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Statistical Framework To Value Network Neutrality

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**STATISTICAL FRAMEWORK TO VALUE NETWORK
NEUTRALITY**

by
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INTRODUCTION

This paper presents a model based on elementary probability and statistics that has been previously applied to financial and economic models illustrating why in the presence of market uncertainty and sufficient choice of services and content for users, a neutral network generates more total revenue¹ than a non-neutral network that biases network traffic in a fashion that is unfavorable to end users. The contribution of this paper is linking the total value of network infrastructure based on the degree of its neutrality to market uncertainty. Rapidly changing Internet technology has created a very uncertain market (market uncertainty is defined below) in the context of providers being able to predict what services users desire and how these users will value services and content, which makes it unlikely that any single service or content provider is the best match for every user. This probabilistic network neutrality model predicts that in today's uncertain market, the expected value of a non-neutral network is only average and that there would be more users willing to pay more if they had greater choice. The model provides evidence that non-neutral networks are not a necessary prerequisite to the promotion of network infrastructure investment, but in fact, will ultimately stifle the creation of a rich competitive eco-system consisting of both infrastructure and downstream service/content providers.

There is renewed interest in network neutrality because organizations such as Google, Microsoft, and other service/content providers require broadband (both traditional wired, and wireless) access to reach end-users. These content/service providers worry because Incumbent Local Exchange Companies (i.e., ILEC telephone companies) and cable companies claim that facilities-based competition make non-discriminatory policies unnecessary, caused the Federal Communication Communications (FCC) and Courts to gut much of the legislative framework provided by the Telecommunications Act of 1996² [Lehr et al 2006]. The FCC has adopted some of Google's open

¹ This greater revenue is shared between the infrastructure service provider and unaffiliated service/content providers using the infrastructure pipes.

² W. Lehr, and M. Sirbu, J. Peha, and S. Gillett, *Scenarios for Network Neutrality Arms Race*. Abstract. Conference on Communications, Information, and Internet Policy (TPRC), (Oct. 2006) available at <http://www.cdt.org/speech/net-neutrality/readingroom.php>.

network suggestions such as open devices and applications or the nation wide C band in the FCC's upcoming 700MHz auction, which our model is critical to maximizing the value of wireless infrastructure.

There are abundant definitions describing what network neutrality means. Tim Wu who is credited with coining the term net neutrality discusses it in the context of "preserving Darwinian competition for every conceivable user of the Internet so that only the best will survive."³ The creator of the Web (Tim Berners Lee) defines network neutrality as follows: "*If I pay to connect to the Net with a certain quality of service, and you pay to connect with that or greater quality of service, then we can communicate at that level.*"⁴ While these definitions vary, the underlying theme is fairness and competition.

There are hard and soft definitions of network neutrality.⁵ For the Internet, the hard-line view is that network infrastructure should have only one class of traffic (i.e. best effort); a softer approach would allow different tiers of traffic as long as QoS is sold in a fair and non-discriminatory fashion to all users and service/content providers.⁶ This paper argues for soft network neutrality for several reasons: it seems unreasonable to micromanage the services available on privately built networks; it fits with products offering QoS functionality from vendors such as Cisco, Alcatel/Lucent and others; the IETF has developed protocols such as MPLS (RFC 3021) and DiffServ (RFC2474 and 2475) that support QoS; best effort only transport might not be good enough because Internet traffic is changing as content and services become more dynamic, VoIP and video traffic grows.⁷ Industry pundits such as David Isenberg argue that a network where the worst QoS works well for real-time traffic is a better approach,⁸ which is discussed in more rigor in a model describing how much additional bandwidth is required to meet a given level of QoS.⁹

³ Tim Wu, *Network Neutrality, Broadband Discrimination*, 2 Journal of Telecommunications and High Technology Law, 141 (2003).

⁴ Tim Berners Lee, *Net Neutrality: This is Serious*, <http://dig.csail.mit.edu/breadcrumbs/node/144> (last visited Dec. 3, 2007).

⁵ <http://gigaom.com/2007/03/13/is-google-changing-its-position-on-net-neutrality/>

⁶ Note that this allows volume discount to larger users as long as this usage and performance based pricing is uniformly available to all users and service/content providers.

⁷ John Borland, *Net Video Explosion Triggers Traffic Jam Worries*, CNET News.com, Feb. 23, 2006, http://news.com.com/2100-1025_3-6042300.html.

⁸ David S. Isenberg, *The Dawn of the Stupid Network*, ACM Networker 2.1, Feb.-Mar. 1998, 24-31, available at <http://www.isen.com/papers/Dawnstupid.html>

⁹ M. Yuksel, M. K. Ramakrishnan, S. Kalyanaraman, J. D. Houle, and R. Sathvani, *Value of Supporting Class-of-Service in IP Backbones*, Proceedings of IEEE International Workshop on Quality of Service (IWQoS), Chicago, IL. (June 2007), available at <http://www.cse.unr.edu/~yuksemy-papers/iwqos07.pdf>.

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Neutral networks do not bias traffic based on content, source, destination, or any other attribute of the data or metadata in ways undesirable to end users or content/service providers. This is fundamental to providing network users' with unbiased choices in an environment conducive to innovation and investment as discussed by Frischmann.¹⁰ Examples of non-neutrality abound in the Internet, cable TV networks, and the Public Switched Telephone Network (PSTN). In the cable TV network, a good example of non-neutrality is Comcast's Video-on-Demand ("VoD") service – the users' only choice of content is from Comcast. Network neutrality boils down to providing users with an unbiased choice of services and content, which our model implies will promote greater user satisfaction as well as opportunities for innovators and entrepreneurs.

Market uncertainty is the inability of service and content providers to predict what users will like and how users value the features of a service or the selection of content.¹¹ This uncertainty exists partly because users often don't know what they want until they see it. Low market uncertainty implies that providers can predict the value of their offerings, high uncertainty means providers must guess. Several examples of market uncertainty are: the format standards battle between VHS and Sony's BetaMax VCR video tapes; the proliferation of hundreds of features for voice calling in the PBX market¹²; the success of the "hello kitty" service in NTT's imode wireless network; and the innovation of the Web itself. These examples illustrate situations where vendors and service providers did not understand a market. Sony bet big on its betamax standard, which it believed to be technically superior, however the market decided otherwise. In the early 1980s, PBX vendors experimented with many voice features in the newly developed software controlled PBX's and users selected features they wanted most such as caller-id and voice mail. Nobody predicted in the early 90s what the Web is today, or the impact it has had on society, yet in ten years the Web has emerged as a requirement for modern commerce. When Netscape started its development process of the first breed of Web browsers there was extreme uncertainty. Users had no idea what they would do with browsers, and vendors had no idea what services would become popular. The Internet today is far different from the predictions of early 1990s, which illustrates the high level of market uncertainty that exists in network-based services, and the way users' preferences evolve with the technology.

¹⁰ Brett Frischmann, *Infrastructure Commons in Economic Perspective*, First Monday, vol. 12, num. 6 (June 2007), available at http://firstmonday.org/issues/issue12_6/frischmann/index.html.

¹¹ Mark Gaynor, *Network Service Investment Guild: Maximizing ROI in Uncertainty Markets*, (Wiley, 2003).

¹² *Id.*

Knowing if market uncertainty is high, medium, or low is important to our model. There are several ways to estimate market uncertainty¹³ including: the ability to forecast the market, emergency of a dominant design, and feature convergence of a service. Network services with low market uncertainty such as with traditional voice services are differentiated by price, not features: all service providers understand what users want and find it easy to satisfy them. However, as user market uncertainty grows, user selection criteria migrates from cost to the feature set or available content which best matches their uncertain needs. Low market uncertainty and price based competition makes it unlikely for any particular service provider to win big. However, high market uncertainty and feature based competition allows service providers to charge more for more successful ideas, which translates into the possibility of capturing a large potential market, thus winning big.

I

NETWORK NEUTRALITY AND ARCHITECTURE

There is no clear link between network neutrality and network architecture because networks with similar infrastructure can be managed in both neutral and non-neutral style. Networks that have centralized control (such as the PSTN) make it easy to control access to content and services. However, even networks with central control can be neutral if the governance of the network allows it. One example of this is the developing infrastructure for wireless WAP Internet services via a GSM or GRPS 3G mobile phone in France that illustrates network neutrality in a traditional centralized network infrastructure.¹⁴ The French government has published a set of conditions promoting network neutrality in the context of WAP mobile wireless Internet services.¹⁵ French courts have ruled that users must have a choice of WAP service providers, and that mobile devices must allow a user to easily change the default WAP gateway to a gateway of their choice.¹⁶ While still too early to see the outcome of these French regulations, based on the results of our model we believe they will foster a competitive environment in which users have a choice of gateways and portals in the emerging market of mobile Internet services.

¹³ *Id.*

¹⁴ Autorité de Régulation des Télécommunications, *Mobile Internet's Development Recommendations*, Nov. 2006, available at <http://www.art-telcom.fr/fileadmin/reprise/publications/intmob-eng.htm>.

¹⁵ See, *Décision proposant au ministre chargé des télécommunications les modalités et les conditions d'attribution des autorisations pour l'introduction en France métropolitaine des systèmes mobiles de 3ème génération*, Autorité de Régulation des Télécommunications, Decision No. 00-0835, Adopted Jul. 28, 2000, available at <http://www.art-telcom.fr/index.php?id=recherchedecisions&L=1> (search for Decision No. 00-0835).

¹⁶ On July 2000 the Paris Court of Appeal decided the sale of locked mobile phone is anti-competitive.

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Networks that have a more distributed architecture, such as the Internet, and that are made up of a collection of autonomously owned and managed networks make it more difficult – but not impossible – to bias traffic end-to-end. ISPs can and do filter, alter, and block traffic to and from their customers, as well as bias traffic between ISPs. Some traffic filtering, such as of malware traffic or Distributed Denial of Service (DDOS), are desirable, but other types of interference such as slowing down or blocking real-time Voice over Internet Protocol (“VoIP”) traffic are not.^{17 18} Several examples of a non-neutral Internet are a broadband infrastructure service provider blocking traffic based on port addresses; or a service provider partnering with a search service such as Google and providing Google with a better quality of service than other search services; or a service provider such as Comcast biasing their VoIP service over another VoIP service provider such as Vonage.

The end-to-end argument has been used to illustrate the value of neutral networks, but this is an insufficient argument. True end-to-end infrastructure, such as the early Internet¹⁹, is neutral simply as a by-product of its pure end-to-end architecture.²⁰ The early Internet and its core best effort service model²¹ was completely application unaware offering only best effort QoS. This end-to-end architectural principle²² enforced neutrality in the context of content and services because the simple network infrastructure was ignorant by design of the content or services it was transporting. Today’s Internet is not a true end-to-end network²³ because of services, such as traffic

¹⁷ See, e.g., *In re Madison River Communications and Affiliated Companies*, Order, 20 FCC Rcd 4295 (2005).

¹⁸ W. Lehr, and M. Sirbu, J. Peha, and S. Gillett, *Scenarios for Network Neutrality Arms Race*. Abstract. Conference on Communications, Information, and Internet Policy (TPRC), (Oct. 2006) available at <http://www.cdt.org/speech/net-neutrality/readingroom.php>.

¹⁹ While NSFNET did implement the IP header precedence field it was only used for management traffic and was never used to provide commercial QoS to end users in the early Internet.

²⁰ See, Peha, *supra* note 8; see also, Barbara van Schewick, *Towards an Economic Framework for Network Neutrality Regulation*, 5 *Journal on Telecommunications and High Technology Law*, 329 (2007); and Joseph Farrell and Phil Weiser, *Modularity, Vertical Integration, and Open Access Policies: Towards a Convergence of Antitrust and Regulation in the Internet Age*, 1 *Harvard Journal of Law and Technology*, 85 (2003).

²¹ Jon Crowcroft, *Net Neutrality: The Technical Side of the Debate: A White paper*, 1 *SIGCOMM Computer Communications Review*, 49 (Jan. 2007), available at <http://portal.acm.org/citation.cfm?id=1198263>.

²² J.H. Saltzer, D.P. Reed, and D.D. Clark, *End-to-End Arguments in System Design*, 4 *ACM Transactions on Computer Systems (TOCS)*, 277-288 (Nov. 1984), available at <http://portal.acm.org/citation.cfm?id=357402>.

²³ Marjory S. Blumenthal and David D. Clark, *Rethinking the Design of the Internet: The End-to-End Arguments Vs. The Brave New World*, *Communications Policy in Transition: The Internet and Beyond*, 91-140, (Benjamin Compaine and Shane Greenstein, eds, The MIT Press, 2001).

shaping that is based on information above the IP layer, routers that inspect packet information above Layer 3, and packet classification. However, as discussed above, any type of network can be managed as a neutral network.

Results from the model presented in the next section indicate that when market uncertainty is high, a non-neutral network providing users with only a single choice of services will at best provide average revenue for services, content, and transport. The expected value of a similar network managed in a neutral fashion where users have many choices for services and content is greater than average and will create social benefit generated by downstream uses.²⁴ When market uncertainty is nonexistent or low, then average revenue is fine because the commodity nature of the services implies that most users are happy with their one choice and would be unwilling to pay more. This model illustrates that market uncertainty is a critical factor in determining the value of network neutrality.

II A PROBABILISTIC MODEL

This model is based on basic probability and statistical theory²⁵ along with several assumptions about users and service providers. It illustrates analytically how market uncertainty affects the value users are willing to pay for network services and content, based on the number of choices and the diversity of these options that users have to choose from within the network. Two extreme cases are discussed: a completely non-neutral network where users only have a single choice of bundled services at a fixed price versus a very neutral network where users have many choices for all service and content providers available at many different prices. While these two extreme cases are not realistic they illustrate the limitations of a non-neutral network versus the potential of network neutrality.

This model builds on other economic models by Farrell and Van Schewick describing the value of network neutrality because it quantifies the role of market uncertainty in the valuation process.^{26 27} Farrell applies

²⁴ See, Frischmann, *supra* note 12.

²⁵ Our theoretical framework is based on a real options framework. See, e.g., Martha Amram and Nalin Kulatilaka, *Real Options: Managing Strategic Investment in an Uncertain World* (Oxford University Press 2001); Carliss Baldwin and Kim Clark, *Design Rules Vol. 1: The Power of Modularity* (MIT Press 2000); Gaynor, *supra* note 5; and Mark Gaynor and Scott Bradner, *A Real Options Metric to Evaluate Network, Protocol, and Service Architecture*, Computer Communication Review (Oct. 2004) available at <http://www.sobco.com/papers/ccr-10-2005.pdf>.

²⁶ Van Schewick, *supra* note 22.

²⁷ Farrell, *supra* note 22.

Internalizing Complementary Efficiencies (ICE) to telecommunication services explaining why ISPs might open up their stream service/content markets if they find it efficient to do so.²⁸ Van Schewick advances Farrell's research by discussing conditions where ICE does not induce organizations to adopt an open garden business model.²⁹ Both authors discuss the limited ability of large ISPs to innovate. Our model quantifies the value of innovation by independent service/content providers, which further defines under what conditions ICE promote open upstream markets.

III MODEL ASSUMPTIONS AND NOTATION

Consider a transport network with "N" potential users such as broadband cable or DSL. Assume that these "N" potential users will subscribe to this broadband service if the price of transport connectivity, services and content provided over the network is equal to, or below, the value placed on these services by each user. The value of this network to the investors who funded it and the organization running it, is related to the number of subscribers, the subscription rate, additional revenues such as advertising or partnerships with service/content providers, and the cost of providing these services. Each user has a bundle of services in addition to basic transport that might include email, VoIP, and a real-time IP-based video service. The model assumes the amount each individual user is willing to pay for each of the specific services within the bundle is a random variable with a normal³⁰ distribution based on their own individual opinion of the value of the service. Since the sum of a set of normally distributed random variables is also a random variable with a normal distribution, each user is willing to pay a random amount that is normally distributed for any randomly selected group of services that compose the bundle. When market uncertainty is high, the range of values placed on this bundle of services is wide and impossible to predict; however, when market uncertainty is low, the range of value is narrow and predictable.

This model assumes that the transport service provider does not differentially price services and transport to end users. This assumption will not significantly affect the results of this network neutrality model because of the limited resources and inability of transport service providers to discover what users want in uncertain markets. With no market uncertainty, our model illustrates that the transport ISP is able to capture most of the value of

²⁸ *Id.*

²⁹ *See*, Van Schewick, *supra* note 22.

³⁰ We use the normal distribution to simplify the mathematics of our model. Our argument works for any distribution that has a parameter defining the variance/range of the distribution.

transport and services because they understand the service market as well as any of its competitors. However, with high market uncertainty the transport service provider is unable to predict the value of these differentiated services. Because of the transport providers limited resources they are unable to offer unlimited choices and must choose a set of differentiated services. This set of services from the ISP is unlikely to meet uncertain markets as well as a group of independent service providers. When users are limited to the ISPs group of services it stifles the generation of positive externalities via the downstream creation of network services.³¹ A single transport service provider will never discover as many innovative services as a group of heterogeneous and independent providers. Our model makes this simplifying assumption because it does not change the flavor of our model – our goal is not a rigorous model covering all contingencies, but a model that abstracts unneeded complexities while maintaining the critical aspects to illustrate the potential value of a neutral network.

³¹ Frischmann, *supra* note 12.

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Figure 1 is an example of a normally distributed random variable describing the value of a single service.³² The bottom axis represents how much a user is willing to pay for a single choice of a service, user satisfaction (and willingness to pay) with this single choice moves from left to right. The mean of this distribution, which we denote as “AP” represents the price where 50 percent of potential users are willing to pay for the service. It would be unusual for any user to be willing to pay 3 Standard Deviations (“SDs”) above the mean, but likely that many potential customers would be willing to pay between +/- 1 SD of the average value of the random variable describing the value of a service to a user. In the middle are 68 percent of users that are moderately happy with the service and willing to pay within one SD of the average value of the service to all users. The users on the far right are very happy with the service and value it far more than the average user does. In this model the standard deviation of the distribution describing the value of services to a user represents the market uncertainty. As SD increases the spread of what users are willing to pay for a service grows.

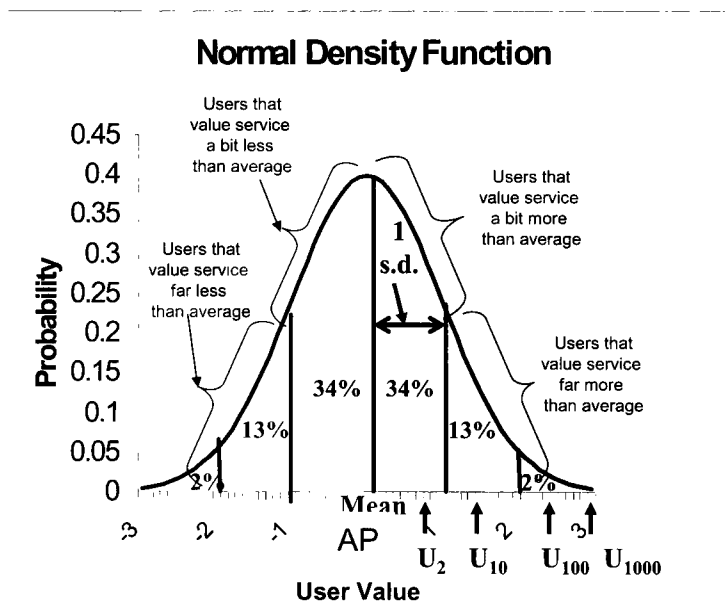


Figure 1 – Market Segmentation of Users

³² This figure also applies to a bundle of randomly selected services that have normal distributions.

The profit for a transport network service provider is total revenue minus total costs. The model makes the following assumptions about revenue and cost:

- Network infrastructure for neutral and non-neutral networks costs the same to build and run;³³
- The only source of revenue is income from transport and other services;³⁴

Users are willing to pay more for basic infrastructure for services they value higher.³⁵

VI MODEL NOTATION

$R(SCP)$ = total revenue from customers for services and content to the provider(s). This is the sum of revenue for all non-transport services and content.

$R(TSP)$ = total revenue from customers for transport service to the transport provider. We assume the value of $R(TSP)$ is proportional to the value of $R(SCP)$, the more the services and content is worth, the more the pathway to these services and content is valued by users.

If “P” is this proportionality constant, then:

$R(TSP) = “P” * R(SCP)$ – This is similar to metered pricing that charges by byte, however in this case the “network tax” is related to the value of the service to the user, not the network resources consumed by the service. Network access charges or cable partnerships such as a contract between AT&T Comcast and AOL are a form of network taxing.³⁶

³³ Providing QoS costs money because of more expensive equipment and more complex management. We assume equal cost because it simplifies the model without altering the high level predictions of the model. In the interesting case of high market uncertainty our model illustrates how neutral network will have a greater total value than a non-neutral network given the models assumptions. The increased cost of a non-neutral network increased this total value because the revenue stays the same while the cost goes down for a neutral network.

³⁴ Advertising can be significant revenue source.

³⁵ See, Ferrell, *supra* note 22, discussion of platform economics using video games as an example where users are willing to pay more for game platforms that have more game titles; see, also, Peha, *supra* note 8.

³⁶ Van Schewick, *supra* note 22.

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In this simple model the total value of the network is just $R(\text{SCP}) + R(\text{TSP})$, which gives:

$$V(\text{Total}) = R(\text{SCP}) * (1 + \text{"P"}) - \text{Total value of the network infrastructure.}$$

Note that $V(\text{Total})$ has two components, the transport service (i.e. $R(\text{SCP}) * \text{"P"}$) and the service component (i.e. $R(\text{SCP})$).

V

CASE (1) – NON-NEUTRAL NETWORKS

The non-competitive environment of a non-neutral network is called a “walled garden”³⁷ business model, which is inherent to a non-neutral network where there exists only one service provider for network connectivity, network services, and access to content. The service provider picks a set of services to include in a standard service bundle and sets a price that includes the price of services and the cost of transport. The revenue from transport services, other network services, and access to content is not shared, with 100 percent going to the service provider offering the bundled services at a fixed price. The users have only one choice, either pay the price the service provider is asking for the bundle of services selected, or not.

A. No Market Uncertainty

With no market uncertainty, services are strictly sold by price as a commodity because users value all choices of services the same with no randomness in their perceived value of the service. All service providers know what users want, and what they will pay for it.³⁸ In Figure 1, each user will value the bundle at the same average with no variation, which is the definition of no market uncertainty. Thus, the single service provider can be expected to get 100 percent of potential users. This assumption of capturing 100 percent of the potential users is based on defining potential users as those who will subscribe to this particular service provider and their bundled services as long as they value the set of services including transport at equal to or above the

³⁷ Lawrence Lessig, *The Future of Ideas: The Fate of the commons in a Connected World* (Vintage Books 2002).

³⁸ In our definition of no market uncertainty there is no variance in how users value services and content. While this is the extreme case examples from traditional wired voice and traditional voice only cellular services come close to fitting this definition. With wired phone service via the PSTN virtually all users are willing to pay the regulated price. Similarly, voice only cellular services have captured a very large market percentage at commodity pricing structures that have little variance.

fixed price for the service bundle. This is not un-realistic given lessons learned from traditional voice services where market uncertainty has previously been low and most users were willing to pay the regulated asking price.³⁹

In this case, $R(SCP) = \text{the number of subscribers, times the fixed price}$. The fixed price with no market uncertainty is just "AP" the mean of the no longer random variable describing the value of a set of services selected by the service provider.

$$R(SCP) = \text{"N"} * \text{"AP"}$$

The value of the network to the single service provider responsible for transport, network based services, and available network content is:

$$V(\text{Total}) = \text{"N"} * \text{"AP"} * (1 + \text{"P"})$$

The single service provider is receiving "N" * "AP" for the services and content, and "N" * "AP" * "P" for transport services providing access to the services and content.

In this case, we expect an average profit because the services and content are not differentiated by service feature set or content selection because there is no market uncertainty. Most users only value the service bundle as average, and thus only value the transport accessing the service bundle as average.

B. High Market Uncertainty

With high market uncertainty, the single service provider in the non-neutral network does not know what feature set is best for services, or what content selection is most valued by users. High market uncertainty implies that there are a few users willing to pay a lot for the right bundle; however if the price for this bundle is too high, it drives away too many users for broadband service providers aiming to satisfy large user bases. The model assumes the service provider is aiming to maximize their revenue. Figure 2 is a course grained analysis based on Figure 1 that illustrates how revenue is linked to asking price (AP = 100 in this example) for a range of standard deviations from 1 to 1000. When the SD is low (i.e. < 50) then profit is maximized by reducing the price a small amount to capture a larger portion of the market. However as market uncertainty increases (i.e. SD >= 50 <= 100)

³⁹ This is changing as many users are giving up land lines for wireless service.

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then profit is maximized by increasing prices to capture approximately 50 percent of the market. With huge market uncertainty rising pricing even more maximizes profit. We justify our believe that $AP = 100$, and the SD is in the 50 – 100 range below in the analysis section. With market research services providers in the long term should be able to determine how potential users value their services (even when they can't figure out how to offer a more valuable service) and thus set the service bundle price to attract the market share to maximize their profit by attracting 50 percent of the market.

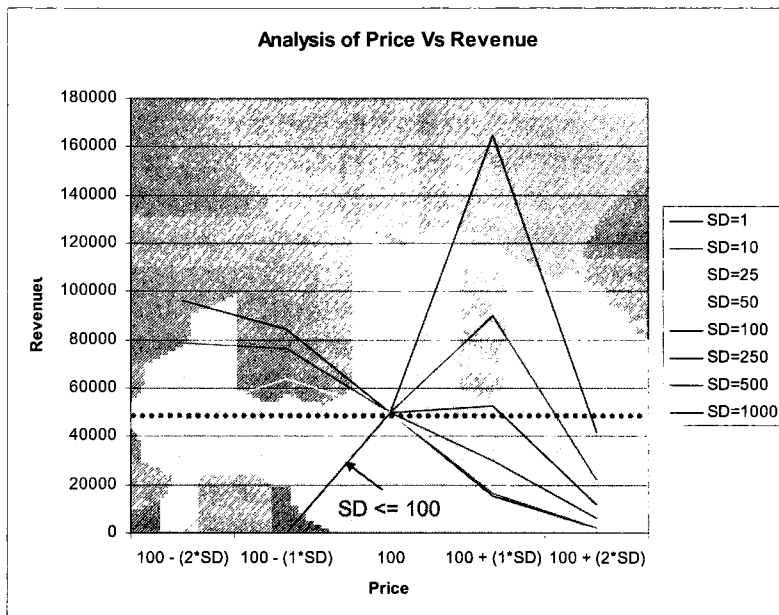


Figure 2 – Price Vs Revenue

The value for the fixed bundle of services selected by the service provider is:

$$V(\text{Total}) = \text{“N/2”} * \text{“AP”} * (1 + \text{“P”})$$

Note that with the models assumptions and high market uncertainty the value of a non-neutral network is reduced by 50 percent compared to the low market uncertainty case. Interestingly, the model predicts the opposite with a neutral network where increased market uncertainty increases the value of the network.

VI

CASE (2) – NEUTRAL NETWORKS

In the second case, the competitive environment enabled by a neutral network allows users to pick services and content from many choices. The transport service provider offers transport services, and a fixed bundle of services, at the same price as in Case 1. The revenue from transport services goes 100 percent to the transport service provider. If users happen to select the bundled services, then this transport provider also receives 100 percent of the revenue for these services. If the user selects other services, these other service providers are paid for their services, and the transport provider gets 0 percent of this service revenue. The transport service provider receives “P” times the total revenue from non-transport services and content. Service providers that guess better about features can charge more, which illustrates market selection.

A. No Market Uncertainty

Choices don't really matter to users because they value them all the same in this commodity market. As in the non-neutral case, 100 percent of potential users subscribe to the service. Thus the total value of the network infrastructure is:

$$V(\text{Total}) = \text{“N”} * \text{“AP”} * (1 + \text{“P”})$$

This is the same total value as the non-neutral network. However in this neutral network case the total network value is divided because the single transport, service and content provider does not receive this total value. The single transport service provider receives “N” * “AP” * “P” for transport services (similar to the neutral case). The revenue for services and content is “N” * “AP”, however this is split between all service and content providers including the transport service provider. To simplify the model we assume that the transport service provider gets 75 percent of the users too also subscribe to their bundled services because, with no market uncertainty, this bundle is as good as all the others. Seventy-five percent is a reasonable estimate because for users, subscribing to the transport providers service bundle is the easy choice, and a good choice, but given many choices some users will always pick one of the alternatives. Thus, the transport service provider receives $0.75 * \text{“N”} * \text{AP}$ for services, and $P * \text{“N”} * \text{AP}$ for transport, while the other service/content providers split $0.25 * \text{“N”} * \text{AP}$.

B. High Market Uncertainty

Each of the “N” potential users can select the best match to their needs from “X” different content/service providers. Each service/content provider has a different set of services and content, some of which are broad while others are focused on particular niches. As assumed above, the value to each of the “N” potential users of picking one of “X” choices is normally distributed. The value of the best of these “X” choices is modeled by a probabilistic framework known as the “*best of many*”^{40]} used by Gaynor and Bradner to value network architecture.⁴¹ In this framework users are willing to pay more for service/content that better matches their needs. In this case, based on the above model assumptions and the “*best of many*” model, the value of a neutral network is greater than the value of a non-neutral network as long as each user has at least one choice in addition to the vendor selected service bundle (i.e. “X” ≥ 2).

Figure 1 illustrates this application of the “*best of many*” model by graphically demonstrating what is expected when many independent and heterogeneous service providers attempt to meet an uncertain market by providing a particular service. It shows the probability of the value of each particular service being a particular distance from the mean. Looking at the percentages in Figure 1, we expect that 34 percent of the service/content choices will fall between the mean and +1 standard deviation from it, 13.5 percent between 1 and 2 standard deviations, and 2 percent between 2 and 3 standard deviations from the mean. This illustrates that finding great services may take on the order of 1000 attempts.

The value of giving users between two and 1000 choices of service providers is illustrated in Figure 1 by U_2 , U_{10} , U_{100} and U_{1000} . If the user has ten choices for a particular service, then we expect they will value the best match at roughly 1.5 SD from the distribution mean of AP (i.e. U_{10} in Figure 1). This valuation makes intuitive sense because from Figure 1 we expect that 13 percent of the service offering will be valued by users between one and two SDs above AP. With 1000 choices, the expected value of a user’s best choice might be worth 3 SD over AP (U_{1000}). In this case of high market uncertainty and a neutral network, each user is allowed to pick the choice that best fits their particular needs, which they are expected to value greater than average. In this neutral network case, the revenue from users is not normally distributed, but follows the “*best of many*” model.

⁴⁰ See, Baldwin and Clark, *supra* note 27.

⁴¹ Graynor and Bradner, *supra* note 27.

Increased total revenue in neutral networks when market uncertainty is high can come from two sources. First is the increased total revenue from the same 50 percent of potential users that were users of the non-neutral network because with choice these users can pick services they are willing to pay more for. All users still have the same choice of bundled services that was available in the non-neutral network, but in this case we assume that many of these users will opt to pay more for services they value higher. With X choices, these users that were willing to pay AP for the average bundle of services from the transport service provider are now expected to pay U_x . Because with high market uncertainty there are real differences between services, the model predicts that the transport provider will not get most of the users to pick their average service bundle. The model estimates the transport provider will retain $\frac{1}{4}$ of the 50 percent of potential users that value the transport service providers bundle at greater than AP. Next, it is likely that some users that did not subscribe to the non-neutral network will be induced to pay for a set of services they value more than the fixed bundle from the transport service provider. The likely new users are the 34 percent of potential users that value the fixed service bundle between AP and AP – SD. These potential new users are not willing to pay AP for the service bundle offered by the ISP, but are likely to pay more if given a choice of many services, some of which are a better match to their needs. With X choices it is likely for them to find a set of services that they value more. We assume the potential users willing to pay between [AP – SD, AP] will become new subscribers, each willing to pay U_x .

$V(\text{Total}) = (\text{revenue of services from transport provider}) + (\text{revenue from services for other providers}) + (\text{revenue from new users}) + (\text{transport revenue})$

$$\begin{aligned} V(\text{Total}) &= ((\text{"N/8"} * AP)) + ((3/8) * \text{"N"} * U_x) + ((34/100) * \text{"N"} * U_x) + \\ &\quad \text{"P"} * ((\text{"N/8"} * AP) + ((3/8) * \text{"N"} * U_x) + ((34/100) * \text{"N"} * U_x)) \\ &= (1+P) * (\text{"N/8"} * AP + (71.5/100) * \text{"N"} * U_x) \end{aligned}$$

Note the total service revenue is $(\text{"N/8"} * AP + (71.5/100) * \text{"N"} * U_x)$, and the network transport tax is P times this service revenue.

Unlike Case 1, the value of a neutral network is linked to both the variance of the normal distribution describing the value of content/services to users and the number of these choices. As users are presented with more choices, the number of SDs from the mean of the best of these services grows, as the SD increases the absolute value of $(U_x - AP)$ increases. For example, with low market and many choices the value of the best service to a user may be over 2 SDs above AP, but because SD is low, U_x is very close in value to AP. However, with high market uncertainty, SD is large, which implies that 2 SDs above AP is much greater in absolute value than AP.

VII ANALYSIS

Above this model predicted that when market uncertainty is large it decreased the total value of a non-neutral network by 50 percent because the transport provider has picked such an average bundle of services that half of the potential users don't value it as high as its price. The opposite is true for a neutral network where high market uncertainty and unbiased choice for users increases the total value of the network. A simple example illustrates the implications of large market uncertainty. Suppose the average price a user is willing to pay for a bundle of services selected at random is \$100.00, which is based on what users are currently paying for broadband connectivity (which includes ISP based email), VoIP services such as Vonage, and cable TV services. If SD is small, such as \$1.00, then it is very unlikely any users will pay more than \$103.00. However, there is reason to believe SD is much larger based on the variability of what users currently pay for services such as cable TV, email, voice, and transport.⁴² For example, SD = \$100, which is equal to the average value users place on the fixed service bundle from the transport service provider. If this is true and users have at least one hundred choices, then the best of these one hundred choices is roughly 2.5 * SDs from the mean. Thus, the marginal benefit from network neutrality is huge to users and independent service/content providers. In addition it may also benefit the transport service provider as the example below illustrates. Make the following assumptions:

AP = \$100.00 -- The average price users are willing to pay for a fixed bundle of services.

SD = \$100.00 -- The standard deviation of the distribution describing the value of services to users.

"N" = 1000 -- Number of potential users.

"P" = .50 -- Fraction of revenue for services that a user pays for transport.

X = 100 -- Number of choices a user has for services.

U₁₀₀ is rounded to 2 standard deviations above AP, thus U₁₀₀ = \$300.00.

⁴² We know from above a reasonable estimate of the average amount a user will pay for a bundle of services is in the \$100 range. I and many of my friends are paying over twice that amount for our broadband, cable, and voice services, which indicates the potential for a large standard deviation.

This gives the following table comparing of the value of network neutrality to transport and other service providers:

No Market Uncertainty						
	Non Neutral Network			Neutral Network		
	Transport	Services	Total	Transport	Services	Total
Transport SP	50K	100K	150K	50K	75K	125K
Other SPs	0	0	0	0	25K	25K
Total network value	50K	100K	150K	50K	100K	150K
High Market Uncertainty						
	Non Neutral Network			Neutral Network		
	Transport	Services	Total	Transport	Services	Total
Transport SP	25K	50K	75K	113,500	12,500	126,000
Other SPs	0	0	0	0	214,500	214,500
Total network value	25K	50K	75K	113,500	227,000	340,500

Table 1 Value Analysis of Network Neutrality

The top half of Table 1 illustrates that with no market uncertainty network neutrality does not out value non neutral networks. Users value both non-neutral and neutral networks the same. However, the transport service provider receives more revenue in the non-neutral case. These results imply that without market uncertainty network neutrality does not provider overall greater network value.

The analysis in the bottom half of Table 1 illustrates that high market uncertainty increases the \$75,000 value of the non neutral network to over \$340,000 for the neutral network. In this case network neutrality is the clear choice for all stakeholders because users have services they value more, the transport service provider is making more money, and the competitive environment for network services and content is good for innovation and investment.

STATISTICAL FRAMEWORK TO VALUE NETWORK NEUTRALITY

The much greater value of a neutral network implies that there exists a “fair” distribution of total revenue to split between infrastructure and content service providers. The infrastructure provider can make as much as before while still leaving this amount on the table to split between other content providers and future network infrastructure. If market uncertainty is as large as it appears, then there is plenty of money to spread around to promote investment in network infrastructure and research.

VIII CONCLUSION

Our basic model illustrates the value of these unbiased choices that exists in neutral networks. Our model demonstrates how much bigger the total revenue pie might be, though it does not find a fair distribution of the increased revenue from neutral networks. Given a pie that could be four times as big for a natural network, a reasonable set of regulations, and a market where users can select what matches their needs best, the value exists that will provide the incentive to build network infrastructure providing a fertile environment conducive to the independent service and content providers, thus creating a surplus benefit to society. The important question changes from should the network be neutral, to how the bigger pie should be fairly split between transport and other service/content providers to insure that incentive exists to build infrastructure while creating a more varied service and content infrastructure that better meets uncertain user needs.

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