**Metro, Micro, and Non-core:**
**A 3-year Portrait of Broadband Supply and Demand in Oklahoma**

Brian E. Whitacre
Department of Agricultural Economics
504 Ag Hall
Oklahoma State University
Stillwater, Oklahoma 74074
Ph: (405) 744-9825
Fax: (405) 744-9835
brian.whitacre@okstate.edu

***Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 6-9, 2010***

**The Internet, Diffusion, and the Role of Rurality**

Similar to most innovations, the Internet underwent a period of diffusion after its introduction to the general population during the late 1990s. Household rates for general access increased from 19 percent in 1998 to 73 percent by 2005 (Fox, 2005). Along this same line, household broadband access rates[1] stood at around 4 percent in 2001 but increased to over 55 percent by 2007 (Whitacre & Mills, 2007; Horrigan, 2008). As Internet access continues to progress, however, uneven rates of access (commonly referred to as "digital divides") among various social groups have led to concerns that existing income and educational discrepancies may be aggravated (Drabenstott, 2001). For example, areas with low levels of education that are not taking advantage of the educational opportunities provided by the Internet may fall further behind their Internet-using peers. In particular, the rural – urban[2] digital divide has received a large amount of attention from both researchers and policy makers, including legislation aimed at increasing rural broadband availability and access rates in the two most recent versions of the U.S. Farm Bill (Strover, 2001; Malecki, 2003; Whitacre & Mills, 2007). Whitacre and Mills specifically document both a general access divide of 13 percentage points between rural and urban households and also a divide in broadband access of around 14 percentage points in 2003. Very few studies, however, have placed the problem in the context of diffusion and even fewer have empirically examined how diffusion has been impacted by the free market.[3] This paper focuses on the economics of the situation by examining both supply and demand aspects of

[1] For the purposes of this paper, broadband access is defined as data transmission of over 200 Kilobytes per second (kbps) in at least one direction. Until 2008, this was the official definition of the Federal Communications Commission, and represents speeds roughly four times faster than a typical dial-up modem.
[2] This paper uses Rural / Urban Commuting Area (RUCA) codes as defined by the USDA / ERS to measure rurality. It further breaks rural areas into micropolitan (codes 4 – 6) and noncore (codes 7 – 10) categories.
[3] For examples of studies looking at the Internet from a diffusion perspective, see Grubesic (2003), Warschauer (2003), and Liu et al. (2006).

diffusion in the context of the rural – urban broadband divide. It attempts to answer the question of whether the market is holding back rural access rates by employing a state-level empirical study and decomposition of the factors involved.

From an economics perspective, there are two basic ways of thinking about why a rural – urban digital divide in Internet access exists. The first deals with the fact that telecommunications companies are less likely to provide rural areas with the needed infrastructure due to lower population density, which translates to smaller profits and a significantly lower return on their investment (Downes & Greenstein, 2002). This line of thought focuses on the supply side – that rural area access rates lag because the infrastructure is not available to them.[4] The second way of thinking about the rural – urban digital divide centers on lower levels of demand. This train of thought suggests that because rural areas have, on average, lower levels of specific factors known to influence the access decision (such as income and education), they will be less likely to adopt the Internet even when it *is* available. In general, then, both supply and demand aspects can contribute to why a rural – urban Internet gap exists. Adding diffusion theory into the discussion allows for examination of how the factors impacting supply and demand have changed over time. This paper applies the concepts of diffusion theory to both the supply and demand components of broadband Internet access. In particular, rural communities are at a disadvantage from both sides – but can particular policies help solve this problem? Would demand-side or supply-side policies be more effective? Using detailed data on broadband supply and demand from the state of Oklahoma, econometric techniques allow for creation of synthetic rates of access that estimate what rural broadband access rates would be if supply diffusion occurred at the same rates as in urban areas. These lead to specific policy

[4] While dial-up availability has become nearly universal across the U.S., the same is not true for broadband access. Significant portions of the U.S. (most of them rural) do not have the infrastructure necessary for broadband Internet connections (GAO, 2006).

suggestions for helping to bridge the rural – urban divide and provide researchers with additional information about the future of broadband access gaps. Using lower-level breakouts of rural areas (micropolitan and noncore) allows for a more in-depth analysis on which factors are most important for a particular geographic entity.

In the following section, a brief literature review focuses on the basics of diffusion and its applicability to the Internet and broadband access in particular. Previous studies focusing on factors impacting both the supply and demand of broadband infrastructure provide direction for the models to be employed. The next section discusses the data, describing the relatively underutilized sources and displaying interesting statistics on broadband diffusion over a three-year period in Oklahoma. The empirical methodology highlights the techniques used to determine how patterns of supply diffusion have impacted overall access rates. The paper concludes with a discussion of the policy implications that follow from the results.

## A Brief Literature Review

The basic concept of diffusion theory, which puts the individual adoption decision into both a temporal and social perspective, originated with the sociologist Tarde (1903) who hypothesized that individuals learned about an innovation by copying the behavior of others. This led to the development of an S-shaped adoption curve (Figure 1).[5] Diffusion theory was brought into the forefront of scientific thought in 1962 by Everett Rogers, whose work *Diffusion of Innovations* discussed the primary concepts and provided numerous examples, and has since evolved through five editions. The basic theory remains unchanged, and defines diffusion as the interaction of four basic elements: (1) an innovation, (2) communication channels, (3) time, and

[5] Several researchers have suggested that the S-curves associated with higher technology items such as television, telephone, and the Internet are more "severe" or have less slope in the tails than traditional innovations (Marvin, 1998; Norris, 2001)

(4) a social system.  The temporal component (3) is further acknowledged by several categories of adopters proposed by Rogers, who suggested that individuals are normally distributed by their likelihood of and time frame for adoption.  The five categories he proposed range from innovators (the first to adopt) to laggards, who are suspicious of change and will be the last to adopt.  Figure 2 displays these categories and some typical characteristics associated with each type, along with the distribution suggested by Rogers.

[Figure 1 about here]

[Figure 2 about here]

This paper looks at the diffusion of broadband Internet access to rural areas from two distinct perspectives:  supply and demand.  From a demand point of view, certain characteristics such as education or income levels have been shown to impact the time frame in which individuals adopt new technologies (as initially hypothesized by Rogers (1962) and displayed in Figure 2).  Rural areas, in particular, tend to have higher rates of older individuals and lower levels of income and educational attainment.  These characteristics have been shown to impact the adoption of several information–oriented technologies, including personal computers (Chakraborty & Bosman, 2005) and the Internet (Mills & Whitacre, 2003; McConnaughey & Lader 1998).  Other characteristics, such as race and number of household members, have also been shown to impact broadband adoption rates (Horrigan 2006; Whitacre & Mills 2007) and also typically vary dramatically between rural and urban areas.  The contributions of these demographic differences (relative to infrastructure differences) in the rural – urban broadband divide will be explored later in this paper.

Turning to the supply side of the discussion, several studies have focused on the reasons for the lack of infrastructure being supplied to rural America.  Most found that lower population densities, the lack of perceived demand, and more difficult terrain negatively impact the likelihood of telecommunications companies servicing these areas (Grubesic, 2003; Strover, 2003; Firth & Mellor, 2005). In essence, these privately-owned companies are behaving as might be expected given a neoclassical view of the economy – investing first where profits are likely to be highest. Johnson (2001) suggests that while rural areas will become connected as telecommunications service evolves, their infrastructure will not only be more expensive to provide but will also be a generation behind levels found in more urban areas. With the recent movement of wireless 3-G networks, which are wide area cellular networks that also incorporate high-speed Internet access, into large urban cities, this prediction is holding true for the time being (Noyes, 2008). While several studies note the potential role for the government to play in addressing this issue (Liu & San, 2006; Papacharissi & Zaks, 2006), several Federal Communication Commission (FCC) reports have concluded that infrastructure deployment is "reasonable and timely" and as a result U.S. policy has been mostly hands-off (Kruger, 2008).

It is important to note that the relatively complex process of broadband adoption results from the interaction of diffusion theory and the free market's influence on infrastructural availability. In particular, the decisions made by the distinct adoption categories suggested by Rogers may be mediated by other variables that have an impact on the market side of broadband supply. Understanding the relative roles and importance of these factors in the particular context of the rural-urban digital divide is a primary goal of this paper.

## Data and Descriptive Statistics

In order to explore the process of diffusion for the Internet (and particularly, for broadband access), we use state-level data from several sources at two distinct points in time. In particular, our focus is on the state of Oklahoma between 2003 and 2006. To determine the status of the supply of broadband infrastructure across the state, we focus on the two dominant providers of broadband: Digital Subscriber Lines (DSL) provided by telephone companies, and cable Internet, which is provided by cable television companies. Over the time frame in this analysis, these two providers composed over 95 percent of the nation's residential broadband lines, with fiber and wireless / satellite services making up the remainder (FCC 2003, 2006). The availability of these two types of providers is determined at the ZIP-code level by utilizing *Warren Publishing's Television and Cable Factbook*, which lists information on every cable system in the U.S., and the National Exchange Carrier Association (NECA) Tariff #4 dataset, which provides similar information on every central telephone office. Both datasets explicitly code whether or not a particular entity (cable office or central phone office) provides broadband access for its customers, making the combined dataset a comprehensive source of information on the presence of wired broadband infrastructure. Other sources of broadband infrastructure availability, such as the FCC's Form 477, have known flaws – namely, depicting a ZIP code as having service if a single subscriber resides there, regardless of the type of service used. Therefore, a ZIP code may appear to have broadband access when in reality a single resident uses a satellite connection, and does not have cable or DSL available to them. GAO (2006), Flamm (2006), and Whitacre (2008) explore these drawbacks in more detail.

There were 320 different cable systems and 640 individual central telephone offices operating in Oklahoma during 2003 (Table 1). Only a relatively small percentage offered broadband service to their customers (8 percent and 10 percent, respectively). By 2006, the number of cable systems and central offices had changed slightly, with some cable systems being taken over by larger ones and several additional phone offices appearing across the state. The largest change, however, was that the number of broadband capable systems or offices more than doubled. Adding broadband capability varies by technology, and can be an expensive undertaking for cable and phone companies. Cable companies typically need to re-lay the cable itself and upgrade to a higher bandwidth technology such as fiber (as opposed to the co-axial cable that was used prior to 2000) to enable two-way transmission. Phone companies can add equipment to enable DSL capability to existing copper lines, but are restricted to a distance of roughly 3 miles from the central office. Providing DSL capability to distances beyond this 3 mile radius generally requires re-laying of the wire. Cable companies were the first to invest in broadband technology, spending over $65 billion to upgrade their lines between 1996 and 2002 (NCTA, 2004). This first-investor spending allowed the cable companies to gain a high market share in the residential broadband market by 2003, but significant investment by the telephone companies after 2003 allowed them to catch up.[6] It is important to note, however, that a significant number (in fact the vast majority) of cable systems and phone offices still did not offer broadband capability in Oklahoma as of 2006. In fact, NECA estimated in 2006 that it would require over $11 billion to upgrade the roughly 6 million rural telephone lines to have broadband capability (NECA, 2006).

[Table 1 about here]

Matching the cities and communities served by each cable system or phone central office to the appropriate ZIP codes allows for a geographic representation of the presence of wired broadband infrastructure across Oklahoma in 2003 and 2006 (Figure 3). ZIP code approximations to Rural – Urban Commuting Area (RUCA) codes provided by USDA / ERS are used to define rurality, where codes 1-3 are used for metropolitan areas, codes 4-6 are for

[6] FCC indicates that cable connections accounted for 66% of all residential broadband connections in 2003, but this number fell to 55% in 2006 as DSL's market share climbed (FCC, 2003, 2006).

micropolitan areas, and codes 7-10 are for noncore areas.  Figure 4 displays the metropolitan, micropolitan, and noncore areas of the state so that supply diffusion trends can be seen in this context.  As expected, the dominant metropolitan centers of the state (Oklahoma City and Tulsa) had broadband infrastructure available to them in 2003 and experienced growth in competition over this period, with most surrounding ZIP codes offering both DSL and cable access by 2006. Interestingly, however, broadband access was available in many micropolitan and non-core areas in 2003, including the extremely low-density panhandle portion of the state.  By 2006, significant diffusion had occurred across the state, but (with the exception of Oklahoma City and Tulsa) without specific geographic patterns.  Numerous relatively rural communities experienced the penetration of broadband infrastructure, including some with rather small populations who now had access to *both* cable and DSL.  Table 2 provides a slightly different look at this diffusion, listing the percentage of the population living in metropolitan, micropolitan, and non-metropolitan areas that had access to different types of broadband infrastructure over this period.

[Figures 3 and 4 about here]

[Table 2 about here]

As table 2 suggests, metropolitan areas of the state already had a strong broadband infrastructure presence in 2003, with over 80 percent of the population having access.  This increased to 89 percent by 2006.  Micropolitan areas of the state experienced dramatic growth, as the percentage of residents with access to broadband infrastructure increased from 59 percent to over 85 percent (close to what existed in metro areas) during the three-year period.  Rural areas also experienced an impressive increase, with the percentage of non-core residents with access to broadband infrastructure more than doubling from 20 percent to over 45 percent.  It is worth noting that the Oklahoma state legislature passed a “broadband parity” bill in 2002, which eased the regulatory environment for high-speed networks. In effect, this bill ended the requirement for incumbent telephone providers to share their lines with competitors, as they were forced to do under the 1996 Telecommunications Act. This bill was largely credited with increasing DSL deployment across the state (Carter, 2003; Armstrong, 2005) and was at least partially responsible for the diffusion of broadband infrastructure observed over this three year period.

Turning to the demand side of the picture, surveys of approximately 1,200 random households conducted in both 2003 and 2006 provide information on household broadband access rates. Although a true panel dataset was not obtained (meaning the same households were not interviewed in both periods), the results are representative of state averages after survey sample weights are applied. These surveys asked questions about household Internet use and type (i.e. dial-up vs. broadband), and also collected basic demographic characteristics such as age, education, and income levels. Removal of observations with missing or inconsistent information led to 906 and 942 observations being available in 2003 and 2006, respectively. Descriptive statistics on Internet adoption rates, along with demographic characteristics that previous research has suggested impact those rates, are broken into categories of metro / micro / non-core location and displayed in table 3.

[Table 3 about here]

In general, trends across the three rural – urban classifications are expected. In both years, residents of metropolitan areas typically have the highest levels of general Internet access, broadband access, and education, followed by those in micropolitan areas and finally noncore residents. In terms of income, metropolitan areas tend to have higher levels of both low-income (under $10,000 per year) and high-income (over $100,000 per year) households. Noncore areas are the poorest, with over 70 percent earning less than $40,000 in 2003 – however, this number fell to only 52 percent by 2006, representing a general improvement in the economic situation across the state. In fact, the percentage of households earning more than $100,000 per year nearly doubled over this period for all three rural - urban classifications. This is consistent with other economic data over this period, as Oklahoma experienced a large boom in their dominant industries of oil and natural gas (Page, 2006; Associated Press, 2007). Other household characteristics also display expected patterns, as age increases and the population becomes more racially homogenous (with the exception of Native Americans) moving across the metro – noncore spectrum.

Table 4 provides a quick look at some descriptive statistics on how broadband access has diffused over the time period of analysis. As indicated previously, households with certain characteristics such as low education or income levels, elderly household heads, or rural location are less likely to adopt broadband based on both Rogers' theory of diffusion and (potentially) supply limitations. Rates of broadband access over time for these groups are displayed in table 4. While some groups have experienced pronounced diffusion (such as the elderly), others have not (those with less than a high school education). Many of the characteristics discussed here have been hypothesized to impact the broadband adoption decision. The shifting contribution of these characteristics as diffusion occurs is further explored using the methodology described in the following section.

[Table 4 about here]

## Methodology

To determine the role that infrastructure diffusion has played in the broadband access decision, the formal statistical model is specified as:

$$y_i^* = X_i\beta + Z_i\alpha + H_i\gamma + I_i\theta + R_1\delta_1 + R_2\delta_2 + \epsilon_i \quad (1)$$

$$y_i = 1 \; if \; y_i^* \geq 0$$

$$y_i = 0 \; if \; y_i^* < 0$$

where $y_i^*$ an unobserved measure of the relative costs and benefits from broadband access for household i and $y_i$ is the actual (observed) level of household broadband access. On the right hand side of the equation, $X_i$ represents household income levels, $Z_i$ specifies household education levels, $H_i$ is a vector of other household characteristics, $I_i$ is a dummy variable for whether or not some type of broadband infrastructure is available[7], $R_1$ and $R_2$ are measures of rurality (micropolitan and noncore); β, α, γ, θ, $\delta_1$, and $\delta_2$ are the respective parameter vectors; and $\epsilon_i$ is the error term associated with the model. Given the binary nature of the broadband adoption decision, a logit model is employed.

The expected signs of all variables are identified using previous research on the topic along with economic intuition. Both education and income levels are expected to positively impact the probability of broadband adoption ($\beta > 0, \alpha > 0$) (Cooper & Kimmelman, 1999; NTIA, 2002). Other household characteristics such as the presence of children, age, and race are expected to have some impact on the access decision ($\gamma \neq 0$) (Horrigan, 2007; Rose, 2003). Higher levels of infrastructure capacity are expected to increase the probability of adoption for a household, although their presence is not a necessary condition due to the availability of wireless broadband applications ($\theta > 0$) (Prieger, 2003). We also expect an increasingly negative relationship between rurality and the probability of access as we move away from a metropolitan area, perhaps due to lower network externalities that exist in these areas ($R_1, R_2 < 0$) (Whitacre & Mills, 2007). Although a lack of data prevents us from including the cost of a broadband

[7] Additional models broke out infrastructure by type (cable / DSL / both) with similar results.

connection in this specification, at least one recent study suggests that the own-price demand for this service is relatively inelastic (Flamm & Chaudhuri, 2007). Further, national survey data from 2004 indicates that households in areas with more than one broadband provider were paying only slightly less than those with more than one - \$43 per month compared to \$38 (Horrigan, 2006). Therefore, omitting this variable should not dramatically bias our results.

*Logit model decomposition technique*

In order to determine the impact of infrastructure diffusion on the adoption decision, we use a modified decomposition of the standard Oaxaca-Blinder technique. We can express the rural – urban (or similarly, metro – micro or metro – noncore) digital divide in a linear format as:

$$\bar{Y}^U - \bar{Y}^R = (\bar{X}^U - \bar{X}^R)\hat{\beta}^U + \bar{X}^R(\hat{\beta}^U - \hat{\beta}^R) \tag{2}$$

where $\bar{Y}^G$ is the average rate of broadband access, $\bar{X}^G$ is a vector of average values of the independent variables, and $\hat{\beta}^G$ is a vector of parameter estimates for rural / urban status G. Since we are utilizing a non-linear functional form in the logit specification, we follow Fairlie (2003) in writing the decomposition as:

$$\bar{Y}^U - \bar{Y}^R = \left[\sum_{i=1}^{N^U} \frac{F(X_i^U\hat{\beta}^U)}{N^U} - \sum_{i=1}^{N^R} \frac{F(X_i^R\hat{\beta}^U)}{N^R}\right] + \left[\sum_{i=1}^{N^R} \frac{F(X_i^R\hat{\beta}^U)}{N^R} - \sum_{i=1}^{N^R} \frac{F(X_i^R\hat{\beta}^R)}{N^R}\right] \tag{3}$$

where $N^G$ is the sample size for metropolitan status G. The decomposition can also be written as:

$$\bar{Y}^U - \bar{Y}^R = \left[\sum_{i=1}^{N^U} \frac{F(X_i^U\hat{\beta}^R)}{N^U} - \sum_{i=1}^{N^R} \frac{F(X_i^R\hat{\beta}^R)}{N^R}\right] + \left[\sum_{i=1}^{N^U} \frac{F(X_i^U\hat{\beta}^U)}{N^U} - \sum_{i=1}^{N^U} \frac{F(X_i^U\hat{\beta}^R)}{N^U}\right] \tag{4}$$

In essence, we are applying rural or urban parameter estimates ($\hat{\beta}^G$) to a specific set of explanatory variables($X_i^G$). In some cases we are constructing synthetic rates which have no real-world counterpart – for example, applying rural parameter estimates to urban variables.

This technique does allow us, however, to determine the specific impact of a particular variable on the gap in broadband access.

The first bracketed term of equations (3) and (4) focuses on the part of the gap that can be represented by differences in the distributions of the explanatory variables - note that the parameters used in this bracket are the same ($\hat{\beta}^U$ in (3), $\hat{\beta}^R$ in (4)), while only the explanatory variables differ ($X_i^U$ and $X_i^R$). The choice of which parameters to use can lead to significantly different results, and has led to suggestions that weighted average parameters from a pooled sample ($\hat{\beta}$ instead of $\hat{\beta}^U$or $\hat{\beta}^R$) should be used (Neumark, 1988; Oaxaca & Ransom, 1994). Calculating the impact of a single explanatory variable (such as infrastructure) requires "replacing" a single rural characteristic with its urban counterpart. To accomplish this, we create a one-to-one mapping based on the probability of broadband access for all observations using the specification in equation (1). We then draw a sub-sample of the largest group (metropolitan) equal in size to the sample of the micropolitan or noncore households. Although this sampling procedure affects $\bar{Y}^U$ and $X_i^U$, bootstrapping a large number of urban samples allows for results from the entire distribution to be approximated (1,000 samples were used in practice).

These two samples (a sub-sample from the metropolitan observations, and a full sample from either the micropolitan or noncore observations) are then ranked by predicted probability of broadband access. In this way, micropolitan or noncore households with characteristics that suggest they are likely to adopt broadband access are matched with similar households in metropolitan areas. This allows us to measure the specific contribution of a characteristic by replacing the micro or noncore value with its metropolitan counterpart. In particular, we can write the contribution of infrastructure to the digital divide as:

$$\frac{1}{N^R}\sum_{i=1}^{N^R} F(X_i^U\hat{\beta} + Z_i^U\,\hat{\alpha} + H_i^U\hat{\gamma} + I_i^U\hat{\theta}) - F(X_i^U\hat{\beta} + Z_i^U\alpha + H_i^U\hat{\gamma} + I_i^R\hat{\theta})$$

which effectively "replaces" urban levels of infrastructure with those found in rural areas. In this way, hypothetical access rates can be estimated for rural areas based on what they would have been if infrastructure levels mirrored those in urban areas. Note that the remainder of the rural – urban gap will be composed both of other characteristic differences that were not altered (such as education and income levels) *and* differences in rural – urban parameters (the second bracketed term in equations (3) and (4)). This technique can be replicated for other characteristics such as education or income, allowing us to see the impacts of differences in *only* those characteristics.

## Results

The pooled parameter estimates for the broadband adoption decision for 2003 are shown in the first column of table 5 and are, in general, as expected. In particular, higher levels of education (relative to the default category of no high school education) lead to higher probabilities of broadband adoption as evidenced by the positive, significant, and increasing parameter values. Additionally, all income levels over $20,000 are highly significant and exert a positive influence on adoption relative to the default category of less than $10,000. Most other household characteristics lack significance. Age is negatively related, suggesting that an older household head reduces the probability of broadband adoption, while the African-American parameter is unexpectedly positive and significant – indicating that this racial group is more likely to adopt than their Caucasian counterparts. Although this result is the opposite of a documented divide between African-American and Caucasion households (NTIA, 2002), African-Americans have recently displayed strong growth in broadband adoption (Horrigan, 2006). As expected, living in an area with broadband infrastructure does have a positive impact on the adoption decision. Interestingly, while both measures of rurality are negative, neither are significant. This suggests that after controlling for demographic and economic characteristics, as well as the presence of infrastructure, households in these areas have a similar propensity to adopt broadband as those in metropolitan areas.

A separate column shows how these impacts change in 2006 as compared to the base year of 2003. If a parameter has a significant shift in 2006, this implies that the underlying relationship has altered during this time frame. It is striking that no measures of education have significant shifts. This implies that household heads with lower levels of education are no more likely to adopt broadband in 2006 than in 2003, which runs counter to diffusion theory. However, we do observe negative and statistically significant shifts for income levels over $40,000; which means that income has become less of a factor in the adoption decision. The only other significant shifts in 2006 are a significant impact for marriage and a negative impact for African-Americans. The positive result for marriage may be correlated with both the age variable and the number of children in a household, which was expected to produce positive results since broadband is necessary for a number of applications popular with this group, including gaming and music / video downloading. The reduction of the African-American impact that occurs in 2006 is more in line with the documentation that suggests their access rates still lag Caucasian households. Measures of infrastructure and rurality do not significantly shift from their 2003 impacts, suggesting that these characteristics have become neither more nor less important.

[Table 5 about here]

*Decomposition Results*

The results of the non-linear decomposition for micropolitan and noncore areas are presented in tables 6 and 7. The first two rows contain observed (actual) rates of broadband access for metropolitan areas and either micropolitan (table 6) or noncore (table 7) areas in both 2003 and 2006. The associated "gap" between these areas is then documented in the third row. For example, the metropolitan broadband rate in 2003 was 40 percent while the rate in micropolitan areas was 32 percent, leading to a gap of 8 percent. The remaining rows present the percentages of that gap that are contributable to differences in specific characteristics using the calculation of "synthetic" access rates.

[Table 6 about here]

[Table 7 about here]

These results suggest that for micropolitan areas, differences in levels of education and income explain a large portion of the gap. Lower levels of education (particularly among those with college degrees) compared to those in metropolitan areas account for roughly 40 percent of the metro – micro gap, while lower levels of income make up between 60 and 90 percent. Differences in other household characteristics actually serve to increase the divide, probably due to higher levels of older household heads and lower levels of African-Americans in micropolitan areas (which, in 2003, were associated with higher rates of access). Infrastructure plays only a minor role for micropolitan areas, accounting for less than 20 percent of the gap in both years. Similar patterns hold for noncore areas, although the gaps to metropolitan rates are significantly larger (23 and 21 percent in 2003 and 2006, respectively). While education and income differences continue to make up over 50 percent of the gap, their relative importance has shifted over time as the lower education levels found in noncore areas accounted for the largest proportion of the gap in 2006. This suggests that while broadband access is diffusing to those with lower income levels over time in noncore communities, an education gap still largely contributes to the lower access rates in these areas. Differences in other characteristics again serve to increase the divide, while lower levels of infrastructure account for between 20 and 26 percent of the broadband divide over this period. Therefore, even after significant increases in micropolitan and noncore infrastructure over this period (figure 3), its role in explaining the broadband gap *increased*. Thus, as information about broadband access diffused to micropolitan and noncore areas over this time frame, the supply of relevant infrastructure did not keep pace. These findings indicate that policy measures focused on increasing levels of infrastructure may be most appropriate *after* allowing the diffusion process to disseminate information about the technology through the initial phases of the S-curve.

## Discussion and Policy Implications

A significant number of studies have suggested that the focus of the rural – urban digital divide should not lie explicitly on lagging levels of infrastructure in rural areas, but should instead promote demand-oriented programs such as courses on basic computer / Internet use; or demonstrations of effective ways to use such technologies (Whitacre & Mills, 2007; Pigg, 2005). However, most empirical studies on the topic have looked at gaps in access at a specific point in time and have neglected the associated temporal component. Further, very few have examined this issue for lower-level specifications of rurality such as micropolitan and noncore. As broadband technology becomes increasingly commonplace in today's society, questions remain not only about what policy options can best be utilized to address discrepancies in access rates, but also the optimal time frame for implementing such programs. The results of this analysis suggest that policies to promote infrastructure in rural areas are most effective once general knowledge about the benefits of broadband access has already diffused to a more general population. As such, the hands-off approach taken early on by the U.S. government in allowing the free market to set broadband infrastructure levels finds support. Initially, efforts to close any type of digital divide should focus on demonstrating the benefits of the technology to groups known to be late adopters – the elderly, those with low income, or those with lower education levels. As this knowledge diffuses, the presence of infrastructure then becomes the limiting factor. In 2006, replacing levels of infrastructure in noncore areas of Oklahoma with those found in metropolitan areas would have raised broadband access rates from 28 to 34 percent – indicating that these areas have significant unmet demand.

While federal programs such as United States Department of Agriculture community connect grants and broadband loans seek to promote broadband infrastructure in rural areas, their effectiveness has been questioned. In particular, an audit of the program in 2005 indicated that many of the funds were awarded to areas that already had broadband providers, and many potential applicants felt that the eligibility criteria were too restrictive (USDA OIG, 2005; Kruger, 2008). This study suggests that, when they focus on appropriate areas, targeted infrastructure programs such as these could have a significant impact in reducing the broadband gaps that currently exist among geographic designations. However, these recommendations are tempered by the fact that differences in other characteristics, such as education and income, still account for large percentages of the divide even after significant diffusion has occurred. Educational programs that promote Internet use among historically low-adopters (such as those suggested by Horrigan (2007) and Byers (2006)) can effectively deal with these demand-side issues. Future policies to promote broadband growth in rural locations should take into consideration the rurality of the area in question, the diffusion history of nearby infrastructure, and how future demand can be stimulated – including understanding its evolution to date.

Finally, from a larger perspective, this paper has attempted to draw attention to the intersection of diffusion theory and market-driven infrastructure availability in the context of broadband adoption. While demographic and economic characteristics are useful in explaining and predicting levels of broadband adoption, a complete analysis will also incorporate supply-side factors and will explicitly acknowledge the associated temporal component. As research on digital inequalities progresses, simply placing these questions in terms of diffusion theory potentially neglects important barriers such as regional variations in availability that need to be addressed from a supply-side view. Future studies should draw from theories associated with both demand and supply to fully dissect the broadband adoption decision.

## References

Armstrong, B. (2005). DSL services available to all Oklahoma residents by 2007. *The Journal Record* 15 December 2005.

Associated Press. (2007). Oil and gas industry lifts Oklahoma economy. 28 March 2007.

Byers, A. (2006). Communities address technology-related development. Tangents: technologies across Nebraska newsletter, Winter 2006.

Carter, R. (2003). SBC begins $300 million Internet service expansion. *The Journal Record* 20 April 2003.

Chakraborty, J. & M. Bosman. (2005). Measuring the digital divide in the United States: Race, income, and personal computer ownership. *The Professional Geographer* 57:395-410.

Cooper, M. & G. Kimmelman. (1999). The digital divide confronts the Telecommunications Act of 1996. Washington, DC: Consumer Federation of America.

Downes, T. & S. Greenstein. (2002). Universal access and local Internet markets in the U.S. *Research Policy* 31: 1035-52.

Drabenstott, M. (2001). New policies for a new rural America. *International Regional Science Review* 24(1): 3 – 15.

Fairlie, R. (2003). An extension of the Oaxaca-Blinder decomposition technique to logit and probit models. *Economic Growth Center: Yale University*. Paper number 873.

Federal Communications Commission, Industry and Analysis and Technology Division. (2003). High-speed Service for Internet Access: Status as of June 30, 2003. http://www.fcc.gov/wcb/iatd/comp.html. Accessed Oct 30, 2008.

Federal Communications Commission, Industry and Analysis and Technology Division. (2006). High-speed Service for Internet Access: Status as of June 30, 2006. http://www.fcc.gov/wcb/iatd/comp.html. Accessed Oct 30, 2008.

Firth, L. & D. Mellor. (2005). Broadband: benefits and problems. *Telecommunications Policy* 29(2) 223-236.

Flamm, K. (2006). Diagnosing the disconnected: Where and why is broadband access unavailable in the U.S.? Paper presented at the Telecommunications Policy Research Conference, Fairfax VA, 30 September.

Flamm, K. & A. Chaudhuri. (2007). An analysis of the determinants of broadband access. *Telecommunications Policy* 31: 312-326.

Fox, S. (2005). Digital divisions. Pew Internet and American Life Project, Washington, DC.

Government Accountability Office. (2006). Broadband deployment is extensive throughout the United States, but it is difficult to assess the extent of deployment gaps in rural areas. Report to Congressional Committees GAO-06-426. http://www.gao.gov/new.items/d06426.pdf Downloaded 17 November 2008.

Grubesic, T. (2003). Inequities in the broadband revolution. *Annals of Regional Science* 37(2): 263-289.

Horrigan, J. (2007). Home broadband adoption 2007. Pew Internet and American Life Project. Washington, DC.

Horrigan, J. (2008). Home broadband adoption 2008. Pew Internet and American Life Project, Washington, DC.

Johnson, T. (2001). The rural economy in a new century. *International Regional Science Review* 24(1): 21-37.

Kruger, L. (2008). Broadband grant and loan programs in the USDA's rural utility service. *Congressional Research Service – The Library of Congress*.

Liu, M. & G. San. (2006). Social learning and digital divides: A case study of Internet technology diffusion. *Kyklos* 59(2): 307-321.

Liu, Y., C. Martin, E. Roehl, Z. Yi, & S. Ward. (2006). Digital information access in urban / suburban communities: A survey report of public digital library use by the residents of Connecticut. *OCLC Systems and Services* 22: 132-144.

Marvin, C. (1998). When old technologies were new: Thinking about electric communication in the late nineteenth century. New York, NY: Oxford University Press, Inc.

McConnaughey, J. & W. Lader. (1998). Falling through the net II: New data on the digital divide. National Telecommunications and Information Administration, http://www.ntia.doc.gov/ntiahome/net2/falling.html. Accessed November 20, 2008.

Mills, B. & B. Whitacre. (2003). Understanding the non-metropolitan – metropolitan digital divide. *Growth and Change* 34: 219-243.

National Exchange Carrier Assocation. (2006). Trends 2006: Making progress with broadband. Whippany, NJ. http://www.neca.org/media/trends_brochure_website.pdf. Accessed November 20, 2008.

National Telecommunications and Information Adminstration (NTIA) and Economics Statistics Administration. (2002). "How Americans are expanding their use of the Internet. US Department of Commerce, Washington, DC.

Neumark, D. (1988). Employers discriminatory behavior and the estimation of wage discrimination. *Journal of Human Resources* 23: 279-95.

Norrix, P. (2001). Digital divide: Civic engagement, information poverty, and the Internet worldwide. Cambridge: Cambridge University Press.

Noyes, K. (2008). 3G network touches down in NYC. Technewsworld. May 5, 2008.

Oaxaca, R. & M. Ransom. (1994). On discrimination and decomposition of wage differentials. *Journal of Econometrics* 61: 5-21.

Page, D. (2006). Oklahoma's oil and gas economy has doubled. *The Journal Record* 4 May 2006.

Papacharissi, Z. & A. Zaks. (2006). Is broadband the future? An analysis of broadband technology potential and diffusion. *Telecommunications Policy* 30: 64-75.

Pigg, K. (2005). Introduction: Community informatics and community development. *Journal of the Community Development Society 36* (1): 1-7.

Prieger, J. (2003). The supply side of the digital divide: Is there equal availability in the broadband Internet access market? *Economic Inquiry* 41: 346-63.

Rogers, E. (1962). *Diffusion of Innovations*. Free Press, New York.

Rose, R. (2003). Oxford Internet survey results. The Oxford Internet Institute, The University of Oxford, UK.

Strover, S. (2003). The prospects for broadband deployment in rural America. *Government information quarterly* 20: 95-106.

Tarde, G. (1903). *The Laws of Imitation*. Translated by E.C. Parsons with introduction by F. Giddings, Henry, Hold and Co., New York.

United States Department of Agriculture, Office of Inspector General (USDA OIG). (2005). *Audit Report: Rural Utilities Service Broadband Grant and Loan Programs*. Audit Report 09601-4-Te. September.

Warschauer, M. (2003). Technology and social inclusion: Rethinking the digital divide. Cambridge, Massachusetts: The MIT Press.

Whitacre, B. & B. Mills. (2007). Infrastructure and the rural – urban divide in high-speed residential Internet access. *International Regional Science Review* 30(3): 249 – 273.

Whitacre, B. (2008). Factors influencing the temporal diffusion of broadband adoption: Evidence from Oklahoma. *Annals of Regional Science* 42: 661-679.

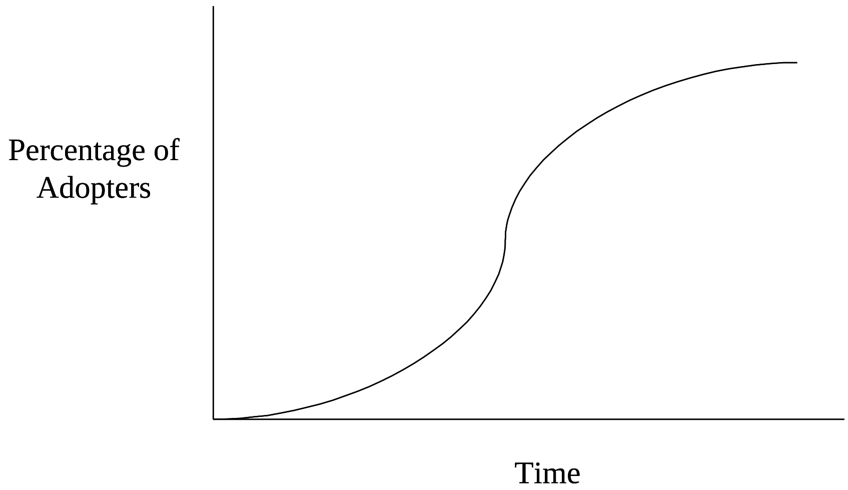


**Figure 1. S-Shaped Adoption Curve**

| Adopter Categories | Characteristics |
|---|---|
| Innovators | Eager to try new ideas. More years of formal education, higher income. |
| Early Adopters | Role models for other members of social system. |
| Early Majority | Interact frequently with peers. Deliberate before adopting new ideas. |
| Late Majority | Respond to pressure from peers. Approach innovation with caution. |
| Laggards | Resistant to innovation. Suspicious of change. Isolated. |

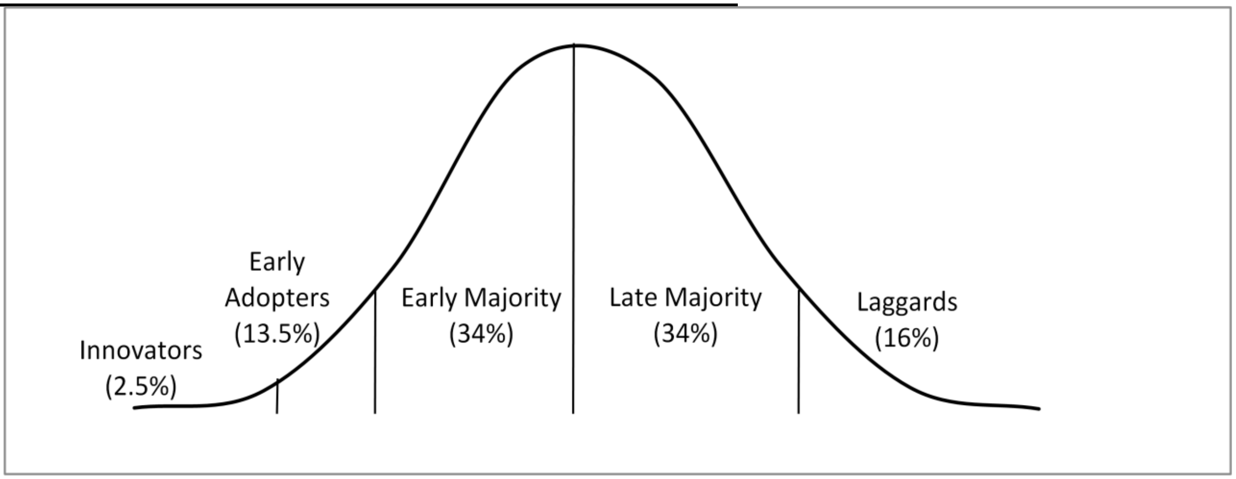


**Figure 2. Adopter categories, characteristics, and distribution**

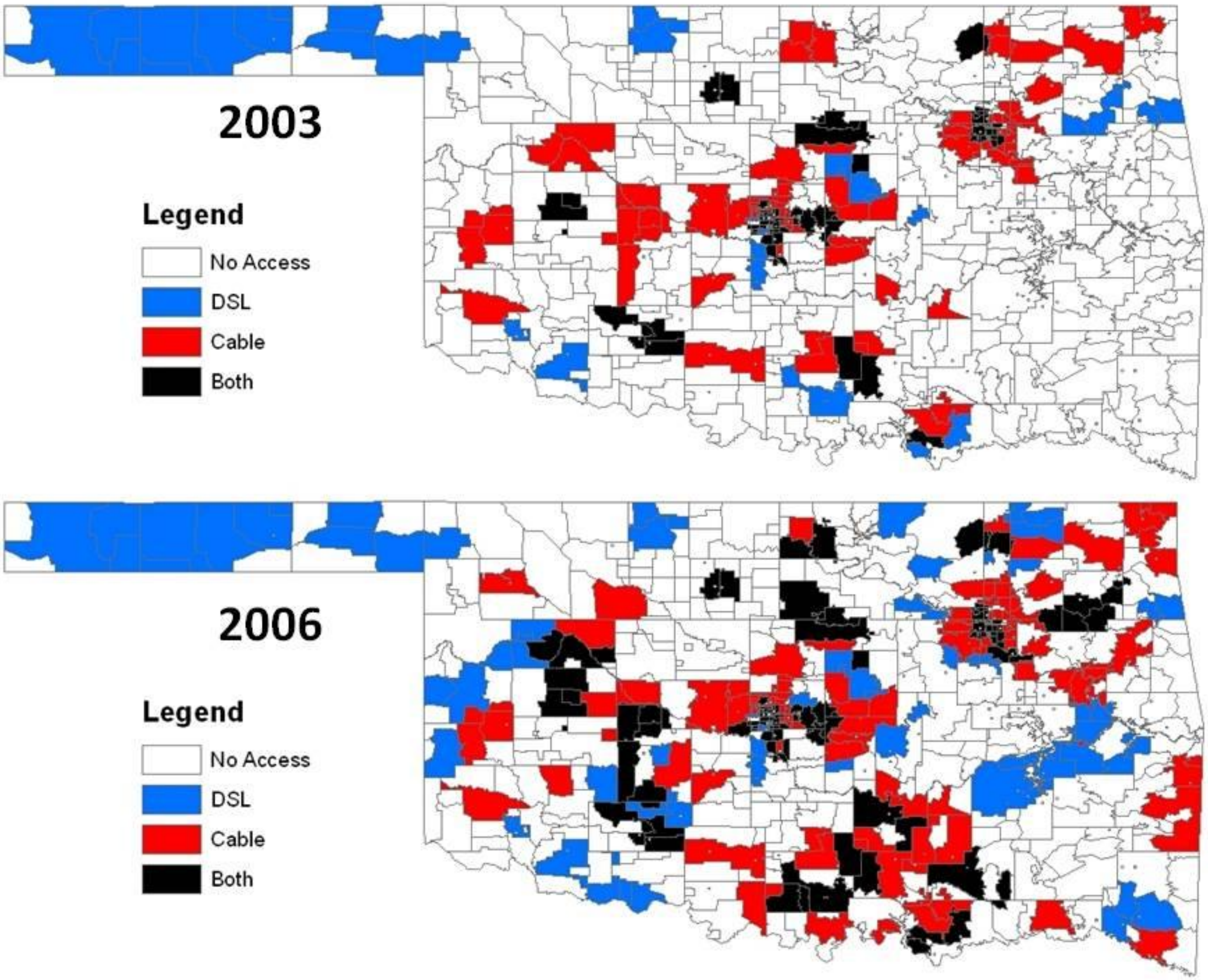


**Figure 3. DSL and cable Internet infrastructure in Oklahoma, 2003 and 2006**

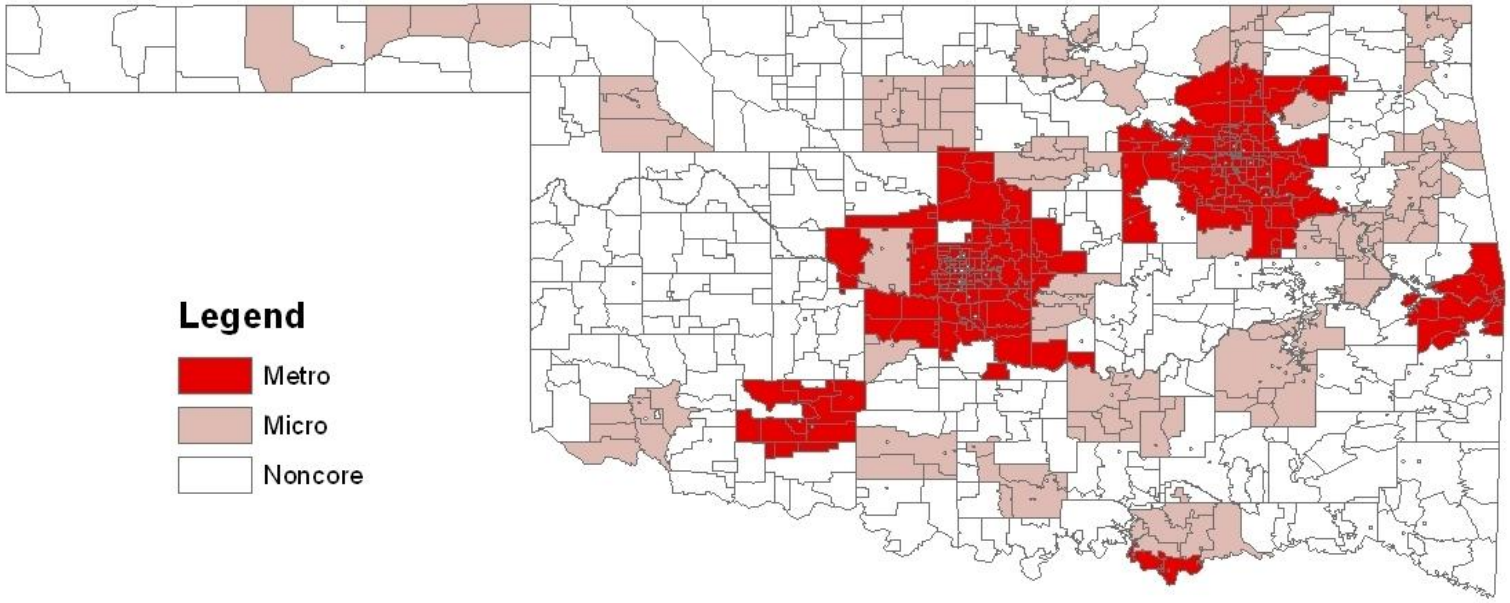


**Figure 4. Metropolitan, micropolitan, and non-core ZIP codes in Oklahoma**

**Table 1. Cable systems and central offices in Oklahoma with broadband capability, 2003 and 2006**

| | Cable Systems | Central Offices |
|---|---|---|
| | Total number of systems | |
| 2003 | 320 | 640 |
| 2006 | 299 | 693 |
| | Number with broadband capability | |
| 2003 | 27 | 62 |
| 2006 | 55 | 142 |
| | Proportion with broadband capability | |
| 2003 | 0.084 | 0.097 |
| 2006 | 0.184 | 0.205 |

Source: NECA Tariff #4 data, Television and Cable Factbook (2003, 2006)

**Table 2. Proportion of metro / micro / noncore Oklahoma residents with access to broadband infrastructure, 2003 and 2006**

| | 2003 | | | 2006 | | |
|---|---|---|---|---|---|---|
| | Metro | Micro | Noncore | Metro | Micro | Noncore |
| Infrastructure | | | | | | |
| Cable Only | 0.04 | 0.11 | 0.07 | 0.06 | 0.12 | 0.11 |
| DSL Only | 0.35 | 0.32 | 0.11 | 0.36 | 0.43 | 0.23 |
| Both | 0.42 | 0.16 | 0.03 | 0.47 | 0.31 | 0.12 |
| Some | 0.81 | 0.59 | 0.20 | 0.89 | 0.86 | 0.46 |

Source: Census 2000; NECA Tariff #4 data, Television and Cable Factbook (2003, 2006)

**Table 3. Demographic characteristics of metro / micro / noncore areas, 2003 and 2006**

| Characteristic | Variable Name | 2003 Metro | 2003 Micro | 2003 Noncore | 2006 Metro | 2006 Micro | 2006 Noncore |
|---|---|---|---|---|---|---|---|
| Home Internet Access | | | | | | | |
| Any Type | internet | 0.63 | 0.56 | 0.52 | 0.66 | 0.61 | 0.51 |
| Broadband | broadband | 0.40 | 0.32 | 0.17 | 0.49 | 0.43 | 0.28 |
| Education | | | | | | | |
| Less than High School | | 0.17 | 0.25 | 0.23 | 0.17 | 0.12 | 0.17 |
| High School Degree | hs | 0.31 | 0.30 | 0.34 | 0.27 | 0.29 | 0.42 |
| Some College | scoll | 0.30 | 0.27 | 0.39 | 0.33 | 0.32 | 0.28 |
| Bachelor's Degree | coll | 0.17 | 0.12 | 0.08 | 0.14 | 0.19 | 0.11 |
| Higher than bachelors | collplus | 0.07 | 0.06 | 0.05 | 0.08 | 0.08 | 0.03 |
| Income | | | | | | | |
| Under $10K | | 0.14 | 0.10 | 0.14 | 0.09 | 0.06 | 0.09 |
| $10K - $20K | hhinc2 | 0.13 | 0.19 | 0.20 | 0.15 | 0.18 | 0.16 |
| $20K - $30K | hhinc3 | 0.19 | 0.17 | 0.27 | 0.17 | 0.18 | 0.16 |
| $30K - $40K | hhinc4 | 0.11 | 0.15 | 0.12 | 0.15 | 0.12 | 0.17 |
| $40K - $50K | hhinc5 | 0.12 | 0.09 | 0.07 | 0.09 | 0.13 | 0.12 |
| $50K - $60K | hhinc6 | 0.08 | 0.07 | 0.07 | 0.07 | 0.03 | 0.08 |
| $60K - $75K | hhinc7 | 0.08 | 0.09 | 0.05 | 0.05 | 0.13 | 0.09 |
| $75K - $100K | hhinc8 | 0.08 | 0.09 | 0.06 | 0.10 | 0.09 | 0.07 |
| $100K + | hhinc9 | 0.07 | 0.04 | 0.02 | 0.12 | 0.08 | 0.05 |
| Other HH characteristics | | | | | | | |
| Age | age | 37.76 | 41.71 | 46.55 | 40.73 | 44.80 | 45.81 |
| Married | married | 0.49 | 0.55 | 0.52 | 0.48 | 0.56 | 0.57 |
| Number of children | numberkids | 1.03 | 0.93 | 0.79 | 0.91 | 0.88 | 0.88 |
| African American | black | 0.15 | 0.04 | 0.01 | 0.09 | 0.02 | 0.00 |
| Native American | indian | 0.06 | 0.10 | 0.12 | 0.06 | 0.15 | 0.16 |
| Other Race | othrace | 0.11 | 0.02 | 0.07 | 0.15 | 0.09 | 0.08 |
| Hispanic | hisp | 0.09 | 0.06 | 0.01 | 0.10 | 0.05 | 0.06 |
| Male | male | 0.54 | 0.63 | 0.42 | 0.48 | 0.54 | 0.54 |
| No. Observations | | 499 | 193 | 214 | 523 | 192 | 227 |

Characteristics without variable name represent the default or base category for that group

**Table 4. Rates of broadband access over time for historically low adopters**

| | 2003 | 2006 |
|---|---|---|
| Education | | |
| nohs | 0.14 | 0.10 |
| hs | 0.30 | 0.33 |
| scoll | 0.40 | 0.55 |
| Income | | |
| under $20K | 0.26 | 0.38 |
| $20K - $40K | 0.51 | 0.78 |
| Racial / Ethnic | | |
| black | 0.41 | 0.32 |
| indian | 0.21 | 0.36 |
| othrace | 0.30 | 0.29 |
| hispanic | 0.16 | 0.16 |
| Rurality | | |
| micro | 0.32 | 0.43 |
| noncore | 0.17 | 0.28 |
| Age | | |
| elderly (65+) | 0.09 | 0.25 |

**Table 5. Logit results for broadband access**

Dependent Variable: Broadband

| | 2003 | | | 2006 shift | | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | S.E. | | Coefficient | S.E. | |
| hs | 0.608 | 0.498 | | 0.575 | 0.757 | |
| scoll | 1.045 | 0.480 | ** | 1.045 | 0.733 | |
| coll | 0.971 | 0.484 | ** | 1.195 | 0.742 | |
| grad | 1.308 | 0.512 | ** | 0.939 | 0.776 | |
| hhinc2 | 0.944 | 0.676 | | -0.886 | 0.836 | |
| hhinc3 | 1.686 | 0.653 | ** | -0.929 | 0.810 | |
| hhinc4 | 2.024 | 0.659 | *** | -1.170 | 0.816 | |
| hhinc5 | 2.799 | 0.680 | *** | -2.015 | 0.847 | ** |
| hhinc6 | 2.443 | 0.684 | *** | -1.588 | 0.881 | * |
| hhinc7 | 3.418 | 0.712 | *** | -2.565 | 0.881 | *** |
| hhinc8 | 3.443 | 0.681 | *** | -2.358 | 0.859 | *** |
| hhinc9 | 3.521 | 0.742 | *** | -1.193 | 0.918 | |
| age | -0.078 | 0.036 | ** | 0.039 | 0.050 | |
| age2 | 0.000 | 0.000 | | 0.000 | 0.001 | |
| married | -0.282 | 0.227 | | 0.750 | 0.316 | ** |
| numberkids | -0.127 | 0.104 | | 0.128 | 0.139 | |
| hispanic | -0.837 | 0.604 | | -0.060 | 0.826 | |
| black | 0.781 | 0.428 | * | -1.309 | 0.598 | ** |
| indian | -0.419 | 0.380 | | -0.119 | 0.512 | |
| othrace | -0.224 | 0.551 | | -0.164 | 0.747 | |
| infrastr | 0.507 | 0.257 | ** | 0.029 | 0.379 | |
| micro | -0.097 | 0.240 | | -0.181 | 0.352 | |
| noncore | -0.317 | 0.317 | | -0.206 | 0.419 | |
| constant | -1.102 | 0.897 | | -0.430 | 1.422 | |
| $R^2$ | 0.247 | | | | | |

*, **, and *** represent statistical differences from zero at the p = 0.10, 0.05, and 0.01 levels, respectively.

**Table 6. Logit decomposition results – micropolitan areas**

| | 2003 | 2006 |
|---|---|---|
| Metropolitan Broadband Rate | 0.40 | 0.49 |
| Micropolitan Broadband Rate | 0.32 | 0.43 |
| Metro - micro gap | 0.08 | 0.06 |
| Contributions from differences in: | | |
| Education | 39.6% | 37.7% |
| Income | 89.4% | 61.6% |
| Other HH Charac | -63.9% | -22.8% |
| Infrastructure | 8.7% | 16.6% |
| All included variables | 73.7% | 93.1% |

**Table 7. Logit decomposition results – noncore areas**

| | 2003 | 2006 |
|---|---|---|
| Metropolitan Broadband Rate | 0.40 | 0.49 |
| Noncore Broadband Rate | 0.17 | 0.28 |
| Metro - noncore gap | 0.23 | 0.21 |
| Contributions from differences in: | | |
| Education | 10.7% | 33.6% |
| Income | 48.0% | 16.7% |
| Other HH Charac | -9.3% | -9.6% |
| Infrastructure | 20.6% | 26.1% |
| All included variables | 70.0% | 66.9% |