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FROM SWITCHES TO PACKETS: THE NEW WORLD OF INTERCONNECTION

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INTRODUCTION

In a striking parallel to explorer Hernando Cortes' decision in the 16th century to scuttle his ships upon his arrival at Veracruz, [1] in 2007 the Associated Press reported that installers working for Verizon remove traditional copper wiring from homes that convert to its fiber-optic service. There are multiple explanations for why a telecommunications provider might disconnect an incumbent network during a transition, including cost savings from lower maintenance and repair requirements for the outmoded network. Other observers point to the clause in the Telecommunications Act of 1996 that requires that incumbent providers such as Verizon to resell access to its traditional voice network at wholesale rates to other, independent, service providers. As described by Bauer, fiber optic connections to homes are exempt from this provision, so removing copper connections potentially forecloses retail competition in services.[2]

Severed connections to copper networks are probably the least disruptive aspect of the rapid transition to Internet-based voice communications. According to the Federal Communications Commission,[3] total telecommunications revenues in the United States, in nominal terms, increased from $269 billion in 1999 to $284 billion in 2009.[4] Adjusted for inflation, this amounts to a real decline in revenue of 23%. Telecommunications carriers typically charge each other for a variety of services. This revenue is a small portion of total revenue, averaging approximately 20%, but it is

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1 Deborah Yao, "Verizon Copper Cutoff Traps Customers, Hampers Rivals," *The Seattle Times*, July 10 2007, accessed Nov. 1, 2012, http://seattletimes.com/html/businesstechnology/2003782083_verizoncopper10.html.
2 Johannes M. Bauer, "Unbundling Policy in the United States: Players, Outcomes and Effects," *Communications & Strategies* no. 57(2005): 59-82.
3 Federal Communications Commission, Wireline Competition Bureau, "Trends in Telephone Service," technical report, September 2010.
4 This revenue is for all telecommunications firms that contribute to the FCC's universal service fund.

uniquely robust. Revenues from intra-industry services grew by 13% over the same period, almost triple the overall rate of revenue growth. The emergence of Internet-based voice communication, also referred to as Voice over Internet Protocol (VoIP), threatens to compromise this source of financial stability for telecommunications.

In a network system with positive spillovers, the value of the network to an individual subscriber is determined by the total number of subscribers who are on the network.[5] When subscribers purchase a service from subnetworks (hereafter called *subnets*) that are owned and operated by multiple independent firms, the interconnection of subnets will determine the effective size of the network for a given subscriber. In turn, interconnection will then determine the number of consumers or firms who will subscribe and the value of the network as well. As described by Dranove and Gandal, there is evidence that technologies with a low level of interoperability experience sluggish adoption.[6] In the context of communication, "walled garden" strategies (such as those adopted in the early days of Internet services like Compuserve) can significantly limit the reach of potential subscribers and hamper network growth.

In traditional voice telecommunications, interconnection markets have emerged as a technique for generating secondary revenue streams from subscribers and incentivizing firms to remove interconnection barriers. Interconnection fees allow communication to flow across subnets, at a price. Individual voice service providers traditionally charge other providers, and possible competitors, for interconnection and communication with its subscribers. As mentioned above these "termination fees" or "settlement charges" are an important and growing source of revenue. Some observers, such as DeGraba, have argued that this system is inefficient and that a "bill and keep" arrangement, in which charges between firms are reduced, would be superior.[7]

Interconnection is equally vital to Internet communications. On the Internet, "transit agreements" play a role analogous to interconnection charges on traditional voice networks. A transit agreement involves one Internet service provider charging another for transmission of traffic to its subscribers. Unlike traditional telecommunications, expensive fee-based agreements for interconnection between Internet subnets are the exception.[8] Instead, much Internet traffic flows across subnets through "peering agreements," in which individual subnet providers agree to exchange traffic for free. As traditional voice services give way to VoIP, termination charges may be rapidly replaced by peering, and fee-based interconnection could become an endangered source of revenue in telecommunications. A key point of this part of our discussion is the differentiation between the respective histories of analog- and digitally-switched networks: termination fees were a common

5 For a thorough overview of this topic, see Michael L. Katz and Carl Shapiro, "Systems Competition and Network Effects," *The Journal of Economic Perspectives* 8, no. 2 (1994): 93-115.

6 David Dranove and Neil Gandal, "The DVD-vs.-DIVX Standard War: Empirical Evidence of Network Effects and Preannouncement Effects," *Journal of Economics and Management Strategy* 12, no. 3 (2003): 363-386.

7 Patrick DeGraba, "Efficient Intercarrier Compensation for Competing Networks When Customers Share the Value of a Call," *Journal of Economics and Management Strategy* 12, no. 2 (2003): 207-230.

8 Bill Woodcock and Vijay Adhikari, "Survey of Characteristics of Internet Carrier Interconnection Agreements," technical report, Packet Clearing House, May 2011, accessed Apr. 30, 2012, http://www.pch.net/docs/papers//peering-survey/PCH-Peering-Survey-2011.pdf.

feature of telephony traffic exchanges from the start, while digitally-switched networks emerged under a different regime, in which peering arrangements tended to dominate.[9]

It is important to note that Internet interconnection is largely unregulated. In contrast, the World Administrative Telegraph and Telephone Conference of 1988 resulted in the International Telecommunication Regulations treaty, which provided a framework for the international exchange of telecommunications traffic. In particular, the treaty provided clear, if high-level, rules for ensuring interoperability and the collection of settlement fees for traditional voice networks. Notably, Article 9 of the treaty provided for "Special Arrangements," which facilitated the establishment and growth of virtual private networks and the exchange of Internet protocol traffic, both of which resulted in a decrease in settlement revenue. This state of affairs provides a central tension at the 2012 World Conference on International Telecommunications (where the entire regulatory framework for telecommunications, both analog and digital, will be revisited): simply put, fixed line termination revenue, an artifact of analog technology, is under pressure, and nations that rely on termination revenue from fixed line telephony have strong incentives to shape the new "rules of the game" to ensure that digital platforms provide similar revenue streams. This, along with other issues relating to the "platform" nature of digital switching, such as spam, malware, cybersecurity, and personal data protection (cloud storage), may lead to a balkanization of communications networks, and a reduction in their realized value.[10]

In this article we explore a model of price setting in unregulated network industries. We find that subscription and interconnection charges are determined by the level of markups and competition in the relevant market segments. Our model predicts that costly interconnection emerges when there is a low level of competition in the subscription market segment. It also provides a positive theory of peering: when competition for subscribers is high individual firms will optimally set interconnection charges to zero in order to maximize network effects and increase the total number of subscribers. We can further employ our model to investigate the impact on traditional telecommunications providers of changing from a costly to a free interconnection regime. If there is symmetry in the industry, a transition to peering may ultimately increase profits. Under asymmetry a transition to peering creates winners and losers, in part according to the pattern of traffic on the network.

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[9] Our analysis abstracts from recent evolutions in interconnection agreements on the Internet. Faratin, Clark, et al. discuss "mongrel" interconnection agreements such as partial transit and paid peering. Peyman Faratin, David D. Clark, Steven Bauer, William Lehr, Patrick W. Gilmore, and Arthur Berger, "The Growing Complexity of Internet Interconnection," *Communications & Strategies*, no. 72 (2008): 51-71.

[10] Basic analog-switched fixed-line telephony essentially provides one-to-one communication between two parties. Digital switching (on legacy and newer fiber networks), on the other hand, provides a sufficient condition for the creation of communications platforms that fundamentally alter the means of communication and the associated fee structure. For fixed line telephony, the fee structure generally consists of a fixed fee and a termination fee for international calls. For domestic calls, at least within the United States, fees for all calls are fixed. With digital switching, a fixed fee covers all costs. Moreover, with digital switching, communications are mediated by an ad-supported development platform, which changes the sources of revenues derived from access. Mobile telephony is a hybrid of the two regimes in terms of fee structure and platform potential: the fee structure for mobile phones is similar to that of landline phones with the associated termination charges (which are in fact often greater with mobile phones, considering some contracts specify termination fees for international calls, roaming fees, data fees, and text fees) but the data capacity of smartphones provides access to the Internet platform.

We explore a number of additional policy issues. Our results suggest that network neutrality concerns may become less pressing as a consequence of the transition to VoIP due to enhanced competition. However, relaxed regulatory review of mergers could result in additional pressure for interconnection regulation. Further, we suggest that through contracting practices a government can alter the topology of traffic flows and indirectly compensate firms that have a vested interest in maintaining costly interconnection.

The remainder of the article is as follows: in the second section we present our model of interconnection and derive the principal results. We analyze the impact of a transition to a peering regime in the following section. In the fourth section we discuss the policy implications of our results. In the final section we provide a conclusion to the article and suggestions for future research.

A MODEL OF INTERCONNECTION

In this section we develop a theoretical framework for analyzing the choices of profit-seeking subnet operators. Our model is general enough to describe the behavior of a firm in any network industry that follows the general principles embedded in our modeling assumptions.[11] After deriving our model's predictions we describe how underlying differences between traditional telecommunications and the Internet might explain the prevailing interconnection regimes in each industry.

Assumptions

For the purpose of our model we assume that there are two subnet operators (identified by an index $i = 1,2$) each of whom can collect subscription and interconnection revenues.[12] We further assume that network traffic is costly due to operating a subnet and adjusting its capacity (either due to network growth or depreciation of equipment). A given operator seeks to maximize its profits by choosing two values: the price of subscriptions, given by S_i; and the price of interconnection, given by I_i.

We further let N_i represent the number of subscribers to a given subnet and the total size of the network is given by $N \equiv N_1 + N_2$. Each subscriber pays the subscription price S_i so total subscription revenue is S_iN_i. By assumption, subscriber demand on a given subnet will depend upon subscription prices and the overall size of the network: $N_i = N_i(N, S_i)$. The law of demand applies to the demand function so $N_i^S \equiv \partial N_i / \partial S_i < 0$. We allow for network effects by assuming that demand for a subnet increases as the total size of the network increases: $N_i^N \equiv \partial N_i / \partial N > 0$. This assumption captures the notion that, given a fixed subscription price and as additional subscribers

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[11] It is important to note that we model unregulated interconnection markets. As mentioned earlier, in many economies traditional telecommunications interconnection markets are regulated while the corresponding Internet markets are unregulated. We leave the comparison of regulated and unregulated interconnection markets to other researchers while noting that our model can be applied for that purpose.

[12] It is trivial to expand our analysis to address an arbitrary number of network operators.

become available on the network, the return from subscribing to a particular subnet increases and draws in additional subnet users.

Traffic on subnets and between subnets has an impact on profits. Interconnection between subnets represents a revenue opportunity since a subnet operator can charge for "delivery" of information. We assume that the parameter t^{ji} represents the average amount of traffic that a user on subnet i receives from network j so total traffic received by subnet i is t^{ji} N_i.[13] Interconnection is charged per unit of total traffic so interconnection revenue received by subnet i is given by $I_i t^{ji}$ N_i. Interconnection costs for subnet i are given by $I_j t^{ij}$ N_j. Finally, a subnet operator has "intrafirm" costs of initiating and receiving traffic. If C_i^{ji} represents the constant marginal cost per unit of total traffic received by operator i from operator j's subscribers then total costs from receiving traffic are given by $C_i^{ji} t^{ji} N_i$. The constant marginal cost of all traffic initiated by operator i's subscribers and bound for subnet j is given by C_i^{ij} so that total origination costs are given by $C_i^{ij} t^{ij} N_j$.

Profit Maximizing Conditions

With these assumptions in hand, the profits for the operator of subnet i are:

$$\pi_i = S_i N_i(N,S_i) + I_i t^{ji} N_i(N,S_i) - I_j t^{ij} N_j - C_i^{ji} t^{ji} N_i(N,S_i) - C_i^{ij}\ t^{ij}\ N_j \tag{1}$$

Profits are given by subscription and interconnection revenue, net of interconnection and intrafirm costs from traffic. The first-order condition characterizing maximization of profits with respect to subscription prices is given by:

$$\frac{\partial \pi_i}{\partial S_i} = N_i + S_i N_i^S \left(1 + \frac{I_i t^{ji}}{S_i} - \frac{C_i^{ji} t^{ji}}{S_i} \right) = 0 \tag{2}$$

The marginal revenue from subscription prices is determined by the number of subscribers, since each pays a subscription price; and cost savings, since a higher subscription price reduces subscribers and traffic (the first and last terms above). There are two sources of marginal cost. A higher subscription price reduces the number of subscribers, which reduces both subscription and interconnection revenue (the second and third terms above). We define the price elasticity of demand as $\eta_S \equiv -S_i N_i^S \,/\, N_i$ and the markup rate, μ_S according $1 + \mu_S \equiv \eta_S \,/\, (\eta_S - 1)$. It is worth noting that in industries where there is substantial competition for subscribers, the elasticity of demand will be large and markup rates will be correspondingly lower. The profit-maximizing level of subscription prices derived from the first-order condition are:

$$S_i = (1 + \mu_S)\ t^{ji}\ (C_i^{ji} - I_i) \tag{3}$$

[13] Throughout the paper the superscripts xy indicate traffic originating on subnet x and terminating on subnet y.

so that subscription prices are a markup over the marginal cost of traffic net of interconnection prices (adjusted for the rate at which subscribers receive traffic).[14] This result illustrates the "waterbed effect" in that a higher interconnection price reduces subscription prices and increases subscribers.[15] When termination is more profitable, an operator has an incentive to reduce its access charges in order to expand subscribers to its subnet and monetize traffic to those subscribers through the interconnection market. Under the waterbed effect, interconnection charges can help support less expensive access to communications networks and increase their rate of adoption.

In order to solve for both profit-maximizing prices (subscription and interconnection) we make the additional assumption that the total size of the network, N, is a decreasing function of the interconnection prices of each subnet operator: $N = N(I_1,I_2)$ with $N^I_i \equiv \partial N / \partial I_i < 0$. This assumption captures the notion that as interconnection charges increase, there is a steeper price "barrier" to traffic flowing across subnets. We are implicitly assuming that this barrier ultimately reduces the expected value of the network to a potential subscriber.[16] If we substitute this additional assumption into the profit function, we obtain a first-order condition for determining the profit-maximizing interconnection fee as:

$$\frac{\partial \pi_i}{\partial I_i} = t^{ji} N_i + I_i N_i^N N^I_i \left(\frac{S_i}{I_i} + t^{ji} - \frac{C_i^{ji}}{I_i} \right) = 0 \tag{4}$$

There are two determinants of marginal revenue from interconnection: the rate at which traffic flows onto an operator's network and the cost savings created from the lower network size when higher interconnection costs discourage subscriptions. The marginal cost of interconnection charges stems from lower subscription and interconnection revenues as a subnet decreases in size.

We define two more elasticity terms: $\eta_N \equiv (N\, N_i^N) / N_i$ is the rate at which an operator's subscriber base increases in response to the network effect, while $\eta_I \equiv -I_i\, N^{Ii} / N$ is the rate at which more expensive interconnection reduces the overall size of the network. If we further define the interconnection markup rate as $1 + \mu_I \equiv (\eta_N\, \eta_I) / (\eta_N\, \eta_I - 1)$ we then obtain the profit-maximizing interconnection charge from the first-order condition as:

$$I_i = (1 + \mu_I) \left(C_i^{ji} - \frac{S_i}{t^{ji}} \right) \tag{5}$$

[14] We are further assuming that the price elasticity is constant and greater than 1.

[15] For one of the earliest discussions of the waterbed effect, see Stephen Littlechild, "Mobile Termination Charges: Calling Party Pays versus Receiving Party Pays," *Telecommunications Policy* 30, no. 5-6, (2006): 242-277. For subsequent research that has found evidence in support of this hypothesis, see Brendan M. Cunningham, Peter J. Alexander, and Adam Candeub, "Network Growth: Theory and Evidence from the Mobile Telephone Industry," *Information Economics and Policy* 22, no. 1 (2010): 91-102; Christos Genakos and Tommaso Valletti, "Testing the 'Waterbed' Effect in Mobile Telephony," *Journal of the European Economic Association* 9, no. 6 (2011): 1114-1142; Christos Genakos and Tommaso Valletti, "Mobile Regulation and the "'Waterbed Effect'," Jan. 4, 2010, accessed Nov. 2, 2012, http://www.voxeu.org/article/mobile-regulation-and-waterbed-effect.

[16] Examples of ways in which interconnection barriers might negatively affect the value of accessing networks include caps on traffic and/or throttling of speeds, and degradation of quality through compression.

Interconnection rates are a constant markup over the costs generated by traffic flowing onto a suboperator's network, net of the subscription revenue which is lost from greater interconnection costs reducing the overall size of the network. This result implies that, as subscription prices increase, a subnet operator optimally reduces its interconnection charge. A higher subscription price creates an opportunity for a subnet operator to increase profits by expanding its subscriber base. The firm achieves the greater network size by reducing its interconnection charge and leveraging the network effect.

If we combine the two solutions to the first-order conditions we obtain the solution to the profit-maximizing levels of subscription and interconnection charges:

$$S_i^* = \frac{\mu_I(1+\mu_S)t^{ji}}{(1+\mu_S)(1+\mu_I)-1} C_i^{ji} \tag{6}$$

$$I_i^* = \frac{\mu_S(1+\mu_I)}{(1+\mu_S)(1+\mu_I)-1} C_i^{ji} \tag{7}$$

Subscription and interconnection prices are fundamentally tied to the costs associated with originating traffic. A subnet operator sets a markup above these costs in order to determine prices and capture profits. It is worth noting that a subnet operator whose subscribers receive a large volume of traffic, on average, will seek to charge high termination rates (t increases S). Our model can help explain the attempt by ISPs to alter subscription terms in response to traffic flows (for example, tiering arrangements).

These results provide a number of interesting predictions regarding subnet prices and the impact of competition levels across market segments. First, it is relatively straightforward to show that as competition in the subscription market softens (μ_S increases) subscription prices decrease while interconnection charges increase. In traditional markets, a softening of competition and higher markups would typically generate greater prices. We obtain the opposite result in our model due to the network effect. A decrease in subscription prices expands the network and, when competition is low, the price-reducing firm will lay claim to a significant portion of the new subscribers. The higher interconnection charges allow the subnet operator to monetize the greater subscriber base and enjoy higher profits.

We further note that large markups in the interconnection market create higher subscription prices and lower interconnection rates. Large interconnection markups are an indicator that one, or both, of the following conditions holds: 1) interconnection costs have a small impact on the overall size of the network, and 2) the network effect is small. In these circumstances, the waterbed effect is weak. Higher subscription prices directly increase revenue but result in smaller networks. A subnet operator can counteract the drop in subscribers, and further enhance revenue gained from higher subscription prices, by cutting interconnection charges. This cut must be very large under a weak waterbed effect.

Our model also suggests that there is only one cause for free interconnection: the level of competition in the subscription market. From previous research we can see that subnet operators will set lower interconnection prices as the markup in the subscription market, μ_S, falls.[17] In other words, as the demand for subscriptions becomes more price sensitive, perhaps due to greater competition or increased availability of alternative communication options, firms will optimally choose to reduce interconnection charges.

In the extreme, when the subscription market is perfectly competitive and markups are zero the optimal interconnection charge is also zero (when $\eta_S \rightarrow \infty$, $\mu_S \rightarrow 0$, and $I_i^* \rightarrow 0$). This result provides a positive theory of why peering, as a free interconnection regime, has naturally emerged for Internet communication in contrast to the relatively expensive interconnection charges that prevail on traditional, incumbent, telecommunications networks. The relatively high level of competition for Internet service through options such as satellite, cable, fiber optic, DSL, wireless, and even dial-up providers implies that subscription markups are likely lower for Internet service. This induces free interconnection.

PROFITS UNDER A PEERING REGIME

We can employ our prior results, and the expression for profits, to evaluate the impact of Internet-based VoIP service on traditional telecommunications providers. Suppose we characterize the Internet as a market in which subscription price margins are zero, that is, $\mu_S = 0$.[18] Substituting this value into the solutions for subscription and interconnection prices, we obtain prices: $S^P_i = t^{ji}C_i^{ji}$ and $I^P = 0$. As mentioned above, interconnection charges are zero and peering arrangements prevail. There is a corresponding network size of $N^P = N(0,0)$ and subnet size of $N_i^P = N_i(N^P,S_i^P)$. The overall network effect is at its maximum. Finally, profits under peering are given by:

$$\pi_i^P = (S_i^P - C_i^{ji}\, t^{ji})N_i^P - C_i^{ij}t^{ij}\, N_j^P \tag{8}$$

Note that interconnection revenues and costs are absent from this expression and profits are completely determined by subscription revenues, traffic flows, and traffic costs.

In contrast, consider a far less competitive, traditional telecommunications market in which markups are 100% so that $\mu_S = 1$. Assume that all other network characteristics, such as traffic flow patterns and costs, are the same as in the more competitive subscription market. In this case, interconnection is costly and the interconnection price is $I_i^T = (1+\mu_I)C_i^{ji} \,/\, (1+2\mu_I) > I_i^P = 0$.[19] This additional interconnection revenue generates a waterbed effect and the telecommunications provider charges a

[17] Cunningham, Alexander, and Candeub; Genakos and Valletti (2010).
[18] Note that under this assumption Internet subnet operators can still earn normal economic profits.
[19] This markup value was arbitrarily chosen in order to illustrate the model's predictions.

lower subscription price (relative to peering) so $S_i^T = (\mu_I t^{ji} C_i^{ji}) / (.5 + \mu_I) < S_i^T$.[20] As a consequence of the greater interconnection cost the overall network size is lower: $N^T = N(I_1^T, I_2^T) < N^P$ and this lower overall network size reduces the demand for an individual firm's network. However, the lower subscription price partially counteracts the drop in demand induced by weaker network effects. Ultimately, an individual network's subscriber base is: $N_i^T = N_i(N^T, S_i^T)$. Under costly interconnection profits are then given by:

$$\pi_i^T = (S_i^T + I_i^T t^{ji} - C_i^{ji} t^{ji}) N_i^T - (I_j^T + C_i^{ij}) t^{ij} N_j^T \tag{9}$$

From this expression we can contrast profits under the two regimes (peering and costly interconnection). It is helpful to begin with the more straightforward case in which subnet operators are similar.

Costly Interconnection Under Symmetry

Suppose that the two telecommunications firms are symmetric in all respects. In that case each will find that its subnet is smaller (a smaller overall network must imply that each subnet operator has a smaller network if all are behaving the same). The smaller subscriber base will reduce all revenue sources as well as total costs. Because of symmetry, the interconnection revenues of an operator will exactly equal its interconnection costs. Charging for interconnection has the same effect on profits as peering: none. The interconnection market is similar to an arms race in which each subnet operator charges the other for interconnection but the interconnection revenues are a wash in terms of profits. The waterbed effect represents a net loss since the revenues gained from interconnection are exactly offset by interconnection costs. Profits simplify to:

$$\pi^T = (S^T - C^{ii} t - C^{ij} t) N^T. \tag{10}$$

Since total revenues are lower due to fewer subscribers, each of whom pay less, profits will be lower under costly interconnection (assuming cost savings from a smaller subnet do not compensate for lost revenue). In this case, moving to a peering arrangement increases profitability, despite the higher level of competition in the subscription market. To a large degree this result is driven by the larger network that is achieved under peering, and the waterbed effect that suppresses subscription prices and "drowns" profits when interconnection is not, on net, profitable.[21]

Costly Interconnection with Traffic Asymmetries

Suppose that the only source of differentiation across subnet operators is traffic so that $t^{ji} \neq t^{ij}$ but costs are symmetric. Suppose there is an "audience" subnet whose subscribers receive a large volume of traffic, on average, and label that average t^E. The other subnet is a "content" network that

[20] An implicit assumption in this discussion is that costs do not change under costly interconnection, relative to peering.
[21] This result would be even stronger if firms incurred transaction costs in order to settle the interconnection charges (such as the development and enforcement of legal agreements). In that case interconnection, under symmetry, would represent a net loss to firms.

receives a small amount of traffic and sends the large volume to the audience network. Call the average traffic received on the content network t^C. Our model predicts that the audience subnet operator will charge a higher subscription price than the content operator ($S_A^T > S_C^T$) but that interconnection rates will be the same for both operators. The audience subnet will be smaller than the content subnet as a consequence of the subscription price differential ($N_A < N_C$). The profits of the audience and content subnet operators will be:

$$\pi_A^T = (S_A^T - C_A^{AC}t^A)N_A^T - C^{CA}t^C N_C^T + I^T(t^A N_A^T - t^C N_C^T) \tag{11}$$

$$\pi_C^T = (S_C^T - C_C^{CA}t^C)N_C^T - C^{AC}t^A N_A^T - I^T(t^A N_A^T - t^C N_C^T) \tag{12}$$

respectively. Provided the traffic flows are sufficiently asymmetric the interconnection market will result in a transfer of profits from the content subnet to the audience subnet. When interconnection charges drop to zero under peering, the audience subnet will lose a source of profits while the content subnet will eliminate a source of costs.

More generally, our model predicts that there are some subnet operators who benefit from a shift to peering while there are others who lose profits under peering. In particular, a subnet operator with subscribers who, on average, receive more traffic through interconnection (relative to subscribers on other networks) will find that interconnection is profitable. In this case, interconnection profits could more than offset any lost revenues from a lower subscriber base and the interconnection beneficiary would lose profits under peering. However, the second firm, which receives a low level of traffic, would find that interconnection is, net, costly and would prefer peering. In this sense, a transition to VoIP would not represent a Pareto improvement, but it would improve profits for one firm.

POLICY IMPLICATIONS

Our modeling results provide a number of insights that are relevant to policymakers. The transition away from "plain old telephone service" (POTS) and toward VoIP can increase competition for subscribers given the relatively heterogeneous pool of Internet service providers. Our model predicts that increased competition will induce lower interconnection charges and, somewhat surprisingly, increase subscription prices. This trend could hamper universal service goals by raising the cost of network access. Public policy could counteract the increase in subscription costs through an extension of the universal service fund to the Internet. However, a low-cost interconnection regime can, itself, induce network growth since it lowers the barrier to communication across subnetworks. This positive network effect will encourage more widespread subscriptions to communication services, thereby furthering universal service objectives.

Our results demonstrate that competition for subscribers is critical in determining the nature of interconnection. Regulations which support municipal Wi-Fi would tend to encourage inexpensive interconnection and encourage network build-out. There are also reasons to believe that the transition to VoIP may reduce the need for network neutrality regulation. Traditional Internet subscribers have employed a particular set of protocols (principally TCP/IP and HTTP). A VoIP subscriber is effectively an Internet subscriber whose predominant traffic flows over a non-traditional protocol. Telecommunications firms that rely upon VoIP are effectively competing for Internet subscribers in need of a particular protocol. This intensified competition for subscribers will dampen an already weak tendency to charge for Internet interconnection. The specter of costly interconnection is one of the more prominent rationales for network neutrality legislation. Thus, our analysis suggests that the transition to VoIP will weaken the need for regulation.

We have also discovered a novel and interesting nexus between merger regulation and policies regarding network neutrality. Under a scenario in which Internet service providers are allowed to merge more frequently, the level of competition would decrease, other things being equal. Our model predicts that this could lead to higher interconnection charges and smaller networks of Internet subscribers. Further, the deregulatory change that precipitated more costly interconnection could, ironically, spur calls towards additional regulation in the form of network neutrality provisions. It is worthwhile for policymakers to know that deregulation could become a zero-sum game in which less regulation in one area induces additional regulation in others.

It is also important to note that, while greater competition can reduce interconnection costs and bolster network growth, there is a tradeoff. A greater number of firms competing for subscribers is likely to place significant downward pressure on profits. Particularly as Internet penetration nears 100% and competition results in "business stealing" rather than market expansion, each firm could face significant risks from regulations that enhance entry. For this reason regulators should carefully consider the impact of the VoIP transition on the stability of incumbent firms in the Internet subscription market.

Our model also suggests that, under symmetric traffic patterns, firms will see an increase in profits as a consequence of the transition to VoIP. Greater profits arise from market expansion and greater subscription prices under a low-cost interconnection regime. Consequently, the transition towards VoIP should not generate industry resistance. It is worth noting that our prediction regarding a profitable transition away from POTS is driven by market dynamics rather than assumptions regarding the high cost of operating outdated network equipment or the potential for innovative, profitable, supplementary voice services uniquely offered by Internet protocols.[22]

In a market characterized by network traffic asymmetries we would expect to see calls, by a subset of firms, for policies that might hamper the transition to VoIP. In particular, firms that specialize in receiving more traffic than they originate will find that traditional interconnection is profitable. Those firms would face financial challenges under a peering regime. Public policies that offer transfers to such parties would soften resistance to the phase-out of POTS systems. Those transfers might also reduce industry interest in regulations that maintain existing interconnection regimes. An

[22] VOIP represents an opportunity to add additional, profitable service layers on top of traditional voice service.

intriguing option is that, through their own contracting practices with telecommunications firms and Internet service providers, policymakers could alter the network topology in a way that lowers the stakes for firms that profit from interconnection. For example, suppose a government agency spends a disproportionate amount of time placing, rather than receiving, telephone calls (or sending rather than receiving Internet traffic). If that agency were to identify firms that have traditionally received more traffic than they initiated and subscribed for service with that firm, then the agency would balance interconnection traffic and render interconnection neutral with respect to profits. In this sense the "transfer" would be indirect. This policy option would require careful coordination with the Federal Communications Commission in order to evaluate potential service providers. Further, it would require careful conformity to the rules of federal contracting.

CONCLUSION

Interconnection markets have historically provided an important source of (termination) revenue to traditional voice telecommunications operators. It is natural to assume that a transition to Internet-based telephony, and the corresponding loss of interconnection revenues under peering, will erode profits for incumbent telecommunications providers. We have presented a model of interconnection which predicts that peering can naturally emerge as a consequence of competition in the subscription market. With soft competition in subscriptions, as typically occurs in traditional telecommunications, interconnection is costly and subscription prices are correspondingly lower as a consequence of the waterbed effect. We show that, under symmetric market conditions, traditional telephony could experience higher profits under peering since the waterbed effect creates an uncompensated loss in subscription revenue.

Our model further implies that, under asymmetries in communication traffic flows, firms with profitable interconnection can lose profits as a consequence of peering. This result suggests that the transition to VoIP will be most disruptive to profits in telecommunication markets characterized by a topology of asymmetric traffic flows. The social welfare impact of the transition to VoIP, and its impact on interconnection markets, remains for future research. Our results suggest that peering generally increases the total size of networks but at greater cost to subscribers. The net effect on consumer welfare of peering is unclear. Future research might also employ information on traffic flows, competitiveness, and interconnection markets to explore the validity of our model's predictions.

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