider the situation where all packets are treated the same.²⁵ In this situation every packet entering a queue during a given time experiences the same expected wait time: the packets simply line up in the queue as they arrive and wait to be processed. Mathematically, the expected or average wait time is represented as the number one divided by the difference between the network capacity and the arrival rate of packets during the time period, where the arrival rate is defined as the number of packets to arrive during the time period divided by the number of units of time during the period. As this formula illustrates average wait time decreases (conversely, increases) if the difference between network capacity and arrival rate increases (conversely, decreases).²⁶

Now consider what happens if some packets are given preferential treatment, i.e., some packets receive the standard transmission service and others receive a premium service. There are various methods by which this could be done.²⁷ One method is called the one processing rate system with priority. In this system the premium group's content moves ahead of the standard group's content in the queue, but does not stop the standard group's content from being delivered once the standard group's content is in the service process. Another method is a two processing rate situation. In this method each group is given its own processing rate and these rates are chosen such that the average wait time

²⁵ To simplify discussion, we consider an $M/M/1$ queuing system, which is a queuing system where interval and distribution times are exponentially distributed and there is one server. The first M represents that the arrival process for packets is random, the second M represents that the processing service time is exponential, and the 1 represents that there is one server. For more detailed explanations, see Gross and Harris (1998).

²⁶ Other implications of this formula for wait time are: (1) Average wait time approaches infinity as the arrival rate of the packets approaches the network capacity; and (2) At least some congestion is expected unless the network capacity is such that the network can simultaneously process the maximum number of packets that content providers and consumers can send at one time. When average wait time is infinity, the average packet does not expect to make it through this network point during the time period. This does not mean that no packets make it through – clearly some do make it through because the network processes information – but the queue continues to grow in length throughout the time period.

²⁷ For more detailed explanations, see Chapter 3 in Gross and Harris (1998).

for the premium service is less than the average wait time for the standard service. In either the one-rate system or the two-rate system, or indeed in any system, the packets with premium transmission experience less wait time than the packets receiving standard transmission. Providing premium transmission for some content may affect the average wait time in a network and may affect the average wait time for content not receiving premium service, depending on how the premium service is provided.²⁸ Some network providers have committed to not degrading service for any content provider if premium service is offered. We call this the non-degradation condition.

Non-Degradation Condition. Under this condition, the network operator keeps its commitment that standard transmission service will be the same regardless of whether premium service is offered.

When the non-degradation condition holds, a network provider will increase network capacity when providing premium transmission service.²⁹ This result follows directly from queuing theory.³⁰ In the one-rate system, the premium group always gets ahead in line and the second group experiences a decrease in its service speed because it loses its place in line unless the total system speeds up. Thus network capacity has to be increased if the first group experiences an improvement in service while the second group experiences no degradation in its service. With the two-rate system the standard group would experience an increase in wait time unless total network capacity was increased so that the second group's access to delivery capacity was not diminished. Thus when the

²⁸ See Gross and Harris, 1998, p. 150.

²⁹ See Jamison and Hauge (2008a).

³⁰ See Gross and Harris, 1998, pp. 141-151.

non-degradation condition holds, the network's provision of premium transmission results in an increase in network capacity, all other things remaining equal.

B. Content Provision

There are many ways of categorizing the content on the Internet, but there are basically two ways that have been shown to be relevant for analyzing the net neutrality issue. One type of content is that whose value decays as it passes through the network because the value of the content is time sensitive. We call this d-content, for decaying-content. Examples of d-content include auction sites such as e-Bay and sites for trading financial securities. For auction sites, some bidders wait until near the close of the auction before entering their final bids. Timely information on other bids is valuable because it decreases uncertainty about what others are willing to pay for the item that is offered for auction. This value provides an incentive for a bidder to purchase broadband Internet access so that information is not delayed by her connection to the network, and it provides an incentive for an auction site to seek ways to speed its delivery of bid data so as to attract bidders. Similarly, securities traders such as day traders depend on timely price information as they attempt to profit from small changes in securities prices. A site that offers timelier price information and faster trades would be more valuable to traders than a site that provided slower service, all other things being equal.

The second type of content is that which does not decay with the time it takes to transit the network. We call this n-content, for non-decaying content. Examples include the Social Science Research Network (SSRN) and news sites. For these types of sites, visitors value their time and so prefer faster delivery to slower delivery, but the value of

the substance of a research paper downloaded from SSRN and the value of the substance of a news article on a recent court decision are unaffected whether it takes 3 seconds or 10 seconds to download the information.

The type of content affects how consumers receive value from the content site. In the case of n-content, the value is simply the difference between the positive value of the content and the value of the time consumed to obtain the information. This is the consumer utility function developed by Mendelson (1985) to represent the value consumers receive from computing services. It has been further applied to analyzing broadband pricing and net neutrality issues.³¹ In the case of d-content, wait time affects consumer utility in two ways. First, wait time decreases consumer utility directly by the time consumed to obtain the information, just as with n-content. Second, wait time decreases consumer utility indirectly by causing decay in the value of the content.

Why does it matter whether content is d-content or n-content? The content type affects which sites have greater preferences for premium transmission. Consider the situation for providers of d-content. When a d-content provider considers whether to purchase premium transmission, she compares the impact of her choice on her revenue to the impact of her choice on her costs. She chooses to purchase the premium transmission if she believes the revenue impact is greater than the cost impact because this improves her overall profit. But d-content providers vary in their abilities to provide useful d-content. For example one auction site might have proprietary algorithms that make it easier to use than rival sites. This raises the question of whether all d-content sites experience the same marginal impacts on revenue and cost. They do not. In situations

³¹ See Bandyopadhyay and Cheng (2006) for applications in analyzing broadband pricing, and Jamison and Hauge (2008a, 2008b) for applications in analyzing net neutrality issues.

where the marginal effect of wait time on the value d-content is positively correlated with the content provider's innate ability to provide content and its investment in content, then lower value sites have a higher preference for premium service than do higher value sites. If instead the marginal effect of wait time on d-content value is negatively correlated with innate ability and content investment, then preferences for premium service depend on the relationship between these marginal effects and how the amount paid for premium service varies with wait time and the number of visits to the site.³²

Now consider how n-content sites would view the choice between premium and standard transmission. An n-content provider would perform the same marginal analysis as a d-content provider: The n-content provider chooses to purchase the premium transmission if he believes the revenue impact is greater than the cost impact because this improves his overall profit. But innate abilities of n-content providers do not affect transmission preferences in the same way that they affect d-content providers.³³ The n-content providers with lower innate abilities consistently value premium transmission more than do n-content providers with greater innate abilities. The reason is that the extra cost of premium transmission to the high-ability n-content provider is greater relative to the extra revenue than for the low-ability n-content provider.

C. Transmission Tariff

There are two issues with the transmission tariff that affect analyses of net neutrality. One issue is whether content providers are able to extract what is called an

³² These relationships have not been worked out in the literature, so we provide an analytical proof in the Appendix.

³³ Jamison and Hauge (2008a, 2008b) formally illustrate this result.

information rent. The other issue is the design of the tariff. We discuss these issues in this section.

An information rent is a net benefit that a seller (conversely, buyer) can obtain because she has information about either her ability or her effort that the buyer (conversely, seller) does not have, or if he does have the information he cannot use it. To illustrate this situation, consider how a network provider might design a tariff for premium transmission. If the network provider gives each content provider a choice between standard transmission and premium transmission, and if the tariff is generally available to all content providers, then in order to induce a particular content provider to purchase premium transmission the tariff prices for premium transmission must allow the content provider to receive just as much profit when she uses premium transmission as when she uses standard transmission. This profit is called the information rent.

Why would a network provider design its tariffs this way? Why not simply force each content provider to use the type of transmission that maximizes profit for the network provider? There are two reasons. First, recall that content providers vary in their innate abilities and that these abilities affect the value of premium transmission. The network provider might not know enough about each content provider's innate ability to know which type of transmission service would be preferred from the network provider's perspective. Second, the network provider might be regulated in the sense that either a sector or competition regulator requires the network provider to offer the same tariff to all content providers. In either case the network provider's tariff must induce content providers to self select the appropriate service.

Studies differ in whether it is reasonable to assume that content providers will receive an information rent. We assert that it is unreasonable to assume an information rent for two reasons. First, economic models of network content assume that customers are able to assess content value, which reveals each content site's innate ability. It seems reasonable to conclude that managers of the network operator also are able to observe content value given that they, too, are consumers. Furthermore, there are no regulations that require network operators to offer generally available tariffs to content providers; network providers and content providers negotiate individual contracts.³⁴

The issue of tariff design is also important because the conclusions about how content providers' abilities affect their preferences for premium transmission depend upon tariff design. The profit maximizing tariff design, given the assumption that there are no information rents, charges for premium delivery of packets based on the advertising revenue that the packets generate for content providers. This tariff structure is profit maximizing for the network provider because it exacts all of the content providers' profits.³⁵

IV. Effects of Premium Transmission on Innovation, Subscription, and Incentives to Harm Rivals

A. Innovation at the Edges

Net neutrality advocates hold that allowing network providers to supply and charge for premium transmission would hinder innovation at the edges of the network, including content sites. Interpreting innovation to mean an increase in the value and

³⁴ Neither Hermalin and Katz (2007) nor Jamison and Hauge (2008a, 2008b) investigate how their information rent assumptions affects their analyses.

³⁵ See Jamison and Hauge (2008b) for formal presentation of this result.

diversity of content available at the edges of the network, we assert the opposite is true for n-content. More specifically, the variety of n-content at the edges of the network increases when the network provider provides premium transmission services, and the value that consumers receive from the sites that purchase the premium transmission service is greater than it would be otherwise.³⁶

To understand why this holds, recall that premium transmission improves the profitability of n-content providers with innately lower value content. This means that there are potential n-content providers who have such low innate abilities that they are unprofitable unless premium transmission is available. So, one result of premium transmission is an increase in the variety of content made available on the network. Furthermore consumers receive greater utility from content sites that purchase the premium speed than they would receive if the premium service were not available. This happens because content providers will purchase the premium speed only if it increases revenues, which happens only if the premium speed increases consumer visits on these sites by increasing the utility that consumers receive from the sites that purchase the premium service.

A corollary from the finding that premium transmission stimulates innovation at the edges is that when lower value n-content sites purchase the premium speed, profits decrease for the sites that do not purchase it. This occurs because, with a downward sloping demand curve for advertising on content sites, advertising prices decline. This price decrease lowers revenue, and thus profits, for every content site that does not increase its hits by purchasing the premium transmission service. The declining price of advertizing and subsequent reduction in content provider profits helps us understand why

³⁶ See Jamison and Hauge (2008a and 2008b) for formal presentation of this result.

content providers with very large web presence are some of the strongest proponents of net neutrality. Although they may have numerous reasons for advocating net neutrality, at least one effect of premium transmission is that high-ability incumbent providers of n-content stand to lose market share and advertising revenue to smaller web sites that are the more likely purchasers of premium services.

The corollary does not mean that all content providers purchase the premium service. From revealed preferences we know that a network provider that had optimally chosen a standard speed when offering only one speed, and that had optimally chosen a premium speed when choosing to provide more than one speed, would choose a premium speed that not all content providers would purchase.

B. Network Subscription

We now turn our attention to the effects of premium transmission service on demand for network subscription. Research indicates that more consumers subscribe to the network service when premium transmission service is offered and at least one content site purchases the service than if the network provider did not offer the premium service.³⁷ We assert that this is simply a consequence of network effects. More consumers subscribe to the network service because the value of the network is greater when premium service is provided than when it is not. The network provider benefits in two ways from the premium transmission service. First, it receives greater profit by being able to charge premium prices for something that at least some content providers value, whereas without the premium prices there would be no direct benefit to offering a higher speed service. Second, the number of consumers subscribing to network access is greater,

³⁷ Both Hermalin and Katz (2007) and Jamison and Hauge (2008a) find this result.

which in turn leads to more hits on the content sites, which stimulates the demand for premium transmission. The greater diversity of content sites also stimulates demand by consumers for network access and increases the number of content sites interested in purchasing the premium transmission service.³⁸

C. Incentives to Harm Rivals

Finally, a common concern of net neutrality proponents is that a vertically integrated network provider, i.e., one that provides both content and network services, would discriminate against its content rivals. We argue that this would not be the case at least for n-content. The network provider's profit from being the content provider is no greater than its profit from selling premium transmission to a non-affiliated entity providing that same content.³⁹ Indeed this may be a situation in which regulation would lead to incentives to discriminate: if regulation were to impose a non-discriminatory tariff requirement on the network and such a tariff requirement resulted in an information rent for content providers, then the network provider might be able to decrease the information rent and improve its profit by vertically integrating and discriminating against its content rivals.

VI. Conclusion

In this chapter, we have analyzed the effects of a network provider offering premium transmission speeds for content providers. We have found that at least some of the claims of the net neutrality advocates do not hold. Specifically, we find that offering

³⁸ Jamison and Hauge (2008b).

³⁹ See Jamison and Hauge (2008b) for formal derivation of this result.

premium service stimulates innovation on the edges of the network because lower-value content sites are better able to compete with higher-value sites with the availability of the premium service. The greater diversity of content and the greater value created by sites that purchase the premium service benefit advertisers because consumers visit content sites more frequently. Consumers also benefit from lower network access prices. We also explain that a vertically integrated network provider does not have an incentive to discriminate against its n-content rivals.

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Appendix

Following the model we develop in Jamison and Hauge (2008a), content provider i 's profit function is

$$\max_{I,S} \pi_i \equiv v(i) \cdot n(a - r(S)) - w \cdot I \quad (\text{A1})$$

Where $v(i)$ is the value a consumer experiences when she visits i 's site, n is the number of consumers with access to the network, a is the revenue per hit that i receives from advertisers, $r(S)$ is the price per hit charged by the network operator for providing speed S for i 's packets, I is the amount of information that i places on its site, and w is i 's cost per unit of information. Normalizing the number of hits per consumer to the value each consumer receives from the site, $v(i) \cdot n$ represents the number of hits that i receives from all consumers. For ease of exposition in this proof, we treat S as a continuous variable. We deviate from our earlier model by assuming that information value decays with delay.

Assuming that content providers are price takers, first order conditions from (A1) for an internal solution include

$$v_i \cdot n(a - r) - w = 0 \quad (\text{A2})$$

and

$$v_s \cdot n(a - r) - r_s v \cdot n = 0. \quad (\text{A3})$$

Taking the total derivatives of (A2) and (A3) with respect to I , S , and i and applying Cramer's rule gives us

$$\begin{bmatrix} v_{I,I} \cdot n(a - r) & n[v_{I,S}(a - r) - r_S v_I] \\ n[v_{S,I}(a - r) - r_S v_I] & n[v_{S,S}(a - r) - 2r_S v_S - r_{S,S} v] \end{bmatrix} \cdot \begin{bmatrix} dI \\ dS \end{bmatrix} = \begin{bmatrix} -v_{I,i} \cdot n(a - r) \\ n[v_{S,i}(a - r) - r_S v_i] \end{bmatrix} \cdot di$$

and

$$\frac{dS}{di} = \frac{v_{I,I}(a - r)[v_{S,i}(a - r) - r_S v_i] + v_{I,i}(a - r)[v_{S,I}(a - r) - r_S v_I]}{v_{I,I}(a - r)(v_{S,S}(a - r) - 2r_S v_S - r_{S,S} v) - (v_{I,S}(a - r) - r_S v_I)^2}. \quad (\text{A4})$$

The denominator in (A4) is positive because of the assumption that second order conditions are met. But, the sign of the numerator is ambiguous. Note that $v_{I,i}(a - r) < 0$ because $v_{I,i} < 0$ by assumption and $a - r > 0$ from (A2), making $v_{I,i}(a - r) > 0$. Furthermore $v_{I,i}(a - r) > 0$ because $v_{I,i} > 0$ by assumption and $a - r > 0$. If $v_{S,i}(a - r) - r_S v_i > 0$ and $v_{S,I}(a - r) - r_S v_I > 0$, then the numerator is positive and higher ability content providers have a greater preference for premium service than do lower types, i.e., $\frac{dS}{di} > 0$. More generally, $\frac{dS}{di} > 0$ if

$$v_{I,I}[v_{S,i}(a - r) - r_S v_i] > -v_{I,i}[v_{S,I}(a - r) - r_S v_I]. \quad (\text{A5})$$