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The broadband digital divide and the nexus of race, competition, and quality

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Abstract

We examine the gap in broadband access to the Internet between minority groups and white households with geographically fine data on DSL subscription. In addition to income and demographics, we also examine quality of service and competition as components of the Digital Divide. The gaps in DSL demand for blacks and Hispanics do not disappear when income, education, and other demographic variables are accounted for. However, lack of competition is an important driver of the Digital Divide for blacks. Service quality is an important determinant of demand, and ignoring it masks the true size of the DSL gap for Hispanics.

JEL classification: L96; D12; D63

Keywords: DSL; Digital divide; Broadband demand; Redlining

1. Introduction

Over the last 10 years, the Internet has become integrated into the lives of many, if not most Americans. The World Wide Web and related information technologies are becoming primary tools of economic production, civic participation, and political involvement, and define the economic, social, and political landscape (Cooper, 2002). While views on its importance differ, and the economic impacts cannot be exactly quantified, it is clear that the Internet has transformed many spheres of modern life, particularly as broadband connection becomes more common. Broadband subscription in the US has grown from fewer than three million lines in 1999 to over 60 million lines in 2006 (Fig. 1), with most residential subscribers choosing either cable modem or digital subscriber line (DSL) connections. Much policy concern is directed toward those who are not taking part in the information revolution. A "Digital Divide" has been found in numerous studies between the computer and Internet use of whites and certain minority groups, the wealthy and the less affluent, the educated

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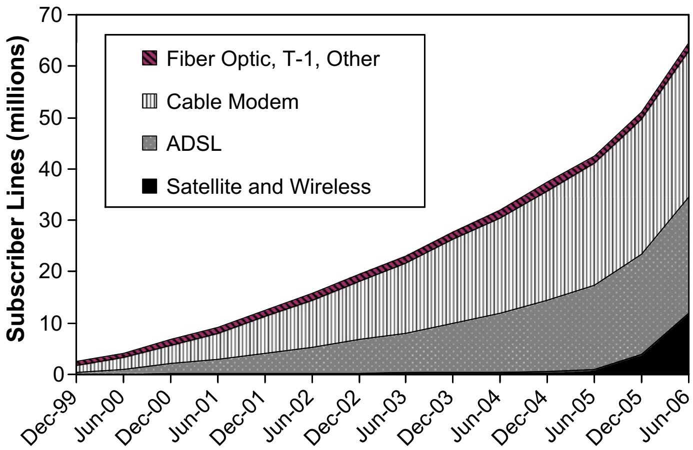

Fig. 1. Growth in broadband lines (US, residential and business subscribers).

and the less schooled, and those residing in urban and rural areas. In this paper, we examine the gap in broadband access to the Internet between minority groups, particularly black and Hispanic households, and white households.

Our choice to examine the racial aspect of the Digital Divide reflects persistent concern and debate among policy makers and analysts. Information technology and the Internet enable, augment, or lower the cost of many basic and important tasks in modern society. In the vocational sphere, these include obtaining an education and acquiring job-related skills, applying for jobs, and telecommuting. In the personal sphere are activities such as searching for the lowest prices or best tariffs for consumer goods and services, conducting financial or business transactions, acquiring medical information, or benefitting from a healthcare provider's use of telemedicine (Hammond, 1997). To pick just one of these activities, one half of Americans say that the Internet plays "a major role" in pursuing more training for their career (Horrigan and Rainey, 2006). Given that more and more websites make use of bandwidth-intensive technologies such as audio and video files, animated content, and interactive applets, broadband connection is becoming increasingly necessary to participate fully in cyberspace, and by extension, society. Baynes (2006) focuses concern on blacks and Hispanics in particular: "Another generation of African Americans and Latinos/as is poised to be left behind and remain at the bottom of the barrel, as citizens, consumers, and entrepreneurs in this new technological era".

In some instances, concern over lack of broadband access for minorities has spilled from the policy to the legal arena. For example, AT&T was sued in Florida for allegedly bypassing minority neighborhoods when deploying broadband.[1] At the federal level, the Telecommunications Act of 1996 charges the FCC to monitor and encourage the "reasonable and timely" deployment of advanced communications services—which it interprets to include broadband—to "all Americans".[2] The FCC has the authority to add broadband to the list of services supported explicitly under federal Universal Service programs, although it has not chosen to do so.

The focus of our study is the gap in broadband Internet usage by certain minority groups, particularly blacks and Hispanics. We investigate the nexus of race, income, quality of service, and competition among broadband providers. We look at the demand for DSL broadband in the operating area of Ameritech, the incumbent local exchange company (LEC) in five Midwestern states. The availability of DSL and the location of subscribers are available in fine geographic detail in our data. Given the numerous existing studies of demand for broadband, which we review in Section 3, a new study must make a unique contribution to the literature. We provide three novelties. Previous demand studies are based on samples for which broadband availability cannot be known with certainty. For example, some studies determine broadband availability

[1] *Warren's Cable Regulation Monitor*, September 9, 2002.

[2] See http://www.fcc.gov/broadband/, where the FCC makes explicit the link between the language in the Act and their goal to "broaden the deployment of broadband technologies".

from survey questions asked of respondents who may not subscribe to broadband. However, more than one-sixth of Americans do not know if broadband service is available in their area (Horrigan, 2004). DSL coverage is even less widely known, with almost one-third of one survey's respondents unsure about DSL availability (Jackson et al., 2002). Poor measurement of availability could bias the results of a demand study, particularly if the measurement error is larger for disadvantaged groups, since availability may be correlated with key variables of interest. Even among Internet users, who presumably would be better informed about the availability of broadband, there is a high (and racially differing) fraction who do not know: 24% of whites, 27% of blacks, and 43% of Hispanics.[3] In contrast with nearly all previous studies, our data provide us with near certainty of DSL availability. Our second novelty is an exploration of the effect of the DSL distance variable, which we show to be hugely important in demand and related to the racial gaps in access. Finally, although the primacy of competition among providers for closing the broadband gap is asserted at the highest policy levels (UNCTAD, 2005), we are not aware of empirical econometric investigation of its importance for demand such as we pursue here.[4]

Our study is not without its limitations. We have nothing to say about the price elasticity of demand for DSL subscription. See Rappoport et al. (2003a) for such estimates. Ameritech offered DSL everywhere in the region for $40/month,[5] so there is no variation available in prices.[6] We also lack household-level data on subscription to cable modem service. Our data are from the early years of broadband deployment, which we discuss in our closing section. These limitations notwithstanding, we come to several important conclusions. Our estimations show that the gaps in DSL demand for blacks and Hispanics do not disappear when income, education, and other demographic variables are accounted for. We also find that competition, or its lack, is an important driver of the Digital Divide for blacks. Finally, we show that not only is service quality—as measured by distance from the central office—a large determinant of demand in our data, it also greatly changes the estimated DSL gap for Hispanics. Ignoring quality masks part of the broadband gap for Hispanics. The importance of quality is particularly notable since ours is the first study to examine how it affects the Digital Divide.

After documenting the Digital Divide in the next section, we review the literature in Section 3. Readers familiar with the issues and the literature may want to skip to Section 4, where we provide an overview of broadband technology and the data we analyze. In Section 5, we outline ideal and feasible empirical strategies to investigate broadband demand with the available data. Our results are in Section 6, and a final section concludes.

2. The digital divide and its causes

Gaps in Internet usage by minority groups in the US are well documented. The Pew Internet and American Life Project found that in 2000, 36% of blacks and 44% of Hispanics had Internet access, compared to 50% of whites (Lenhart, 2000). Official statistics from the Department of Commerce (NTIA, 2000) show similar gaps for households: 23% for both black and Hispanic households, versus 46% for white. Over time, attention has shifted from basic to broadband Internet access. The Department of Commerce (NTIA, 2000) found in the early years of broadband adoption that the subscription rate of black and Hispanic households for broadband lagged that of white households. We show broadband subscription rates from 2000 to 2006, broken out by race and ethnicity, in Fig. 2. We link two data sources in the figure: the Current Population Survey (CPS) for the earlier years, supplemented by data from the Pew Internet and American Life Project for the latter years.[7] It is clear that the

[3] The figures are based on the crosstabs for the February 2004 Tracking Survey from the Pew Internet and American Life Project, available to researchers from www.pewinternet.org. The figures are for the response "do not know/refused".

[4] The effect of competition on broadband penetration rates, which commingle supply and demand factors, is studied by Distaso et al. (2006).

[5] We gathered prices from current local newspaper announcements of Ameritech/SBC's DSL service in the area. In each instance a specific price was mentioned, it was $39.95 for basic DSL service.

[6] To get around the lack of price variation in market studies, some researchers turn to experimental designs and stated preference approaches to estimate the sensitivity of demand to price (e.g., Savage and Waldman, forthcoming).

[7] The US Census Bureau CPS data in Fig. 1 are from the Computer Use Supplements from 2000, 2001, and 2003 (subscription rates are the authors' calculations). The Pew data are from surveys administered 2004–2006, taken from the crosstab files available to researchers on the project website (www.pewinternet.org). For both sources, the percentages are calculated using population weights, and figures are to be read as the percentage of persons living in households with broadband access to the Internet.

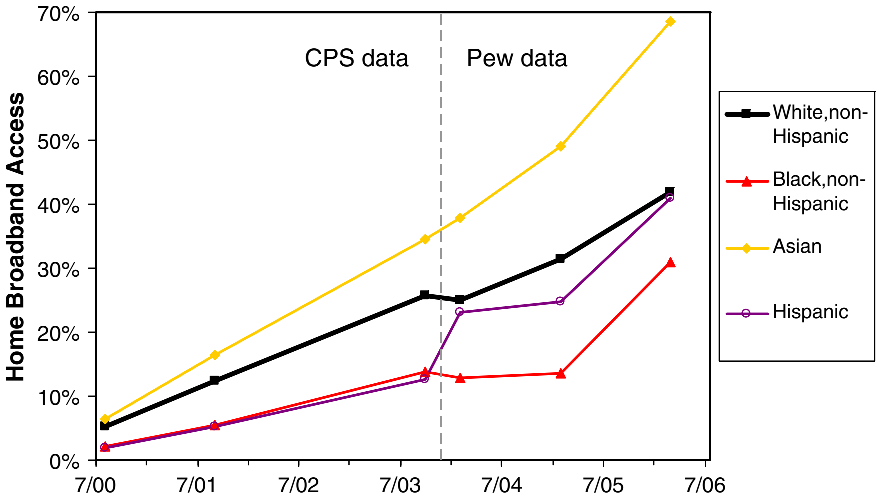

Fig. 2. Home broadband access by race and ethnicity.

gaps in online access are also present in broadband connections. In 2000, the white, non-Hispanic broadband subscription rate was 5.2%, compared to rates of 2.1% for black non-Hispanics and 2.0% for Hispanics. These gaps widened in absolute terms (but not in percentage terms) through 2003. In later years, the gap narrowed for blacks and closed for Hispanics by 2006. However, the data from Pew for Hispanics excludes those who do not speak English, which probably accounts for much of the shift in their trend compared to the earlier years. In all years, Asians have the highest broadband access rate.

Explanations proposed in the literature for the broadband gap focus on the nexus of race, computer ownership, income, and broadband availability. Fairlie's (2004) exploration of the CPS data shows that blacks and Hispanics are less likely to have a computer in the home, which (but for little-used WebTV and web-enabled cell phones) precludes household access to the Internet. A natural suspicion is that racial and ethnic differences in computer ownership and Internet access are due mainly to income differences. Leigh (2003) finds that after controlling for income, education, and locality, race is an insignificant determinant of broadband Internet access. However, several other studies find that even after using multiple regression to control for confounding factors, race remains a statistically significant predictor of Internet access (Fairlie (2004) for Internet access and computer ownership; Flamm and Chaudhuri (2007) and GAO (2006) for broadband access). Reasons posited for less use of technology in the home for blacks and Hispanics include lack of skills from not using computers at work (Krueger, 2003) and lack of friends and families who use the technology (Goolsbee and Klenow, 2002).

The availability of broadband may also be a component of the racial Digital Divide. Baynes (2004) (and the lawsuit against AT&T) charges telecommunications providers with "electronic redlining," which he defines as the failure to provide service to minority communities, and suggests that firms may make irrational decisions based on negative stereotypes. Prieger (2003) shows that when controlling only for location, broadband is less likely to be available for blacks, Hispanics, and Native Americans. However, once demographic and socioeconomic variables are controlled for, the evidence for redlining based on black or Hispanic concentration in the community disappears. Hu and Prieger (2008) come to similar conclusions with data covering the DSL deployment decision in the same region examined in the present study. The availability of broadband is less of a determinant of the access gap over time, as broadband access has now diffused over much of the US.[8]

We suggest and explore two additional components of the Digital Divide nexus: quality of service and competition. Poor quality of telecommunications service in inner-city areas has been proposed as an element of the broadband gap for blacks (Baynes, 2004). We look at a different aspect of quality. The quality of DSL

[8] The FCC (2007a) found in its comprehensive survey that there was at least one customer for high-speed service in 99% of all ZIP code areas in the United States.

transmission degrades with distance from the provider's central office. We measure how far households in our data are from the central office, and thus we can control for one important quality driver that is unobserved in other studies. We also explore the impact of broadband competition on the racial gaps. Competition can increase demand by lowering prices and increasing quality, and if competition varies systematically with the socioeconomic composition of communities, then it can contribute to the Digital Divide.

3. Literature review

There are many studies on demand for broadband access to the Internet. We review main examples of previous research in this section, with particular focus on the data used, restricting attention to studies using subscriber-level data. Existing studies provide many interesting and useful results. To highlight the contribution of the present study, we focus on results (and limitations) pertinent to the Digital Divide.

The basic information needed for any demand study is whether broadband is available to the household and whether the household subscribes. We organize our review by the data used for the subscription decision. There are three major data sources for household-level broadband subscription: official data from the CPS, commercially provided survey panels, and non-commercial survey data.

The only data provided by the US government on household broadband subscription are from the Computer Use Supplements to the CPS.[9] Stanton (2004) and Leigh (2003) analyze the CPS data, the former finding that blacks have lower broadband demand after controlling for demographic factors, and the latter finding that race (when grouped into white and non-white categories) is not a significant factor. In neither study is it known whether broadband options are in the choice set of the household.

The most widely used of the commercial datasets is from TNS Telecoms. Their Request survey asks households whether broadband is available in their area and what form of Internet access they have, if any. Thus, from these data, researchers can determine some areas where cable modem and DSL service is available, but must rely on stated availability data (or external sources) for other areas. The TNS data are analyzed by Rappoport et al. (2003), Crandall et al. (2002), and Kridel et al. (2001). While none of these examine the impact of race on demand, they all find that lower income groups are less likely to subscribe to broadband. Some mismeasurement of the availability of broadband is inevitable in these studies, due to the limitations of the data. The data require Rappoport et al. (2003), for example, to treat cable modem coverage as ubiquitous in a (five digit) ZIP code area if it is available anywhere in the area, and DSL coverage as ubiquitous in the local telephone serving area. Due to the irregular geography of cable serving areas and the line-length limitation on DSL provision (which we explain in the following section), availability is perforce measured with error in these studies, the degree of which cannot be known. Recall also the difficulties of relying on stated availability data mentioned above.

Another commercially provided dataset on broadband subscription, notable for its use in a study by the GAO (2006), is from Knowledge Networks/SRI.[10] The survey does not include information on broadband coverage, and the GAO (2006) determines availability from the FCC's list of ZIP codes with broadband available. While the FCC data are attractive, because a survey respondent's ZIP code can be readily matched to the list, and are used in several supply side studies (Prieger and Lee, 2008; Flamm, 2005; Prieger, 2003), ubiquity of access throughout the ZIP code area is not assured.[11] The GAO (2006) found that non-whites have lower demand for broadband after controlling for other demographics.

Academics and non-governmental organizations have conducted several large-scale surveys of Internet and broadband usage and subscription. The best known of these is the Pew Internet and American Life Project, an ongoing household survey. The Pew data have been examined by Flamm and Chaudhuri (2007) and Chaudh-

[9] The Department of Commerce derives official statistics on Internet usage from the CPS data (NTIA, 2000). Few demand studies use the CPS data, because neither the location of the household nor broadband availability is known.

[10] See Rappoport et al. (2002) and Goldfarb and Prince (2007) for uses of other commercial sets of Internet usage data. The authors do not examine the dimensions of race or ethnicity.

[11] A ZIP code appears on the FCC's list if there is a single broadband subscriber of any type (including satellite service, or business customers who may be using T-1 dedicated lines) anywhere in the ZIP code. Flamm (2005) discusses the potential geographic inaccuracy of the FCC broadband data at length.

uri et al. (2005). Both studies find that blacks are less likely to access either dialup or broadband, even after controlling for many other factors. Broadband availability is inferred from the FCC ZIP code list in the former, and not addressed in the latter.[12]

In conclusion, many studies find that race is an important dimension of the Digital Divide, even after holding other demographic and economic factors constant. However, others find race to be unimportant. A goal of our study is to see if better measurement of broadband availability than has been previously available helps resolve the issue. Finally, none of these studies considers the impact of distance from the central office, which can affect the quality of DSL transmission. If line length is correlated with income or race, its omission in regression analysis could bias the estimated impact of these important variables on demand. In our data, for example, we find a markedly different relationship between Hispanic ethnicity and broadband demand when we control for distance from the central office.

4. Broadband technology and data

Broadband access to the Internet via DSL uses the existing telephone line between the central office and the subscriber's computer to provide an always-on connection.[13] To offer DSL in an area, the local exchange company installs equipment in its local central offices. Due to technological restrictions, transmission speeds degrade beyond 2.2 miles of wire length from the central office. Wires often run along roads arrayed in a grid, and so the distance "as the crow flies" between a house 2.2 wire miles from the central office may be as short as 1.5 miles.[14] From the local exchange company's central office, data travels through intermediary networks on its way to the Internet backbone.

The other main mode of broadband connection is cable modem service. In cable data networks, coaxial cable connects the subscriber's premises to fiber optic networks deployed by the cable company. Although DSL and cable modem account for the bulk of broadband connections in the US, other options are available: wireless, satellite, high-speed dedicated access lines, and (in a few locations) fiber optic cable (sometimes called FTTC [fiber to the curb] or FTTH [fiber to the home]). In 2000, the vintage of the data we analyze, cable modems and DSL together had 95% market share (Fig. 1).

On October 8, 1999, SBC and Ameritech merged.[15] Mergers between dominant telecommunications service providers such as these require approval from the FCC. The FCC approved the transaction subject to (*inter alia*) an agreement by the company to promote broadband Internet access. Failure to meet the conditions was to trigger penalties of more than $2 billion in payments. In particular, SBC was required to locate at least 10% of their advanced service facilities in low-income areas in the Ameritech region.[16] State regulators in Ameritech's operating region (Illinois, Indiana, Michigan, Ohio, and Wisconsin) also pushed for the merged firm to accelerate broadband deployment.

To allow regulators and other stakeholders to gauge the progress of DSL deployment and subscription, the company made available to the public a one-time list of their DSL subscribers by nine-digit ZIP code (ZIP + 4). ZIP + 4 areas are typically very small geographic areas, comprising a few blocks worth of addresses at most. The data are a snapshot of DSL deployment shortly after the merger. The list contains every ZIP + 4 code (with deployment date) in Ameritech's subscriber database, but does not indicate how many customers there are in the ZIP + 4 area. Thus, the DSL subscription data are aggregated and binary: whether at least one household or business in the ZIP + 4 area subscribes to DSL. A unit of observation in our estimations is the aggregation of ZIP + 4 areas into the smallest area for which demographic data are available, a Census block.

[12] Many other studies are also based on privately initiated surveys, often with a relatively small number of respondents (e.g., Savage and Waldman, 2005). Some of the larger surveys (e.g., Cole, 2000) contain much interesting data about online usage, but nothing on availability. Other studies such as Rappoport et al. (2003b) and Goolsbee (2006) gather stated (rather than revealed) preference data from respondents (but do not focus on race or the Digital Divide).

[13] Jackson (2002) provides a good primer on broadband technology for the layperson.

[14] If the wires take right angle turns along streets, the "worst case" scenario is a right triangle with base and height each of length 1.1 miles. In this case, the distance from the house to the central office by air (the radius) is only 1.5 miles. Remote terminals can extend the distance limit, but were apparently not used in the area at the time of our data.

[15] The background information on the data in this section draws on Hu and Prieger (2008).

[16] These conditions are discussed in SBC's quarterly and annual SEC filings from the time.

In addition to the DSL deployment list, the other data for the study come from several sources: a database of ZIP + 4 codes and locations, a telecommunications wire center locations database, the FCC local telecommunications competition database, various sources for cable modem coverage, and the US Census Bureau for household demographic information. A complete list of variables and summary statistics for the data are in Table 1, and we describe the data more fully below.

4.1. DSL availability data

There are over 170,000 entries in the Ameritech DSL ZIP + 4 list, which provides a lower bound for the number of DSL subscribers. ZIP + 4 "areas" are not geographic areas in the strict sense, but rather a collection of addresses along a few blocks (at most) of a street. The ZIP+4 areas are, on average, much smaller than a Census block.[17] The pattern of DSL deployment can be seen by plotting the geographic centroids of the ZIP + 4 areas on the list (Fig. 3). The striking picture shows that DSL is available in a small fraction of the total geography in Ameritech's five-state region. Most deployment is in the vicinities of Chicago, Detroit, Cleveland, and Milwaukee, the most populous areas in the region. There is no DSL at all in Indiana. However, it is important to remember that we do not observe DSL deployed by incumbent phone companies other than Ameritech, and that Ameritech is not the incumbent carrier in many rural areas in these states.

As mentioned above, transmission speeds for DSL degrade beyond 2.2 line miles. Since line miles are not available to us, we determine the geographic distance threshold from the data. Fig. 4 shows that Ameritech clearly had 1.5 miles "as the crow flies" as a threshold, official or not; about 95% of customers are within that distance, and there is a sharp turn in the distribution at that distance. This distance threshold is clearly visible when taking a closer look at DSL deployment (Fig. 5). Accordingly, we restrict attention to households within 1.5 miles of the central office, to make sure that DSL is available.[18] We also demonstrate that our results are not sensitive to a smaller radius of 1.0 miles. These factors matter most in rural central offices. The more rural the central office, the greater is the discrepancy between the central office area and the DSL deployment area. See the bottom of Fig. 5 for two rural central offices. The circles on these maps represent a distance of 1.5 miles from the central office. Two facts are evident: a large part of the central office area may not be within range for DSL (seen best in McHenry, IL, in Fig. 5), and, even within range, some areas have no subscribers (e.g., Strongsville, OH, in Fig. 5). Identification of demand drivers in most of our models comes from variation in DSL take-up within a central office area.

4.2. Market characteristics data

Factors influencing demand for broadband are captured by socioeconomic statistics at the Census block or block group level. The unit of observation is a Census block, and block group variables are assigned to all blocks in the group.[19] Including these variables in the demand estimations captures differences in demand for broadband among groups with varying characteristics. Variables are included for race and ethnicity, and characteristics such as household size, age, and gender, all of which are available at the block level from the 2000 Census. Additional characteristics are available at the block group level: median income, language spoken in the household, whether the primary householder commutes to work, and education completed. We also include an indicator for high-commuting metropolitan areas, available at the Census tract level.[20] The commuting variables capture factors that may influence the demand for telecommuting, as well as serve as a proxy for rural versus urban location. We also include variables on the time DSL has been available in the

[17] There are an average of about three entries in the ZIP + 4 list per Census block. Given that the list includes only those ZIP + 4 codes with DSL subscription, the number of ZIP + 4 codes per Census block is necessarily higher.

[18] Potential subscribers are also matched to their central office area, so that the 1.5 mile radius around the central office includes only neighborhoods actually served by the wire center.

[19] Because we assign Census block group variables to multiple blocks, we cluster on block groups in the calculation of the asymptotic standard errors.

[20] These are metropolitan areas outside the core, with at least 30% commuting to an urbanized area. The data are from the rural–urban commuting area codes provided by the Economic Research Service of the USDA.

Table 1
Summary statistics for the census block level data

Variable	Mean	Std. dev.	Min	Max	Source
DSL	0.846	0.361	0.000	1.000	a
Race and ethnicity					
% Asian	0.027	0.074	0.000	1.000	b
% Black	0.185	0.336	0.000	1.000	b
% Other	0.060	0.123	0.000	1.000	b
% Hispanic	0.085	0.175	0.000	1.000	b
Language					
Non-english language	0.188	0.157	0.000	1.000	c
Linguistic isolation	0.041	0.066	0.000	0.667	c
Income (log)	10.826	0.502	7.824	12.206	c
Education profile					
% Less than H.S.	0.177	0.146	0.000	1.000	c
% Some college	0.268	0.085	0.000	1.000	c
% College degree	0.305	0.225	0.000	1.000	c
Other demographics					
Household size	2.735	0.735	1.000	14.000	b
% Female	0.512	0.087	0.000	1.000	b
Median age/10	37.140	9.863	2.800	91.500	b
Area profile					
% Work at home	0.029	0.032	0.000	1.000	c
High commuting area	0.020	0.140	0.000	1.000	d
Rural Central Office (CO)	0.027	0.161	0.000	1.000	e
Distance from CO	0.934	0.367	0.015	1.500	Authors' calculation
Time deployed in CO	0.616	0.567	0.038	2.201	a
Broadband competition					
Cable modem service	0.544	0.498	0.000	1.000	f
CLEC presence	0.998	0.048	0.000	1.000	g
CLEC broadband	0.373	0.484	0.000	1.000	h
States					
Illinois	0.530				
Michigan	0.108				
Ohio	0.344				
Wisconsin	0.018				

Source notes.
[a] SBC (see text).
[b] 2000 US Census of Population and Housing (block level variable).
[c] 2000 US Census of Population and Housing (block group level variable).
[d] USDA (tract level variable, http://www.ers.usda.gov/briefing/Rurality/RuralUrbanCommutingAreas/).
[e] Designation by state commissions for purposes of compliance with merger conditions.
[f] Duffy-Deno (2000), Rappoport et al. (2003a), and Grubesic (2003) (see text).
[g] FCC (http://www.fcc.gov/wcb/iatd/comp.html).
[h] New Paradigm Resources Group, *CLEC Report 2001*.

central office area, since new technology diffuses over time, and the distance from the centroid of the Census block to the central office, to control for the quality of transmission.

Local telecommunications competition increased rapidly from the passage of the Telecommunications Act of 1996 until the telecom bust of 2000, around the time of our data. The FCC makes available a list of ZIP codes in which there is local competition. In some specifications we include a dummy for the presence of at least one competing local exchange company (CLEC) in the area.[21] The FCC data do not indicate whether

[21] The FCC's CLEC data are subject to the same criticism regarding geographic imprecision as the FCC broadband data. However, since CLECs are often located in the incumbent's central office (collocation), a CLEC in the same ZIP code as the incumbent is likely to have a similar service footprint. The exception may be in dense urban areas, where CLECs may deploy their own central offices. In such areas, however, ZIP code areas are small and the imprecision is accordingly smaller.

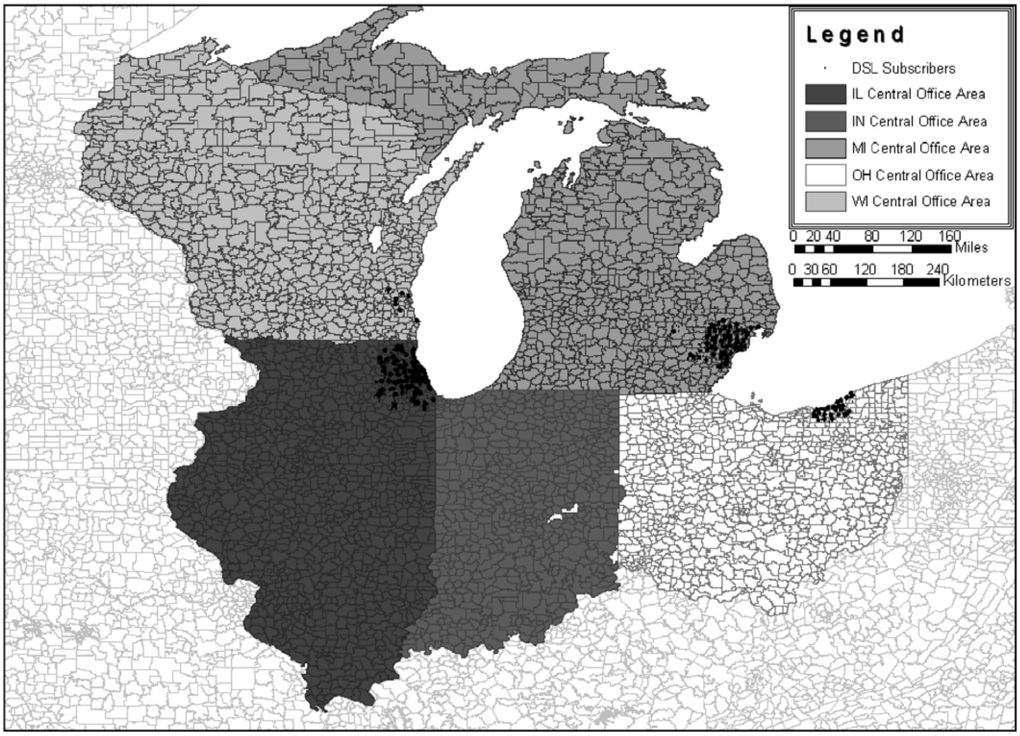

Fig. 3. DSL subscribers in the Ameritech region.

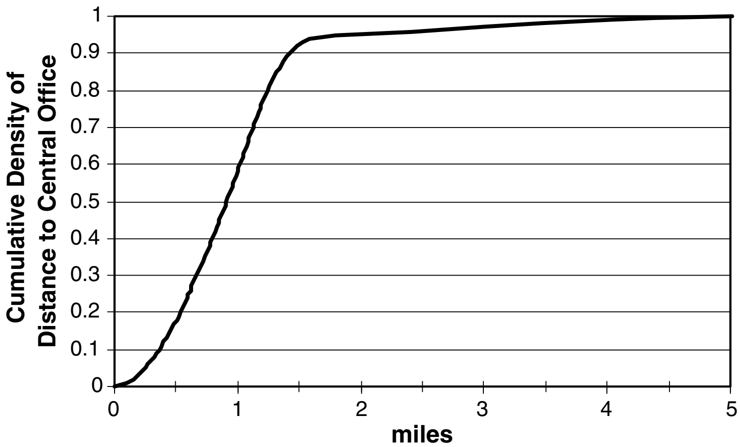

Fig. 4. Distribution of DSL deployment distance from the central office.

the CLEC is actively offering broadband, although many of them did. We augment the CLEC data with a second variable marking observations in cities where competitive DSL is reported in an industry source to be available.[22] For a subset of observations, we also know whether cable modem service was available to

[22] The data are from New Paradigm Resources Group, *CLEC Report 2001* (data are for 2000). Data are presented by city names, which we matched to central office locations, and may be less precise than the FCC ZIP code-level data on CLEC operations.

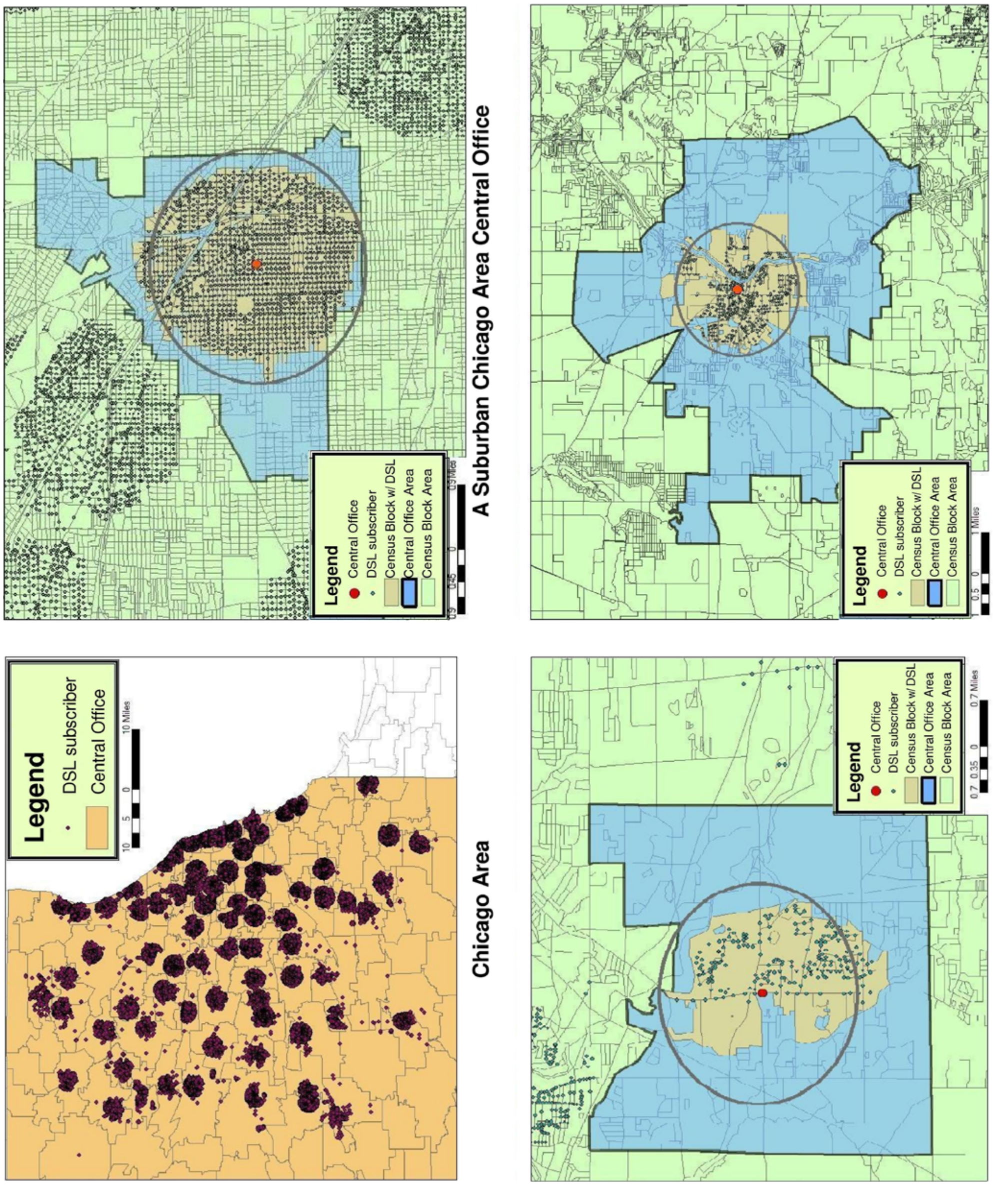

Fig. 5. DSL deployment.

households. The cable modem data cover a random sample of ZIP codes in the region[23] except for Ohio, where coverage is complete.[24] Other things equal, we expect competition to decrease demand for the incumbent's DSL.

4.3. Other variables

There are undoubtedly other factors influencing household demand for DSL that we cannot measure. Potential examples include the ease of installation, the attractiveness of the installation package (e.g., a free

[23] These data were collected by Kevin Duffy-Deno and are described more fully in Duffy-Deno (2000) and Rappoport et al. (2003a). We gratefully acknowledge permission to use these data.
[24] The cable modem data for Ohio townships are from Grubesic (2003). We gratefully acknowledge permission to use these data.

Table 2
Estimated probability of broadband DSL adoption

	Broadband DSL adoption (%)	Gap (% points)	Relative gap (% difference)
All	6.8		
White	7.9		
Black	6.5	1.4	−17.5
Asian	0.6	7.3	−92.4
Hispanic	4.6	3.3	−42.1

Notes: Gaps are calculated with respect to white. Figures are based on estimations as described in the text. Figures for the white, black, and Asian rows are calculated from an estimation including only those variables. Figures for the Hispanic row are calculated from an estimation including only a Hispanic indicator variable.

DSL modem is included), and the quality of the competitors' offerings. To the extent that these factors do not vary within a central office area, they are absorbed by the fixed effects we use in our main estimation. If these factors vary within the area, and are furthermore correlated with the local racial composition, then our estimates of the racial gaps in DSL adoption may stem in part from differences in the choices available to households. We cannot know how important such omitted factors might be, but doubt that they vary much within the 1.5 mile radius of a central office.

5. Methodology

We model the decision to subscribe to broadband in a random utility framework. The demand decision for household i is a function of the utility of the relevant options to connect to the Internet:

$$\begin{aligned} &\text{Utility of option } k: && U_{ik} = \beta_k' x_{ik} + \varepsilon_{ik} \\ &\text{Outside option (no ISP)}: && U_0 = 0 \end{aligned}$$

where k indexes options such as narrowband dial-up (DU) access, DSL, cable modem (CM), and other access options. The elements of vector x may include characteristics of the household such as income and of the technology such as speed. A household subscribes to DSL if it gives the most utility:

$$U_{i,\mathrm{DSL}} > \max(U_{i,\mathrm{CM}}, U_{i,\mathrm{DU}}, \ldots, U_0) \tag{1}$$

If we had complete data on the availability and characteristics of all these options at the household level, then we could use multinomial probit or logit models to estimate the determinants of P_{ij}, the probability that (1) holds so that household i in Census block j adopts DSL. Such a technique is followed by Rappoport et al. (2003a). Since we do not have household data, we instead model P_j, the probability that at least one household in block j has DSL. Given P_{ij}, this probability is

$$P_j = 1 - \prod_{i=1}^{N_j} (1 - P_{ij}) \tag{2}$$

where N_j is the number of households in area j. Eq. (2) is the probability of the complement of the compound event that no household in block j subscribes to DSL.

In this paper, we use MLE based on (2) to estimate the structural parameters in P_{ij}. To make estimation feasible, we have to confront three problems. First, we do not observe geographically detailed subscription information on cable modem usage like we do for DSL. We sidestep this problem by lumping together all non-DSL options, and set up a binary choice problem for each household: to subscribe to DSL or not. The second problem is lack of information on the number of firms in each Census block. These data are available at no finer than a five digit ZIP code level. If we aggregated up to a ZIP code area, most of the areas would have at least one DSL subscriber and there would be very little variation in the dependent variable,

Table 3
Household broadband demand: the effects of race and income

Variable	Estimation 1		Estimation 2		Estimation 3	
	Marginal effect (×100)	*P*-Value	Marginal effect (×100)	*P*-Value	Marginal effect (×100)	*P*-Value
Asian	−14.64***	0.000	−9.23***	0.000	−9.05***	0.000
Black	−1.41***	0.000	−1.83***	0.000	−1.55***	0.000
Other race	−0.28	0.548	3.66***	0.000	3.78***	0.000
Hispanic	−2.65***	0.000	−2.49***	0.000	−2.38***	0.000
Income (log)					0.44**	0.010
Central Office fixed effects	Not included		Included		Included	
Log likelihood	−32,787.2		−28,512.9		−28,450.9	
N	51,822		51,822		51,796	
Pseudo R^2	0.013		0.142		0.143	

Notes: Dependent variable is 1 if there is at least one broadband customer in the Census block area, 0 if not. Estimation method is the structural probit model described in the text. The sample includes all blocks in Ameritech central office areas where DSL is deployed and within the distance threshold. *Marginal effect* is the marginal effect of x on the probability that a household chooses to subscribe to DSL, averaged over the sample. Asterisks and *P*-values are for the estimated coefficient from which the marginal effects are calculated. Estimations also include a constant. Standard errors are clustered on Census block groups.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

leading to highly imprecise estimates. We bypass this problem by tacitly assuming that all subscription is by households or businesses run out of homes. This is incorrect, but does not do gross injustice to the facts. At the time of the data, businesses accounted for only about 20% of DSL subscription.[25] The third problem is that we do not observe those elements of x that pertain to individual households. We use block level averages instead (unless otherwise noted in the previous section), and care should be taken when interpreting the coefficients.

With these simplifications, we derive the likelihood for MLE. If $\varepsilon_{i,\mathrm{DSL}}$ above is distributed standard normal, we have a probit binary choice model, and P_j in (2) is

$$P_j = 1 - \prod_{i=1}^{N_j}(1 - \Phi(\beta' x_j)) = 1 - \Phi(-\beta' x_j)^{N_j} \tag{3}$$

where x_j is the average value of the regressors in area j. The log likelihood of the data y_j, where $y_j = 0$ if none of the DSL ZIP + 4's fall into Census block j and $y_j = 1$ if at least one does, is then

$$\ln L(\beta) = \sum_j 1(y_j = 0) N_j \ln \Phi(-\beta' x_j) + 1(y_j = 1) \ln[1 - \Phi(-\beta' x_j)^{N_j}] \tag{4}$$

The MLE was carried out in FORTRAN using the BFGS variant of the DFP algorithm with analytic derivatives, and convergence was readily attained in all models from a variety of starting values.

6. Results

In Table 2, we calculate the overall implied probability of household DSL adoption to be 6.8%. The figure is higher than the national estimate of broadband penetration for 2000 of 4% from the CPS,[26] as we expect, since our estimate is conditional on the availability of DSL, and DSL was unavailable in many areas at the time. Our estimate of 6.8% is found as the probit household probability of subscription, $\Phi(\beta_0)$, from an estimation of the structural demand Eq. (3) including only a constant. For a breakdown of demand by race (also in Table 2), we estimate the demand equation including an exhaustive set of racial variables (white, black,

[25] Tables 1 and 3 of FCC (2007b) show that in December 1999, businesses accounted for 21% of DSL subscription; that figure had dropped to 19% by June 2000. Most businesses at the time used T-1 dedicated lines for broadband service; only 11% of business broadband lines are DSL. A caveat to the above is that the FCC data do not distinguish between residential and small business customers.
[26] Authors' calculation from the Current Population Survey Computer Use Supplement, August 2000.

Table 4
Household broadband demand: the effects of all covariates

Variable	Estimation 4		Estimation 5		Estimation 6	
	Marginal effect (×100)	*P*-Value	Marginal effect (×100)	*P*-Value	Marginal effect (×100)	*P*-Value
Race and ethnicity						
Asian	−6.83***	0.000	−7.97***	0.000	−6.15***	0.000
Black	−2.50***	0.001	−0.39	0.289	0.35	0.794
Other race	6.88***	0.000	4.72***	0.000	7.72***	0.000
Hispanic	−11.68***	0.000	−6.12***	0.000	−11.36***	0.000
Language						
Non-English language	3.47**	0.030	−3.94***	0.000	7.71**	0.016
Linguistic isolation	−18.55***	0.000	−10.42***	0.000	−35.68***	0.000
Income						
Income, 1st quartile (log)	3.20***	0.000	1.26***	0.000	0.49	0.630
Income, 2nd quartile (log)	−0.96	0.614	1.37	0.196	2.21	0.525
Income, 3rd quartile (log)	7.13***	0.000	3.92***	0.000	5.63	0.117
Income, 4th quartile (log)	5.84***	0.000	7.24***	0.000	8.69***	0.000
Education profile						
Less than high school	8.64***	0.001	7.35***	0.000	9.50**	0.049
Some college	−4.72*	0.067	1.52	0.308	−0.64	0.894
College graduate	−7.98***	0.000	−6.58***	0.000	−2.21	0.507
Other demographics						
Household size	4.64***	0.000	4.69***	0.000	4.63***	0.000
Female	−11.40***	0.000	−11.36***	0.000	−13.48***	0.000
Median age/10	2.73***	0.000	2.12***	0.000	1.78***	0.002
Median age, squared/100	−0.14***	0.000	−0.05**	0.020	−0.03	0.599
Area profile						
Work at home	23.59***	0.000	10.27***	0.000	5.51	0.569
High commuting area			2.34***	0.003		
Rural CO			−6.26***	0.000		
Distance from CO, <1 mile	−10.24***	0.000	−3.34***	0.000	−6.72***	0.000
Distance from CO, >1 mile	−56.58***	0.000	−42.36***	0.000	−53.72***	0.000
Time deployed in CO			1.02***	0.000		
Broadband competition						
Cable modem service					−2.40**	0.014
CLEC presence			−6.99***	0.000		
CLEC broadband			−2.28***	0.000		
Fixed effects	Central office		State		Central office	
Log likelihood	−17,785.6		−21,816.7		−6,062.9	
N	51,789		51,789		17,783	
Pseudo R^2	0.464		0.343		0.468	

Table notes: The income quartiles are $38,750, $51,761, and $68,839. Standard errors are clustered on Census block groups. See also notes to previous table.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Asian, and other).[27] The estimated probability of adoption for a race is then calculated as the probit household probability with the race variable set to 1 (e.g., $\Phi(\beta_0 + \beta_{\text{black}})$ for blacks). Similarly, for Hispanics we repeat the exercise including only a Hispanic variable included in the estimation. We do not report the coefficient estimates from these basic regressions, but note that all were highly significant.

Our data show a broadband gap between whites and blacks, as in the national statistics in Fig. 1 discussed above. The adoption rate for black households, 6.5%, is 17.5% lower than the rate of 7.9% for white households. The adoption rate of 4.6% for Hispanic households is 42% lower than that for white households. The

[27] Recall that since we do not have household-level observations on demographics, these variables measure the fraction of the population that falls into each racial category in the census block containing the ZIP + 4 area.

estimate for Asians is surprisingly low at 0.6%. However, there are relatively few Asians living in the Midwest (they compose 3.8% of our sample), and we suspect that the high adoption rates among Asians observed nationally in Fig. 1 are driven largely by those living on the West Coast, in particular the large number of them living in proximity to Silicon Valley. While it is interesting to note that national-level statistics can mask regional digital divides, due to the small number of Asians in our sample we do not know how representative our results are.

In our demand estimations, we investigate the determinants of the gaps we have uncovered in broadband access, paying particular attention to the nexus of race, income, and broadband availability and competition. In all estimations, the unit of observation is a Census block in an area that had access to DSL, the dependent variable is one if there is at least one subscriber in the block, and estimation is MLE based on the structural demand equation (2). We begin with Estimation 1, in which only race and ethnicity variables are included (Table 3). In the table, we report the marginal effect of the variable on the probability that broadband is deployed by a household, and the *P*-value for the hypothesis that the coefficient is zero. All variables we discuss have statistically significant coefficients at the 1% level, unless otherwise noted. The marginal effect of −1.41 (in percentage points) for black households, compared to the excluded category of white households, mirrors the broadband gap shown for blacks in Table 2. The marginal effect for Hispanics is −2.65. The marginal effects for black and Hispanic households change little when fixed effects for the central office areas are included (Estimation 2 in Table 2). The fixed effects control for unobserved area characteristics, so that identification of the marginal effects comes only from within-area variation.[28] In both estimations, Asian households are much less like to subscribe to DSL. The marginal effect for "other race" is positive in Estimation 2 (and in subsequent estimations), although this effect should probably be viewed as a partial offset to the Hispanic effect, since the correlation between claiming Hispanic ethnicity and race "other" is high ($\rho = 0.78$).[29]

Controlling for income in the estimation (Estimation 3 in Table 3) reduces the marginal effects in magnitude for black and Hispanic households as expected, but by a surprisingly small amount. Even though income is a significant determinant of access at the 5% level, with an implied income elasticity of 0.62, income by itself apparently explains little of the broadband gap alone.[30]

When the full set of covariates is added (Estimation 4 in Table 4), the marginal effects for black and Hispanic households increase in magnitude. Thus, differences in income or education do not appear to be responsible for a broadband gap for these groups. The marginal effect for Asian falls in magnitude to −6.8. The income effect is modeled more flexibly than in Estimation 3, with a linear spline with breaks at the quartiles. Income is positive and significant for all but the second quartile group.[31] The income elasticities from the significant coefficients, calculated as the average in the sample, are 0.28 for incomes in the first quartile group ($0–38,750), 0.63 for incomes in the third quartile group ($51,761–68,839), and 0.51 for the highest income group, so DSL is a normal but not a luxury good.

We also control for language and many other market characteristics in Estimation 4. The use of a non-English language in the home increases demand for DSL by 3.5% points, which is more than offset by the marginal effect of −18.6 points if the house is linguistically isolated in addition.[32] Education has an unexpected impact: those with less than a high school education have greater demand for DSL than the excluded group of high school graduates, and college graduates have less demand. This may be one area where the lack of household-specific demographics leads to contrary results. Larger households, males, and those working at home have greater demand. The latter marginal effect of 23.6% points is particularly large, indicating that those who work from home may have strong demand for high-speed connections to ease telecommuting. Age, entering the specification in quadratic form, displays a positive impact on DSL demand over the range of age in the data.

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[28] The fixed-effects probit model suffers from the incidental parameter problem, which can lead to inconsistent coefficient estimates. Since our structural model is based on a household-level probit, the same danger may apply to our model in principle. However, the incidental parameter problem arises as the number of observational units (central office areas) goes to infinity, holding the number of observations per unit constant. In our data, the average number of observations per area is over 300, and there are fewer than 200 areas, so inconsistency is not likely to be a practical problem in our application.

[29] Many households confuse race with ethnicity and enter "Hispanic" or "Latino" as their race, which ends up coded as "other".

[30] Income elasticity is calculated as the average elasticity in the sample.

[31] Kridel et al. (2001) also found non-monotonic impacts from income.

[32] A household is "linguistically isolated" if no one speaks English as a first language or "very well" as a second language.

The final variable we include in Estimation 4 is the distance of the household from the central office. We discuss the impact of distance in detail, because we know of no other demand study that has considered its effect. Distance has a large and significant effect on subscription. The marginal effect of distance is about −10 for households within a mile and −57 for households between a mile and 1.5 miles, the maximum in our data. The variable is measured in miles, and so the implied impact of increasing the household's distance from the central office from 1 to 1.1 miles, for example, is a reduction in the probability of subscription by 5.7% points. Including the distance variable also greatly improves the likelihood and the R^2 of the fit.[33]

Distance to the central office is also related to the ethnic dimension of the Digital Divide. While the marginal effect for blacks does not change much if the distance variables are excluded from Estimation 4, the effect for Hispanics changes markedly. Without the distance variables (results not reported), the marginal effect for Hispanics is estimated at only −3.8% points, one-third its size in Estimation 4 (−11.7) when distance is included. The data show that Hispanics tend to live closer to the central office, so that the negative effect of distance on demand masks some of the broadband gap for Hispanics when distance is not controlled for.

The remaining unexplained demand factor is broadband competition. Other studies variously find that demand for a particular broadband technology changes when other broadband options are available Rappoport et al. (2003) or that the number of broadband providers in an area has no discernible effect on demand (GAO, 2006). To investigate the impact of CLEC presence on demand for the incumbent's DSL, we add the two CLEC variables described above to Estimation 5. Because the CLEC variables do not vary within a central office area, we replace the central office fixed effects with state indicator variables. The presence of a CLEC in the central office area, which may or may not be offering DSL, reduces demand for Ameritech's DSL by 7.0% points.[34] If there is a confirmed DSL-providing CLEC in the area, demand for Ameritech's DSL falls by another 2.3% points.

Including the CLEC variables could lead to untrustworthy results if there are factors omitted from the model that stimulate demand for incumbent DSL and entry of competitors. For example, an area might have poor network infrastructure, leading to lower service quality (and less demand) by the incumbent and less entry by rivals. If so, the CLEC variables would be endogenous and the coefficients inconsistent. However, since the omitted factors cause incumbent demand and CLEC entry to move together, endogeneity would positively bias the coefficients on the CLEC variables. Since we find negative coefficients, if endogeneity has any effect its removal would likely only strengthen our finding.

The result that CLEC presence reduces the incumbent's demand is as expected if the competitors steal broadband business from the incumbent. Competition could have competing impacts on the DSL gaps for blacks and Hispanics. If greater competition spurs the incumbent to provide better prices, perhaps due to equipment rebates or waiving of installation fees,[35] and if minority subscribers are more price sensitive due to lower income on average than whites, then competition could narrow or close the gap. The gap may also narrow in percentage points if equal proportions of customers of all races choose competitors' broadband over Ameritech's DSL.[36] Adding the competition variables in Estimation 5 reduces the marginal effect for blacks to −0.39 and removes the statistical significance. The marginal effect for Hispanics is about half of its size in Estimation 4. It appears, therefore, that the availability of competitive options for minority households is an important piece of the DSL gap. However, before drawing this conclusion, remember that not only were the CLEC variables added in Estimation 5, but the central office fixed effects were dropped. To verify that the change in the marginal effects for blacks is not driven by dropping the fixed effects, we re-ran Estimation 5 without the CLEC variables (results not reported). The marginal effect for blacks is −1.88, in the range of Estimations 1–4. Thus, the competition variables are responsible for reducing the magnitude of the marginal

[33] Compared to an estimation identical to Estimation 4 but without the distance variable (results not reported), the log likelihood of Estimation 4 increases by 9829 and the pseudo R^2 more than doubles, improving by 0.296.

[34] If the number of CLECs is included instead (results not shown), the effect is also negative and significant, and the other coefficients change little.

[35] The monthly service price for DSL appears to have been about $40/month in all Ameritech areas.

[36] For example, for the sake of illustration assume that the DSL subscription rate when there is no competition is 5% for blacks and 10% for whites. If competition takes half of all customers, then the resulting DSL subscription ‘‘gap'' between blacks and whites falls from 5% to 2.5% points.

effect for blacks. However, without the CLEC variables, the marginal effect for Hispanics is about the same as in Estimation 5. For the Hispanic gap, then, the fixed effects appear to be responsible for the change between Estimations 4 and 5, not CLEC competition.

By dropping the fixed effects in Estimation 5, we are able to add three other variables that have little or no variation within central office areas: high commuting area, rural central office, and the time that DSL has been deployed in the central office. We find that high commuting areas have more demand for broadband, probably because when commutes are longer, the incentive to telecommute (and therefore the demand for fast connections) increases.[37] Rural central offices (as designated by regulators) have lower demand. Finally, as one would expect from the evidence regarding the diffusion of consumer technology, the longer DSL has been available in the area, the more likely the household subscribes to it. This is evidence that diffusion among consumers takes time, even after supply is available.

We add the cable modem availability variable, for the subset of observations for which it is available (mostly in Ohio), in Estimation 6. This estimation includes fixed effects. As with the CLEC variables, the cable modem variable has a significant negative marginal effect (−2.4). Thus, competition from other broadband providers reduces demand for Ameritech's DSL. While the marginal effect for blacks loses significance, comparison with an estimation using the same subsample but not including the cable modem variable shows that the change in sample, not the cable modem variable, is the cause.

As a final check on the results, we repeat Estimations 4 and 5 including only households within a mile of the central office. Perhaps some of the households between 1 and 1.5 miles from the CO actually do not have DSL available to them, because of excessively long loop lengths due to geographical barriers. If so, the implied gaps for black and Hispanic households may be an artifact of where they are located. However, using the "near" subset (results not shown) does not change the conclusions for blacks and Hispanics: the negative marginal effects persist and are even larger, and the effect for blacks in Estimation 5 gains statistical significance.

7. Conclusions

The empirical results indicate that race and ethnicity matter independently of other related factors such as income and education in the demand for DSL broadband Internet connection. Our findings extend earlier phenomena discovered for narrowband online access to broadband. The Pew Internet Project (Lenhart et al., 2003) found that blacks and Hispanics are less likely to go online than whites, even after controlling for other demographic factors. Why does race matter independently of income, education, and area characteristics? Perhaps this question belongs more properly to sociology than economics. Survey evidence suggests reasons particular to blacks and Hispanics, including lack of time to go online, a perceived lack of relevance of online content, and less social contentment, the latter of which is a strong predictor of online access (Lenhart et al., 2003).[38] However, some racial differences in the use of the Internet would seem to increase the demand for broadband. Blacks and Hispanics spend much more time on average than whites on entertainment activities such as downloading and listening to music online and on online gaming (Madden, 2003), which usually require fast Internet connections to enjoy the experience.

We also uncovered several other important determinants of demand, some of which interact with the racial element. The income elasticity of DSL demand is positive and significant, although (surprisingly) income explains little of the broadband gap for blacks and Hispanics. Distance from the central office has the largest marginal effect on demand, and ignoring this important variable leads to gross understatement of the broadband gap for Hispanics. Competition from CLECs and cable modem providers causes demand for the incumbent's DSL offering to fall. Furthermore, controlling for the presence of competition from CLECs reduces the size and significance of the marginal effect for blacks. Although

[37] Jackson et al. (2002) explore the connection between telecommuting and broadband, and find that teleworking did not appear to be spurring adoption of broadband *en masse*. We nevertheless want to measure the impact of the commuting variables on demand in our data.

[38] In the Pew study, "social contentment" is a variable derived from factor analysis for respondents who think most people are fair and can be trusted, and who have a social support network. The variable "white" also is heavily weighted in this factor, and blacks and Hispanics score lower on this measure of social contentment.

DSL service prices do not vary in the data, perhaps competition spurred promotional rates on installation or equipment. Thus, lack of access to competitive broadband options may play a role in creating some dimensions of the Digital Divide, and policymakers may want to continue their emphasis on promoting competition.

Because we examine data from the nascent years of DSL deployment in the US, the details of our results require some extrapolation to the broadband Digital Divide of today. For example, there is more competition now in the provision of broadband Internet access than there was in 2000. Our results from above suggest that competition can help close racial gaps in adoption, which is in accord with the narrowing of the gaps in recent years discussed in Section 2 (see Fig. 2). Furthermore, as remote DSL terminals and fiber to the curb are deployed in local networks, distance's importance in transmission quality is lessened, which in turn weakens the role that household location plays in creating broadband gaps. The world of information technology continues to evolve, and there will always be new dimensions of the divide to address. Just as the racial gaps in Internet access seen in the days of narrowband access carried over to the broadband arena, we can expect that factors we have identified such as race, income, and competition will continue to affect household adoption of future technological waves.

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