

Broadband Adoption in the United States: An Empirical Analysis

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Abstract

There is a policy debate at both state and federal levels over how to facilitate consumer adoption of the Internet and, particularly, broadband technology to access the Internet. The objective of this study is to offer empirical evidence directly relevant to this debate. In so doing, we examine the influence of availability, competition, and demographics on the adoption of broadband technology in the U.S. The focus of our study is on the effect of intermodal (cable modem v. DSL) competition on broadband penetration, relative to the effect of simple broadband availability. The econometric results indicate that after controlling for the demand and cost influences on adoption, intermodal competition drives increased penetration in a state. In fact, while total broadband penetration in a state increases with total broadband availability in the state, the effect of total availability disappears when intermodal competition is controlled for. It appears, then, that broadband availability in a state is driven by intermodal competition and the demand and cost factors, but not by raw availability of broadband services, given those other factors. The independent effect of direct, intermodal competition is statistically significant and of substantial magnitude.

I. INTRODUCTION¹

There is growing concern over the rate at which the Internet and broadband access to the Internet are being adopted in the U.S. By historical standards of new product adoption, Internet and broadband adoption have been nothing short of extraordinary. Nevertheless, these rates have fallen short of previous expectations and have even declined in the last few years.^{2, 3} As a result, a policy debate has erupted over how to

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² Based on an annual survey by Harris Interactive, the percentage of adults with access to the Internet (be it from home or work) increased from 9 percent in 1995 to 63 percent by the end of 2000, whereas since then it has only increased 4 percentage points to 67 percent by the end of 2002. "The Harris Poll: Online Population Continues to Expand but Just Barely," *Wall Street Journal Online*, February 5, 2003.

³ In June and December of 2000, the (trailing six month) percentage growth in broadband subscribership was approximately 60 percent; in subsequent reporting periods the (trailing six month)

facilitate consumer adoption of the Internet and, particularly, broadband technology to access the Internet.⁴ At its base, the debate is over arcane topics such as defining broadband (information service vs. telecommunications service) and who gets access to the telephone lines and cables reaching consumers. In practical terms, the issues pertain to the regulatory conditions placed on providing access to existing broadband infrastructure and promoting an environment in which existing technologies – principally, cable modem and digital subscriber line (DSL) – can compete effectively against each other.

The premise of much policy pronouncement in the U.S. is that the greater is the geographic coverage of broadband availability, the greater broadband adoption and (of course) the greater the resulting social welfare. Needless to say, the determinants of broadband adoption are more complex and include both demand and supply factors. On the demand side, many have argued that there will be no mass-market adoption of broadband, regardless of availability, until sufficiently attractive broadband applications emerge that make the additional cost of broadband access worthwhile (known as the “killer app” theory).⁵ Naturally, others argue that there will be no substantial investment in developing and deploying a “killer app” until broadband availability is sufficiently widespread that the investment in applications is worthwhile.⁶ On the supply side,

percentage growth had declined from 36 percent in June 2001 to 27 percent in June 2002. FCC (2002), Table 1.

⁴ See, for example, Jim Landers, “Broadband believer: FCC’s chair presses for big leap for U.S. high-speed Internet,” *The Seattle Times*, October 21, 2002 (“One of the few points of agreement in the broadband debate is that the move to high-speed access will remain slow till the FCC clears away a dense fog of regulatory ambiguity.”); and Charles H. Ferguson, “The U.S. Broadband Problem,” The Brookings Institution, Policy Brief #105, July 2002 (“The pace of deployment and technological progress in broadband, or highspeed, services remains seriously inadequate...”); George Gilder, “Broadband’s Narrow Minds,” *The Wall Street Journal*, February 19, 2003 (“Just three years ago, the U.S. was overwhelmingly dominant in communications technology and deployment ... Today, the U.S. is falling precipitously behind.”).

⁵ Howell (2002) observes that content availability is the primary factor “stimulating demand for cable products, [and] thereby creating competitive pressure on DSL offerings. While local loop unbundling posits faster response to this competitive pressure...the evidence implies that application cost-benefit tradeoffs are the primary drivers of broadband uptake.”

⁶ See, for example, William E. Kennard, *Consumer Choice Through Competition*, Remarks at the National Association of Telecommunications Officers and Advisors 19th Annual Conference, September 17, 1999 (“Our challenge today is to make broadband happen ... The demand is there. Americans want it. If we can get it there, it will open up a whole new horizon for electronic commerce in this country.”); and TechNet, “TechNet CEOs Call for National Broadband Policy,” January 15, 2002 (John Chambers, President and CEO Cisco Systems and Co-Founder of TechNet contends that “[i]n order to stay

substantial investment is necessary either to upgrade existing cable infrastructure from a television-centric technology to one that permits two-way digital broadband Internet access,⁷ or to extend fiber optic cable into the neighborhoods in order to expand the geographic footprint of availability of DSL service.⁸ The expected return on such investments depends not only on investors' expectations about forthcoming demand, but also on the extent of competition that is likely to arise. Finally, consideration must be given to the obligations of incumbents to unbundle their broadband infrastructure and provide pieces of it at regulated rates that may not be compensatory for the risks and costs assumed by the investors.

Unbundling obligations imposed on one technology affect the desirability of investment in all broadband technologies. Unbundling obligations imposed on incumbent telecommunications providers' DSL facilities decrease those carriers' incentives to invest in DSL build-outs and, thereby, affect the cable and wireless providers' desire to invest in broadband technologies. On the one hand, it may decrease the urgency of cable providers to expand their geographic presence and gain any first-mover advantage won thereby. On the other hand, it might encourage cable deployment in areas that would otherwise be uneconomical given the prior presence of DSL. In either case, however, where cable providers have no competition from DSL technology (or vice versa), one would expect a decrease in the sole provider's incentives to compete vigorously for customers. Hence, one might anticipate supply factors that would drive broadband adoption to include the extent to which there is direct competition across broadband technologies (intermodal competition) at any level of overall availability of broadband services.

competitive, educate the workforce and increase productivity, the United States must have ubiquitous broadband.").

⁷ Figures from the NCTA indicate that over the past five years, the cable industry has invested nearly \$50 billion "to upgrade more than three-quarters of a million miles of plant with fiber optics." National Cable & Telecommunications Association, "Remarks of Robert Sachs, NCTA President and CEO at Cable 2001, 'We're Making Broadband Happen,'" Press Release, June 11, 2001.

⁸ SBC, for example, announced in early 2000 an ambitious \$6 billion investment, dubbed "Project Pronto," that seeks to build out its fiber plant and, accordingly, extend the reach of its DSL services. Computer Science and Telecommunications Board (2002), pp. 259-263.

It might be predicted, a priori, that an empirical examination of the effect of availability on penetration would show a positive relationship, namely, more availability, more penetration. However, our discussion suggests that once the effect of competition is taken into account, the relationship may not be so straightforward. In fact, it is not clear which factor would have a more powerful impact on broadband adoption: the raw availability of broadband services, or the extent of competition across broadband platforms. This theoretical ambiguity can have unexpected effects on the relationship between total availability and penetration. Consider, for example, two hypothetical states: in one state, half the residents have DSL available, but not cable, and half have cable, but not DSL; in the other state, half the residents have no broadband available, but the other half have both platforms available. In the first state, the provider would price to maximize profit given the lack (in the short run) of an alternative provider in the state. An optimal price in the first state, given the absence of a competitor is most likely to limit the fraction of customers purchasing the service. In the second state, however, the normal mechanisms of competition between the platforms would drive price, advertising, quality, and other factors to encourage penetration, within the area in which the platforms are available. Hence, the first state might have a higher or lower overall level of penetration than the second.

II. OBJECTIVE

The objective of this study is to offer empirical evidence directly relevant to the policy debate. To date there has been little research responsive to the issues raised and the limited research that has been conducted is only partially relevant. This could be attributed to the sheer novelty of the issue. Likewise, it might be due, in part, to the difficulty in modeling the relationships between competition, availability, and broadband adoption; namely, the nature of broadband availability and competition are clearly endogenous to a model of broadband adoption. In this study, we examine the influence of availability, competition, and demographics on the adoption of broadband technology in the U.S. The focus of our study is on the effect of intermodal competition on broadband penetration, relative to the effect of simple broadband availability. Our efforts

to model this relationship should be viewed as a first step to bringing empirical evidence to the table. We take measures to control for the endogenous effects of competition and availability on adoption, but we admit, this effort is imperfect. Nevertheless, we believe the strength of the results and their intuitive appeal are compelling.

To motivate the empirical analysis, consider the following stylized representation of the broadband penetration. For purposes of this exposition, we model penetration very simply. That is, we assume that penetration in areas in which broadband is available is a function of whether there is or is not intermodal competition (we assume that if there is no availability of broadband service, broadband penetration in such areas is zero). Let $P(O)$ represent the percent of broadband penetration in geographic regions in which there is “overlap,” by which we mean head-to-head intermodal competition between cable modem and DSL platforms; that is, $P(O)$ is the number of broadband subscribers in the geographic regions in a state in which both platforms are available, divided by the population of those geographic regions. Let $G(O)$ represent the fraction of the state’s population who reside in the geographic regions in which there is overlap availability (i.e., in which both DSL and cable broadband services are available). Similarly, Let $P(E)$ represent the percent of broadband penetration in geographic regions in which one or the other platform is available, but not both (“exclusive” availability); that is, $P(E)$ is the number of broadband subscribers in geographic regions in a state in which one or the other platform is available, but not both, divided by the number of residents in such regions. Let $G(E)$ represent the fraction of the state’s population who reside in the geographic regions in which there is exclusive availability of one or the other platform. In this notation, total broadband availability in the state, TA , is $G(O) + G(E)$. With this notation, total broadband penetration in a state (TP) would be:

$$TP = P(O)G(O) + P(E)G(E).$$

We define “total penetration” in a state to be the number of subscribers divided by the state’s population; that is, penetration measures actual subscribership, while availability reflects the extent to which customers could subscribe.

One could then ask, as a simple mathematical relationship, how does TP vary with the availability measures, G(O) and G(E)? The relationship must recognize that, empirically, there may be a positive or negative underlying relationship between G(O) and G(E). Both of these variables are determined by factors that affect the attractiveness of the market for broadband providers, including expected intensity of demand and expected costs of service. Suppressing these factors, in reduced form:

$$\partial TP / \partial G(O) = P(O) + P(E) \partial G(E) / \partial G(O),$$

and

$$\partial TP / \partial G(E) = P(E) + P(O) \partial G(O) / \partial G(E).$$

Hence, depending on the signs of the cross partials between G(E) and G(O), penetration may increase or decrease with G(E) and G(O), when $P(O) \neq P(E)$. If $P(O) = P(E)$ (i.e., if intermodal competition has no effect on broadband penetration), then total penetration is simply a function of total availability, and one would expect, unambiguously, a positive relationship between penetration and availability. However, if G(O) and G(E) are negatively correlated across states, then the sign of the effects of overlap availability and exclusive availability on total penetration would depend on the magnitude of the correlation and the relationship between P(E) and P(O). If, for example, there were no effect of competition on penetration ($P(E) = P(O)$), then an increase in overlap availability would be associated with an increase in total penetration as long as overlap penetration were positively correlated with total penetration (i.e., $\partial G(E) / \partial G(O) > -1$); and an increase in exclusive availability would be associated with an increase in total penetration as long as exclusive availability were positively correlated with total penetration (i.e., $\partial G(O) / \partial G(E) > -1$). Our primary interest is in determining if intermodal competition (overlap availability) has a positive effect on penetration. Hence, we are interested in determining whether $P(O) > P(E)$.

We model empirically the effects of both overlap availability (intermodal competition) and exclusive availability on broadband penetration, controlling for demand variables, cost variables, and other factors. In doing so, we adopt a weighted logit model

that employs a single cross-section of state level (grouped) data. The model controls for demand and cost factors that influence the level of broadband adoption in a state, such as education, Internet access, line density and average loop length. The focus of primary importance in this paper is the influence of the overall availability of DSL and cable modem services in a state, and the overlap of this availability to both cable modem and DSL technologies. We cannot directly measure $P(O)$ and $P(E)$. However, we can address the question of interest by estimating the following linear model:

$$TP = \alpha + \beta(G(O), G(E), \text{demand controls}, \text{cost controls}).$$

In this model, the coefficient on $G(O)$ estimates $P(O)$, and the coefficient on $G(E)$ estimates $P(E)$.

The econometric results indicate that, in fact, $P(O)$ appears to exceed $P(E)$, controlling for demand and cost drivers. That is, we conclude that after controlling for the demand and cost influences on adoption, intermodal competition drives increased penetration in a state. In fact, while total broadband penetration in a state increases with total broadband availability in the state, the effect of total availability disappears when intermodal competition is controlled for. It appears, then, that broadband availability in a state is driven by intermodal competition and the demand and cost factors, but not by raw availability of broadband services, given those other factors. The independent effect of direct, intermodal competition is statistically significant and of substantial magnitude.

The organization of this paper is as follows. Section III summarizes previous studies that have addressed Internet and broadband deployment and adoption. Section IV provides a description of our econometric model, the variables employed in the model, and data sources. In Section V, we present our results, and in Section VI, we conclude with a discussion of the policy implications of our findings.

III. PREVIOUS STUDIES THAT HAVE ADDRESSED BROADBAND DEPLOYMENT AND ADOPTION

To our knowledge, the first econometric study to examine broadband adoption is Madden, Savage, and Simpson (1996) (MSS) who examine survey data on a sample of Australian households. The survey asked participants to describe their preferences for a yet-to-be deployed broadband service. The authors discover a variety of demographic characteristics that influence an individual's decision to adopt broadband. They find, among other things, that individuals without a secondary degree express less interest in broadband; individuals residing in households with at least one member originating from Europe or Asia express greater interest; and age matters – respondents expressed less interest in broadband if one or more people in the household was 65 years or older. Surprisingly, a negative but statistically non-significant coefficient is found on the variable controlling for households with Internet access.

Rappoport, Kridel and Taylor (2002) (RKT) estimate the demand for broadband but within a slightly different context than MSS. RKT rely on survey data comprised of demographic information on a sample of households from across 10 U.S. cities. The households in the sample all subscribe to Internet access, but their choice of access is split between narrow-band (dial-up) and broadband. The authors separate the data into two groups, those who have chosen narrowband access and those that have chosen broadband access. The focus of their paper is, accordingly, on the characteristics that distinguish broadband users from narrowband users, rather than on what distinguishes Internet users from non-users (as does MSS). They find, using a probit model, that income and household size affect positively the likelihood of selecting broadband over dial-up. A somewhat surprising result of their study is the correlation between age and broadband subscribership: older users, they estimate, are more likely than younger users to choose broadband over dialup.

Another recent study that considers the demographic influences on adoption is the U.S Department of Commerce (2002). The study explores the same set of issues as MSS, except that it employs survey data on a sample of U.S. respondents and considers actual adoption patterns (as opposed to anticipated adoption, in the case of the Australian

study). Not surprisingly, the Commerce study reached conclusions similar to those of MSS. In particular, the Commerce study finds that among the adult population, a smaller proportion of people aged 50 or older use the Internet than do those in younger adult age groups. Likewise, ethnic groups are found to have different levels of use; 50 percent of those surveyed in the White and Asian ethnic groups use the Internet, compared to 29 and 24 percent in the Black and Hispanic groups. The study finds a stark difference in Internet use by education group. For instance, only 13 percent of those surveyed with less than a high school education used the Internet, while 75 percent of those surveyed with a Bachelors degree or higher used the Internet.

While each of the above studies provides us with valuable information about who is more or less likely to be using the Internet or adopt broadband Internet access, they do not tell us whether or how the outcomes are affected by availability or how competition affects uptake. In sum, the Commerce study, MSS and RKT provide insight as to the demand characteristics associated with adoption, but do not tell us how cost and market structure factors affect adoption.

Gabel and Kwan (2000) address this deficiency in the literature by examining the cost and demand influences on the availability of residential broadband Internet access. The authors compile a detailed data set comprised of observations at the wire center level across the U.S. Using a stratified sampling method, they select a sample of nearly 300 observations. They employ a logit model to estimate demand and supply factors that influence the probability that DSL or cable modem are available in a wire center service area. Of the demand variables that are statistically significant, the authors find that where adults between 30 and 34 years in age are in greater number, there is a greater probability of deployment. Likewise, median income has a significantly positive influence on deployment. The cost variables they consider that are found to be statistically significant are teledensity (i.e., the number of telephone lines per square mile) and the estimated cost of transporting data traffic to the Internet backbone. The coefficients on both variables are negative, as anticipated. An interesting conclusion of their study is that none of the coefficients on the RBOC dummy variables in their regression are statistically significant. Based on this finding, they conclude that “residential customers in areas served by

Regional Bell Operating Companies, all else equal, are equally likely to have high-speed access to the Internet as customers served by Independent telephone companies.”⁹

In a report that perhaps most directly addresses the areas of interest in our study, the Organization for Economic Cooperation and Development (2001) (OECD) examined the adoption of broadband technology across the 30 OECD member countries. Unlike OECD (2001), however, our study takes an econometric approach rather than a survey approach, and we examine the variations in broadband adoption across U.S. states, rather than the variations across countries. The OECD report found that “[o]ne of the key ingredients in why some countries are forging ahead, is whether there is competition between different networks and networks with different technologies,” and that “[t]here is a significant correlation between the growth of cable modems and DSL services.”¹⁰

Countries where cable and DSL compete (rather than being jointly owned by the same entity) generally have a stronger broadband market. In Belgium, for example, Telenet launched its cable Internet access service as early as 1997. The existence of cable as a competitive alternative had a significant impact on the incumbent carrier’s efforts to market DSL. As a result, Belgium is among the OECD countries with greater broadband penetration. Canada, ranked second in the OECD in terms of broadband penetration, is another case in point. Cable networks in Canada were among the first to introduce cable modem services, dating as far back as 1996. This early launch of broadband access with cable technology almost immediately spurred the reaction of telecommunications carriers. In November 1996, Sasktel became the first carrier in the OECD to offer broadband access using DSL technology. By June 2001, broadband penetration in Canada was close to five subscribers per 100 inhabitants, twice as much as the U.S. penetration rate, which is 2.25 per 100 inhabitants according to the same OECD study.

Another key finding in the OECD report is that both competition between technologies (intermodal competition) and among the facilities-based providers of the same technology (intramodal facilities-based competition) are important factors in the

⁹ Gabel and Kwan (2000), p. 1.

development of broadband markets. The report points to the case of South Korea, where the penetration rate of 9.2 subscribers per 100 inhabitants exceeds by far that of all other OECD countries. In South Korea, there are multiple companies competing with their own infrastructure, be it cable or DSL. The OECD study concludes that “[t]he most fundamental policy available to OECD governments to boost broadband access is infrastructure competition.”¹¹

The existing research provides a helpful starting point in developing our study. However, the focus of our investigation is different from and complementary to the existing research. Our study investigates the demand and cost influences on broadband adoption, as do the existing studies. But the primary focus of our study is an issue that has not been dealt with previously in an econometric fashion; namely, we seek to estimate the impact on adoption of variation in the competitiveness of availability, from instances of no availability, to single platform availability, to multiple platform availability. From this we hope to discover how and to what extent intermodal competition influences broadband uptake in the U.S. This is a difficult issue to investigate empirically and it entails certain shortcomings that we describe below. Our study is motivated by the absence of empirical literature on this important topic and the urgency with which a better understanding is needed to properly devise policy in this area.

IV. THE EMPIRICAL MODEL

To determine the impact of demographic and market structure characteristics on broadband adoption, this paper examines the following reduced form relationship:

$$\text{PENETRATION} = f(\text{EDUCATION, INTERNET, TELEDENSITY, LENGTH, PLOOP, AVAILABILITY, OVERLAP, SKEW, BELLSOUTH, VERIZON, QWEST})$$

Where each variable is measured at the state level and defined as:

¹⁰ OECD (2001), p. 9.

| | | |
|--------------|---|---|
| PENETRATION | = | The number of broadband subscribers in the state, weighted by population, as of December 2000; |
| EDUCATION | = | The percentage of the population in the state, 25 or over with a Bachelors degree or higher, as of December 1990; |
| INTERNET | = | The percentage of households in the state with Internet access, as of October 2000); |
| TELEDENSITY | = | The number of incumbent local exchange switched access lines in the state, per square mile, as of December 2000; |
| LENGTH | = | The average length of an incumbent local exchange switched access line in the state, as of December 1998; |
| PLOOP | = | The regulated price for a Regional Bell Operating Carrier (RBOC) unbundled network element (UNE) loop in Zone 1 (urban areas) in the state, as of May 2001; |
| AVAILABILITY | = | The percentage of the population in the state residing in a city where cable modem or DSL are deployed, as of April 2000; |
| OVERLAP | = | The percentage of the population in the state residing in a city where cable modem and DSL are deployed, as of April 2000; |
| SKEW | = | The percentage by which cable modem penetration exceeds DSL penetration in the state, as of June 2002; |
| BELLSOUTH | = | Binary (1/0) variable indicating states where BellSouth is the RBOC (1); |
| VERIZON | = | Dummy (1/0) variable indicating states where Verizon is the RBOC (1); and |
| QWEST | = | Dummy (1/0) variable indicating states where Qwest is the RBOC (1). |

Descriptive statistics and data sources are provided in Table 1.

¹¹ OECD (2001), p. 4.

**Table 1:
Variable Names, Descriptive Statistics, and Sources**

| Variable | Mean | Standard Deviation | Source |
|-----------------|-------------|---------------------------|---------------|
| PENETRATION | 150,353 | 228,839 | a |
| POPULATION | 6,101,113 | 6,386,824 | b |
| EDUCATION | 0.1298 | 0.0245 | b |
| INTERNET | 0.4999 | 0.0646 | c |
| TELEDENSITY | 108 | 168 | a, b |
| LENGTH | 14,461 | 3,112 | a |
| PLOOP | 13.51 | 4.73 | d |
| AVAILABILITY | 0.2411 | 0.1201 | e |
| EXCLUSIVE | 0.1346 | 0.0881 | e |
| OVERLAP | 0.1064 | 0.0989 | e |
| SKEW | 0.3688 | 0.2165 | a |
| BELLSOUTH | 0.1957 | 0.4011 | f |
| VERIZON | 0.2174 | 0.4170 | f |
| QWEST | 0.2826 | 0.4552 | f |
| SBC | 0.2826 | 0.4552 | f |

Sources:

(a) Federal Communications Commission, Industry Analysis and Technology Division, *High Speed Services for Internet Access* (various reports).

(b) U.S. Census Bureau, various reports.

(c) U.S. Department of Commerce, National Telecommunications & Information Administration, *Falling Through the Net: Toward Digital Inclusion*, October 2000, Table I-B.

(d) Billy Jack Gregg, *A Survey of Unbundled Network Element Prices in the United States*, April 2001.

(e) Rural Utilities Service & National Telecommunications & Information Administration, Joint Project, *Advanced Telecommunications in Rural America: The Challenge of Bringing Broadband Service to All America*, Appendix A and B, April 2000.

(f) Company websites.

The dependant variable in our analysis, PENETRATION, consists of total broadband subscribership in a state. Our source for data on PENETRATION is the FCC's biannual report on broadband adoption, *High Speed Services for Internet Access*.

The report includes, among other things, two measures of broadband adoption: (1) total subscribership, and (2) small business and residential subscribership. The results of our study are effectively unchanged by our choice of total subscribership as opposed to total small business and residential subscribership. There are, of course, other possible dependent variables that are interesting to consider, most obviously the price of broadband within a state. We do not consider price in our study due to the absence of available data.¹²

The independent variables in the above equation can be classified into four categories:

i. Demand Controls. The variable INTERNET is included to control for the hypothesized complementary relationship of Internet access to broadband adoption. Therefore, a positive estimated coefficient is expected.¹³ We include the variable EDUCATION to control for the hypothesized positive influence that education has on demand.¹⁴ This variable may also partially control for the influence of income on demand, which one would also expect to be positive. A preliminary regression was run controlling for the influence of income. It was found to be statistically insignificant and the results of an F-test indicated that we should leave the income variable out of the regression.

ii. Cost Controls. TELEDENSITY is included to control for the cost of deploying broadband technology. The decision to deploy broadband should be less costly in those states where there are more switched access lines per square mile. Therefore, a positive

¹² Moreover, the extent of cross-jurisdiction variation in prices is not clear. The “rack rate” price observed from providers’ websites, for instance, may differ from their actual region/city-specific prices, depending on the promotional offerings available in that market (such as a waiver of installation and/or equipment charges, a limited introductory rate, a discount for purchasing a bundled offering, etc.). However, quantifying this region/city specific variation information (assuming it exists) can be difficult. Hausman, Sidak and Singer (2001) did not observe significant cross-jurisdiction variation in the price of cable modem service in their study.

¹³ Madden, Savage, and Simpson (1996) include a control for internet access in their pioneering study of survey data on the demographic criteria that influence household subscription to broadband in Australia.

¹⁴ This hypothesized relationship is made by Gabel and Kwan (2000) and Madden, Savage, and Simpson (1996). Both studies uncover the anticipated coefficient, however, only the latter study finds a statistically significant relationship.

coefficient on TELEDENSITY is anticipated.¹⁵ Likewise, LENGTH affects the cost of deploying broadband technology and, in particular, DSL technology. The speed of DSL service diminishes with the distance from a customer's home to the central office, and typically not available to customers with loops greater than three miles in length. Measures to extend the reach of DSL to these customers are technically feasible but entail additional cost.¹⁶ The coefficient on LENGTH should be negative. Finally, PLOOP is strictly controlled by state regulators and is a major input cost to competitive local exchange carriers (CLECs) offering broadband services via ILEC facilities. To some extent we might also expect PLOOP to proxy for the costs to the ILEC, though this relationship is likely to be noisy. Both possibilities suggest a negative coefficient on PLOOP.

iii. RBOC Controls. The dummy variables BELLSOUTH, VERIZON, QWEST, and SBC are intended to control for the behavior of the primary DSL provider (as proxied by the particular RBOC present in the state) across states that is not controlled for by the demand and cost variables. SBC is the excluded RBOC in our model. To the extent that, for instance, one RBOC pursues a more aggressive broadband strategy than another RBOC, all things equal, this would be reflected in a positive coefficient on the RBOC. There are, however, many possible region-wide factors that might influence the sign of the coefficient on the dummy variables. Accordingly, we do not have a preconceived notion as to the anticipated coefficient on these variables.

iv. Market Structure Controls. Consistent with our previous discussion in Section 2, an increase in AVAILABILITY ought to have a positive impact on broadband adoption; in those states where broadband services are more widely available, we should observe greater adoption. The data on AVAILABILITY, however, allow for disaggregation of

¹⁵ A more accurate control for line density would measure both the volume and the distribution of lines within the state. For instance, consider two states with the same square mileage and the same number of telephone lines. In one state, the lines are scattered uniformly throughout the state, while in the other state the lines are concentrated within a single city block. Our measure of TELEDENSITY will be the same despite the differences in density attributed to the distribution of lines in the two states. Ideally, we would like to be able to disaggregate TELEDENSITY (as well as other controls) across the overlap and exclusive territories, and our inability to do so clearly decreases the effectiveness of the controls.

¹⁶ For instance, SBC announced a \$6 billion DSL loop renovation program known as "Project Pronto" that will extend the reach of DSL services to customer locations where it was previously unavailable. Computer Science and Telecommunications Board (2002), pp. 259-263.

this variable into two components: EXCLUSIVE, the percentage of state population with access to one platform and only one platform, cable modem *or* DSL; and OVERLAP, the percentage of state population with access to two platforms, cable modem *and* DSL. The data for AVAILABILITY and its components are based on observation of cable modem or DSL deployment at the city level, and in some instances at the county level.¹⁷

We anticipate the coefficients on the variables OVERLAP and EXCLUSIVE to be nonnegative, consistent with our prediction of the sign of the coefficient on AVAILABILITY. The objective of this analysis, however, will be to examine whether overlap has an incremental positive effect, controlling for the other factors that we expect to influence penetration.

The variable SKEW is distinct from AVAILABILITY (as well as EXCLUSIVE and OVERLAP) in that the former does not consider how broadband is *available*, but instead controls for the extent to which *actual penetration* is dominated by a single platform. In every state in our sample, except California, Kentucky, and Utah, the share of cable modem exceeds that of DSL. Given that we are examining penetration levels at an early stage in the development of broadband, we expect that cable modem's first-mover advantage will be reflected in a positive coefficient on SKEW.

V. THE EMPIRICAL RESULTS

Our data consist of observations on 46 U.S. states. Observations on the variable SKEW were not available for Delaware, Hawaii, Rhode Island, and Wyoming. The District of Columbia was excluded because it was an outlier for many of the variables of interest. Including the District of Columbia in the sample did not affect significantly the coefficients or their signs but it did diminish the model's adjusted R-squared. To estimate the determinants of broadband adoption we employ a weighted least-squares logit regression. Because the dependent variable is constructed from grouped data (total broadband subscription in a state, divided by the state population) with unequal size

¹⁷ As Gabel and Kwan (2000) indicate, broadband deployment within a city may not be ubiquitous. Our data do not permit us to determine the extent to which this is or is not the case.

groups, the OLS assumption of uniform variance is violated; that is, given populations of varying size over the states that make up the sample, heteroskedasticity will be present across the disturbances. The solution in this case is to model variation in broadband adoption with weighted least-squares estimates in a grouped logit equation.¹⁸

To understand the influence of availability on penetration, we present the regression results of two model specifications. Our first specification examines the influence of overall availability on adoption, and our second specification examines a disaggregated measure of availability. In particular, we disaggregate total availability (AVAILABILITY), into what we previously defined as G(O) and G(E). The empirical notation for these variables is OVERLAP and EXCLUSIVE, respectively. The grouped logit regression results of the aggregate (AVAILABILITY) model are presented in Table 2, and the regression results of the disaggregated (OVERLAP + EXCLUSIVE) model are presented in Table 3.

A. The Restricted Model

Overall, the model with AVAILABILITY performs well, explaining 71 percent of the variance in broadband adoption. Moreover, many of the coefficients of interest are statistically significant (at the 10 percent level or better) and all achieve their expected signs (of the coefficients for which we predict an effect). The magnitude of these effects can be seen by simulating expected levels of broadband adoption, given specified changes in the values of the independent variables. These results are presented in Table 2, column (3). The range of the specified change in the independent variable is assumed to be one standard deviation from the mean of the independent variable, except in the case of a dichotomous variable where we assume a change between 0 and 1. Given their intuitive interpretation, we will refer to column (3) results in our discussion below.

Both of the demand controls, INTERNET and EDUCATION, have a positive effect on penetration, consistent with our hypothesis. However, only EDUCATION is

¹⁸ The models below are run with the `-glogit-` command of Stata 7.0. Glogit estimates weighted least squares, accounting for different sized denominators (state populations) and, in principle, different variances across states.

statistically significant. Moreover, EDUCATION is found to have a profound impact on penetration; the model predicts that a one standard deviation increase in EDUCATION in a state increases the per capita penetration level by 96 percentage points. The positive effect of education is consistent with the results of the U.S. Department of Commerce (2002), discussed earlier. The size of the coefficient may reflect the fact (we believe) that education is capturing demand, and demand is a powerful determinant of both entry and penetration. Likewise, each of the cost control variables – LENGTH, TELEDENSITY, and PLOOP – achieve their expected sign. TELEDENSITY is statistically significant (at the 5 percent level). The coefficient on TELEDENSITY suggests that a one standard deviation increase in the density of switched access lines results in a 0.0016 percentage point increase in per capita penetration. It is interesting to note that, while the coefficient on PLOOP has the expected sign, it is not statistically significant. This might be considered surprising in light of the perceived importance of UNE pricing on promoting penetration. It is possible (though speculative) that this result suggests that CLECs deploying DSL using UNEs have little effect on overall broadband penetration. It may also be that CLECs, rationally, make entry and investment decisions not on just the basis of current UNE prices but on the basis of expected future prices. Given the substantial uncertainty that existed at the time, and still exists, regarding future UNE prices, it is not surprising to find weak correlation between contemporaneous UNE prices and CLEC decisions. Notice that while we do not control for the extent to which provisioning of UNEs varies across states, which might be correlated with PLOOP, the influence of RBOC-specific variation is captured by the RBOC dummy variables.

LENGTH is marginally significant at the 15 percent level, slightly below the standard threshold of statistical significance (10 percent or better). The coefficient on LENGTH suggests that a one standard deviation increase in the average length of ILEC loop reduces penetration by 0.00005 percent. The coefficient on SKEW, which controls for the percentage cable modem penetration exceeds (or is less than) the penetration of DSL, is positive and statistically significant. We interpret the coefficient on SKEW as identifying the advantage cable modem derives from a first-mover advantage into the broadband marketplace. A one standard deviation increase in the percentage cable

modem penetration exceeds DSL is estimated to result in a 1.2 percentage point increase in per capita penetration.

The coefficient of primary interest in the restricted regression is that on AVAILABILITY. As expected, the coefficient on this variable is positive, it is statistically significant, and its magnitude is relatively large. We estimate that a one standard deviation increase in AVAILABILITY results in over a 5 percentage point increase in the per capita penetration level. Importantly, however, the regression omits disaggregated information on the nature of AVAILABILITY in state, the impact of which we investigate in our regression on the unrestricted model.

Before describing the regression results of the unrestricted model, we should first comment on the potential endogeneity of AVAILABILITY and SKEW. In particular, it is possible that even after including the demand and cost controls there might be unobserved effects that are correlated with cost and/or demand and AVAILABILITY and SKEW. We do not have a definitive solution to this problem; there are no instruments of which we are aware that can be employed to control for the potential endogeneity of AVAILABILITY and SKEW. We can, however, assess the effectiveness of the demand and cost controls that are included in the model. The more effective these controls are, the more reassurance we can have that our model controls for the major demand and cost drivers, and the less distortion the unobserved variables should have on AVAILABILITY and SKEW. To examine the impact of our cost and demand variables on the fit and coefficient estimates on AVAILABILITY and SKEW, we run the restricted model omitting the demand and cost controls. The results of this regression are presented in Appendix A. They suggest that the demand and cost controls employed in the model have an important impact on regression results. The adjusted R-squared is 27 percent, 47 percentage points less than the adjusted R-squared that results when including the demand and cost controls. Moreover, the coefficient on SKEW changes sign and loses significance. AVAILABILITY, in contrast, retains its sign and statistical significance.

Table 2:
 Weighted Least-Squares Logit Regression
 Dependent Variable: PENETRATION
 Weight: POPULATION
 Specification: Restricted Model

| Variable | (1) Coefficient Estimates (SE) | (2) Odds Ratio | (3) Net Change in the expected per capita adoption of broadband |
|--------------------|--------------------------------------|-------------------|---|
| Intercept | -5.523* (0.581) | -- | -- |
| INTERNET | 1.163 (1.088) | 3.2009 | 5.018% |
| EDUCATION | 7.677* (2.76) | 2157.745 | 95.73% |
| TELEDENSITY | 0.007* (0.00028) | 1.0007 | 0.0016% |
| LENGTH | -0.00002 (0.00001) | 0.99998 | -0.00005% |
| PLOOP | -0.012 (0.012) | 0.9878 | -0.029% |
| AVAILABILITY | 1.176* (0.396) | 3.242 | 5.107% |
| SKEW | 0.396* (0.185) | 1.486 | 1.155% |
| BELLSOUTH | 0.345* (0.135) | 1.413 | .982% |
| VERIZON | 0.033 (0.111) | 0.834 | -0.399 |
| QWEST | -5.523 (0.137) | 1.033 | 0.08% |
| Observations | 46 | | |
| F statistic | 12.05 | | |
| R-Squared | 0.775 | | |
| Adjusted R-Squared | 0.7107 | | |

Notes: The entries in column (1) are weighted least-squares logit estimates for grouped data (standard errors in parenthesis). Columns (2) and (3) are based on the exponential linear predictions generated by the `-or-` routine in Stata 7.0, and they are calculated assuming all other variables are set at their mean values. The net change in the expected per capita adoption of broadband is a simulated probability calculated by adjusting the independent variables by one standard deviation from the mean value for the continuous variables and between 0 and 1 for the dichotomous variables.

* Significant at the 5% level; and ** Significant at the 10% level.

B. The Unrestricted Model

In this model, we disaggregate AVAILABILITY into its component parts, EXCLUSIVE and OVERLAP. We conjecture that the impact of broadband availability on penetration in locations where both DSL and cable modem are present (OVERLAP) will differ from its impact on penetration in locations where only a single platform is available (EXCLUSIVE). As with the restricted model, the unrestricted model performs well, achieving a slightly higher adjusted R-squared of 74 percent, compared to the restricted model. All of the coefficients achieve their expected sign (of the coefficients for which we predict an effect) and most of the coefficients of interest achieve statistical significance at the standard levels (10 percent or better). As in our presentation of the restricted model, we estimate the magnitude of the effects of each coefficient by simulating expected levels of broadband adoption, given specified changes in the values of the independent variables. These results are presented in Table 3, column 3. Again, given their intuitive interpretation, we will refer to column (3) results in our discussion below.

There is little change in the coefficient estimates on the variables appearing in both equations. Therefore, we will not repeat these findings. The coefficient estimates of interest in this regression are those on the availability variables, OVERLAP and EXCLUSIVE. Both coefficient estimates are positive, as anticipated. However, they have substantially different effects on penetration. The coefficient on OVERLAP is quite large and statistically significant (at the 5 percent level); a one standard deviation increase in overlap availability is estimated to increase per capita penetration by 6.5 percentage points. In contrast, the magnitude of the coefficient estimate on EXCLUSIVE is small and is not statistically significant. In interpreting this result, it is informative to compare it to the equivalent regression excluding the demand and cost variables. The results of this regression are found in Appendix B. The adjusted R-squared is 28 percent, compared to 74 percent in the regression including demand and cost variables. However, the coefficient estimates on both OVERLAP and EXCLUSIVE are positive and statistically significant (at the 5 percent level). Both variables are estimated to have large effects on penetration, but the relative magnitude of their effect is the opposite of that

found when we include demand and cost variables in the regression. A comparison of these two regressions suggests that after controlling for the influences of demand and cost, OVERLAP retains its magnitude and its statistical significance, while EXCLUSIVE falls to zero and loses its predictive power. An F-test confirms (at the 5 percent level) that the coefficients on these two variables are statistically different from each other. In fact, an F-test suggests that EXCLUSIVE is not needed in the regression. The regression results when EXCLUSIVE is dropped achieve a marginally higher adjusted R-squared and the coefficients estimates (and their t-statistics) are little changed from the output of the regression that retains EXCLUSIVE. In sum, the effect of exclusive availability is de minimus, if not zero, when controlling for the effect of overlap availability.

This result suggests that the demand and cost controls fully explain availability, and there is no incremental explanatory power of the raw availability measure, while intermodal competition (OVERLAP) retains significant additional explanatory effects. This interpretation is consistent with the results of an alternative specification we ran, in which we estimated the effects of overlap and total availability (OVERLAP and AVAILABILITY), rather than overlap and exclusive availability. We found that given overlap, the effect of total availability was not statistically significant given the presence of the other controls.

Table 3:
 Weighted Least-Squares Logit Regression
 Dependent Variable: PENETRATION
 Weight: POPULATION
 Specification: Unrestricted Model

| Variable | (1) Coefficient Estimates (SE) | (2) Odds Ratio | (3) Net Change in the expected per capita adoption of broadband |
|--------------------|--------------------------------------|-------------------|---|
| Intercept | -6.048* (0.612) | -- | -- |
| INTERNET | 2.407** (1.204) | 11.096 | 19.43% |
| EDUCATION | 8.23* (2.65) | 3754.17 | 96.5% |
| TELEDENSITY | 0.0005** (0.00028) | 1.0005 | 0.0013% |
| LENGTH | -0.00003* (0.00001) | 0.9999 | -0.0001% |
| PLOOP | -0.006 (0.012) | 0.9936 | -0.02% |
| EXCLUSIVE | 0.0089 (0.893) | 1.009 | 0.02% |
| OVERLAP | 1.357* (0.389) | 3.884 | 6.47% |
| SKEW | 0.419* (0.178) | 1.52 | 1.23% |
| BELLSOUTH | 0.399* (0.132) | 1.49 | 1.17% |
| VERIZON | -0.256* (0.112) | 0.774 | -0.546 |
| QWEST | -0.061 (0.139) | 0.941 | -0.142% |
| Observations | 46 | | |
| F statistic | 12.35 | | |
| R-Squared | 0.7998 | | |
| Adjusted R-Squared | 0.735 | | |

Notes: The entries in column (1) are weighted least-squares logit estimates for grouped data (standard errors in parenthesis). Columns (2) and (3) are based on the exponential linear predictions generated by the -or- routine in Stata 7.0, and they are calculated assuming all other variables are set at their mean values. The net change in the expected per capita adoption of broadband is a simulated probability calculated by adjusting the independent variables by one standard deviation from the mean value for the continuous variables and between 0 and 1 for the dichotomous variables.

* Significant at the 5% level; and ** Significant at the 10% level.

VI. CONCLUSION

Our results demonstrate a substantial and statistically significant positive impact on broadband adoption of intermodal (facilities-based) broadband competition, even controlling for broadband availability. These results are consistent with the observations made by OECD (2001), in its cross-national study discussed earlier in our paper. We believe that in providing econometric evidence of this effect, our results are unique and make a new contribution to the understanding of broadband adoption in the U.S. Our results are also not surprising, in that one would expect facilities-based competition to drive additional broadband adoption, over and above pure availability of the service. What is perhaps surprising is that controlling for demand and cost factors, and intermodal competition, exclusive availability (availability in areas without intermodal competition) has no additional predictive power for adoption.

As a policy matter, these results suggest that the focus in the current policy debate on ubiquitous access to broadband service may not be the most effective in driving adoption. Rather, policies that encourage facilities-based competition—and, therefore, policies that encourage facilities investment by all platform providers, are perhaps more important. Policies that discriminate across platforms, to the effect of encouraging investment in one (or more) but discouraging investment in another, will frustrate policy objectives to increase adoption.

We view our results as a first step at modeling and estimating the effects of competition on broadband adoption. It would be useful in further research on these issues, in our opinion, to seek to improve controls on the potential endogeneity of the supply factors. Ours is a reduced form model, and additional structure might add additional insights. In addition, our data on the demand and supply controls (education, teledensity, and so forth) are at the state level, and therefore do not specifically identify demand and supply factors within the overlap and exclusive territories. We are unaware

at this time of more granular data, but to the extent such data can be developed, they would add useful refinement to the analysis.

BIBLIOGRAPHY

Computer Science and Telecommunications Board, National Research Council, *Broadband: Bringing Home the Bits*, National Academy Press (2002).

Federal Communications Commission, *High Speed Services for Internet Access: Status as of December 31, 2000*, August 2001.

Federal Communications Commission, *High Speed Services for Internet Access: Status as of June 30, 2002*, December 2002.

Ferguson, Charles H., "The U.S. Broadband Problem," The Brookings Institution, Policy Brief #105, July 2002.

Gabel, David, and Florence Kwan, "Accessibility of Broadband Telecommunications Services by Various Segments of the American Population," Paper Prepared for the Telecommunications Policy Research Conference, August 2000.

Gilder, George, "Broadband's Narrow Minds," *The Wall Street Journal*, February 19, 2003.

Gregg, Billy Jack, *A Survey of Unbundled Network Element Prices in the United States*, April 2001.

Hausman, Jerry A., Gregory Sidak, and Hal J. Singer, "Cable Modems and DSL: Broadband Internet Access for Residential Customers," *American Economic Review*, Vol. 9, No. 2, May 2001, pp. 302-307.

Howell, Browyn, "Broadband Uptake and Infrastructure Regulation: Evidence from the OECD Countries," New Zealand Institute for the Study of Competition and Regulation, Working Paper BH02/01, February 2002.

Kennard, William E., *Consumer Choice Through Competition*, Remarks at the National Association of Telecommunications Officers and Advisors 19th Annual Conference, September 17, 1999.

Landers, Jim, "Broadband believer: FCC's chair presses for big leap for U.S. high-speed Internet," *The Seattle Times*, October 21, 2002.

Madden, Gary, Scott Savage, and Michael Simpson, "Information Inequality and Broadband Network Access: An Analysis of Australian Household Survey Data," *Industry and Corporate Change*, Oxford University Press, 1996, pp. 1049-1056.

National Cable & Telecommunications Association, "Remarks of Robert Sachs, NCTA President and CEO at Cable 2001, 'We're Making Broadband Happen,'" Press Release, June 11, 2001.

Organization for Economic Cooperation and Development, *The Development of Broadband Access in OECD Countries*, October 29, 2001.

TechNet, "TechNet CEOs Call for National Broadband Policy," Press Release, January 15, 2002.

U.S. Department of Commerce, National Telecommunications & Information Administration, *Falling Through the Net: Toward Digital Inclusion*, October 2000.

U.S. Department of Commerce, and National Telecommunications & Information Administration, *A Nation Online: How Americans Are Expanding Their Use of the Internet*, February 2002.

Rappoport, Paul N., Donald J. Kridel, and Lester D. Taylor, "The Demand for Broadband: Access, Content, and the Value of Time," Working paper presented at the Southern Methodist University economics workshop, August 23, 2002.

Rural Utilities Service, and National Telecommunications & Information Administration, *Advanced Telecommunications in Rural America: The Challenge of Bringing Broadband Service to All America*, April 2000.

Wall Street Journal, "The Harris Poll: Online Population Continues to Expand but Just Barely," February 5, 2003.

Appendix A:

Weighted Least-Squares Logit Regression

Dependent Variable: PENETRATION

Weight: POPULATION

Specification: Restricted Model, Excluding Demand and Cost Variables

| Variable | (1) Coefficient Estimates (SE) |
|--------------------|---|
| Intercept | -4.022* (0.204) |
| AVAILABILITY | 1.32* (0.44) |
| SKEW | -0.243 (0.24) |
| BELLSOUTH | -0.039 (0.151) |
| VERIZON | 0.214 (0.135) |
| QWEST | -0.007 (0.156) |
| Observations | 46 |
| F statistic | 4.33 |
| R-Squared | 0.3513 |
| Adjusted R-Squared | 0.2702 |

* Significant at the 5% level

** Significant at the 10% level

Appendix B:

Weighted Least-Squares Logit Regression

Dependent Variable: PENETRATION

Weight: POPULATION

Specification: Unrestricted Model, Excluding Demand and Cost Variables

| Variable | (1) Coefficient Estimates (SE) |
|--------------------|---|
| Intercept | -4.102* (0.215) |
| OVERLAP | 1.04* (0.498) |
| EXCLUSIVE | 2.022* (0.741) |
| SKEW | -0.182 (0.242) |
| BELLSOUTH | -0.042 (0.151) |
| VERIZON | 0.253** (0.138) |
| QWEST | 0.002 (0.155) |
| Observations | 46 |
| F statistic | 3.87 |
| R-Squared | 0.3734 |
| Adjusted R-Squared | 0.277 |

* Significant at the 5% level

** Significant at the 10% level