Broadband and Local Growth

Jed Kolko
Public Policy Institute of California
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ABSTRACT

I find a positive relationship between broadband expansion and local economic growth. This relationship is stronger in industries that rely more on information technology and in areas with lower population densities. Instrumenting for broadband expansion with slope of terrain leans in the direction of a causal relationship, though not definitively.

The economic benefits of broadband expansion for local residents appear to be limited. Broadband expansion is associated with population growth as well as employment growth, and both the average wage and the employment rate—the share of working-age adults that is employed—are unaffected by broadband expansion. Furthermore, expanding broadband availability does not change the prevalence of telecommuting or other home-based work. Like other place-based policies, expanding broadband availability could raise property values and the local tax base, but without more direct benefits for residents in the form of higher wages or improved access to jobs.

The analysis relies on the uneven diffusion of broadband throughout the United States, allowing comparisons between areas with greater and less growth in broadband availability. I combine broadband data from the Federal Communications Commission, employment data from the National Establishment Time-Series database, and other economic data from the U.S. Census and BLS to examine broadband availability and economic activity in the U.S. between 1999 and 2006.

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Author contact information: kolko@ppic.org, +1 415 291 4483.

I. Introduction

Policymakers expect broadband to lead to job creation and economic growth. The 2009 American Recovery and Reinvestment Act (ARRA) allocated $7.2 billion for broadband investment, and the agencies granting these awards were directed to consider the effect on economic development. The Federal Communication Commission's National Broadband Plan, submitted to Congress in March 2010, explicitly names job creation and economic growth among eleven goals for national broadband strategy. Other federal and state initiatives cite broadband as a tool for local economic development.[1]

This paper assesses the effect of broadband availability on local economic development measures like employment, payroll, and the employment rate. The analysis relies on the fact that broadband technology has diffused unevenly throughout the United States, making it possible to compare economic indicators in areas with greater and less broadband expansion. Using broadband data from the Federal Communications Commission and economic data from several government and proprietary sources, this paper examines broadband availability and economic activity throughout the nation between 1999 and 2006.

The analysis indicates a positive relationship between broadband expansion and economic growth, especially in industries that rely more on information technology and in areas with lower population densities. Although the evidence leans in the direction of a causal relationship, the data and methods do not definitively indicate that broadband caused this economic growth.

The economic benefits to residents appear to be limited. Broadband expansion is associated with population growth, and both the average wage and the employment rate—the share of working-age adults that is employed—are unaffected by broadband expansion. Also, expanding broadband availability does not change the prevalence of telecommuting or other home-based work.

[1] See Kolko (2010a) for an overview of broadband policy at the federal level and in California.

II. Related Literature

Several recent papers have tried to assess how broadband affects local economic development by comparing economic outcomes in states, counties, or ZIP codes with better and worse broadband access.[2] Four empirical issues distinguish these papers from each other: (1) how broadband is measured; (2) which economic development outcomes are measured; (3) which control variables are included; and (4) which geographic level is the unit of analysis. These four issues are related: For instance, some broadband measures are available only for states, not ZIP codes or counties, so the choice of broadband measure can determine the geographic level of analysis. This section reviews several papers, highlighting these issues, and then suggests why some approaches are preferable to others. Overall, most studies find that broadband has a positive relationship with employment and establishment growth, yet the relationship between broadband and income (or wages) is mixed—consistent with this paper's findings.

Crandall, Lehr, and Litan (2007) measure broadband using FCC data on broadband lines in use per capita. These broadband data are reported annually for each state by the FCC and reflect broadband adoption by households and businesses. Their outcome measures include employment and output (GDP) growth for the state overall as well as for individual sectors (e.g., manufacturing, finance) in the state, over a one- or two-year period. Control variables include average annual temperature, a measure of the business tax burden, unionization, average wages, level of education, and Census region. They find that broadband adoption is positively correlated with employment growth but not output growth for states overall; the effect on employment and GDP is positive for a minority of economic sectors. They speculate that the different effects on employment and output growth could be due to the Bureau of Economic Analysis's estimation process of annual state output, which is less precise than employment measures.

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[2] This paper and other papers reviewed here estimate the effect of broadband on local outcomes. A related literature considers national economic effects of broadband from estimates of consumer surplus (Crandall, Jackson, and Singer, 2003; Greenstein and McDevitt, 2009). Estimates vary wildly because of different assumptions about consumer willingness to pay.

Van Gaasbeck et al. (2007) also use adoption as their broadband measure in their study of counties in California. They use proprietary residential broadband adoption estimates from a household survey by Scarborough, a market research firm, and construct an annual panel of broadband adoption and economic development outcomes (employment, establishments, and output).[3] Their main finding is that higher broadband adoption is associated with higher employment and fewer establishments in the full model with county fixed-effects. Intending to test for endogeneity, they find that the effects on the key outcome variables are unchanged when using the one-year lag of broadband adoption instead of contemporaneous broadband adoption, though this result is hard to interpret because they omit contemporaneous adoption, and of course broadband adoption could be the effect of predicted future growth.

Crandall, Lehr, and Litan (2007) and Van Gaasbeck et al. (2007) suggest that adoption may better reflect the extent to which broadband can affect a local economy than availability since broadband affects economic and social outcomes only if adopted. However, adoption is more likely than availability to be endogenous with respect to economic growth since the decision to adopt broadband, conditional on availability, could be the outcome of economic growth rather than the cause. Furthermore, from a policy perspective, increasing broadband availability is more feasible—whether through regulation, subsidy, or direct provision—than increasing broadband adoption since adoption depends on a range of demand factors, some of which are beyond the reach of feasible public policy. Also, adoption measures exist only for states and the largest metropolitan areas, whereas availability measures exist at the more finely disaggregated ZIP code level. While labor markets are as large as a metropolitan area or small state, broadband infrastructure requires detailed geographic analysis: Firms can hire workers that live ten miles away, but they cannot easily get broadband service if the nearest infrastructure network ends ten miles away.

[3] They do not report the sample size in Scarborough's survey, but the considerable annual fluctuations – upward and downward – in broadband adoption for many smaller regions within California suggest small samples with large standard errors.

Several other papers use broadband availability measures instead of broadband adoption measures. Osorio (2006) assesses whether broadband provision by a municipal electric utility (MEU) affects employment and output; he uses a matching estimator, matching places based on past employment trends and composition, residential demographics, and private-sector broadband provision. He finds a positive effect of MEU broadband provision on the number of establishments but not on employment, average salaries, or the number of high-tech establishments. Shideler, Badasyan, and Taylor (2007) measure county-level broadband availability in Kentucky based on broadband providers' proprietary infrastructure data, collected and mapped by ConnectKentucky. They regress county-level total employment growth and sector employment growth on broadband availability, controlling for past growth, education, unemployment, and road density. The effect of broadband is positive and statistically significant for total employment and for employment in the construction, administrative/support/waste services, and information sectors.

Gillett et al. (2006) define broadband availability at the ZIP code level as whether at least one provider had subscribers in that ZIP code in December 1999 according to the FCC's Form 477 data. Controlling for past employment growth, sectoral composition, and demographics, they find a positive, statistically significant effect of broadband availability on employment, the number of establishments overall, and the number of establishments in high-tech sectors. Gillett et al. also perform a state-level analysis using number of broadband lines per capita (as did Crandall, Lehr, and Litan, 2007), but after finding few significant effects they dismiss the state-level analysis as too coarse to reveal the effect of broadband. They conclude that states are too large a geography for the analysis of broadband on economic development: Even small states show considerable intra-state variation in broadband availability and adoption.

Stenberg et al. (2009) find faster employment growth in counties with more broadband availability but no effect on per capita income growth in most years. To measure broadband availability at the county level, they, like Gillett et al. (2006), use FCC Form 477 provider counts by ZIP code, which they aggregate to the county level. Unlike Gillett et al., they use the continuous provider count level rather than a binary measure indicating at least one provider in the area. They argue that the continuous provider count measure gives additional information about the extent of broadband availability. They estimate their effects for rural counties only, using a matching estimator; they match using similar variables to the economic and demographic controls used in other studies.

Another possible outcome of broadband deployment is increased telecommuting, but little data on telecommuting exists. Song, Orazem, and Singh (2006) look empirically at the relationship between broadband and telecommuting, which the authors proxy with a UCLA survey question about "using the Internet for work from home." The authors attribute the urban-rural gap in telecommuting largely to the greater availability of broadband in urban areas, which seems to contradict their finding that the effect of county-level broadband availability on county-level telecommuting is not statistically significant.[4] In addition to a questionable interpretation of their results, their study has two shortcomings. First, broadband availability can vary considerably within a county, so it would be better to focus on availability at the ZIP code level. Second, having a formal agreement with an employer to telecommute regularly is not synonymous with using the Internet to work from home, which encompasses everything from a formal agreement to work from home to bringing work home occasionally.

The literature—despite a near-consensus that broadband is positively related to employment growth—leaves many open questions about causality, heterogeneity, and other economic outcomes. Although several studies raise the issue of causality, and Gillett et al. (2006), Van Gaasbeck et al. (2007), and Stenberg et al. (2009) are careful to caution that their results do not imply causality, none of them uses an instrument for broadband availability or adoption in order to identify a causal effect or tries to infer causality using more informal approaches. And while several consider the effect of broadband on employment in individual industries, none of the studies discussed explores how broadband interacts with

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[4] Table 2 of their paper seems to show that the relationship between the number of broadband providers in a county and using the Internet (column 1) to work from home is not statistically significant at the 5 percent level, though they report these results to be statistically significant in the text on pp. 14–15.

local conditions to affect economic outcomes.[5] Finally, while some studies look at income or wages, none considers the effect on employment relative to working-age population, which – as will be shown – turns out to be important for understanding the relationship between broadband and economic development and the likely outcome of policies to raise broadband availability.

III. Theoretical Motivation

Broadband and other information and communications technologies lower the cost of sending and receiving many forms of data, including documents and audio and video content. According to the theory of the firm, lowering the cost of one input into the production process could raise or lower demand for labor depending on whether the output or substitution effect dominates and whether labor is a complement or substitute for these technologies. The effect on aggregate employment in a locality where an input gets cheaper – such as when broadband service expands thus lowering the cost of sending and receiving data – also depends on how much this cost reduction affects the geographic distribution of economic activity. Thus, even if broadband expansion caused individual firms to substitute away from labor and therefore reduce employment, economic activity could shift to locations where broadband is more widely available, raising aggregate employment there relative to other areas.

The relationship between broadband and employment growth could be heterogeneous with respect to industry or location. First, industry: Industries reliant on information technology might increase their employment of workers skilled in using new technology and possibly even reduce their employment of others – shifting, in other words, toward labor that is complementary with broadband technology. Broadband would therefore have a larger positive effect on employment in industries whose workers are more skilled in using information technology. Furthermore, locational shifts in economic activity would be

[5] Although not a study of broadband per se, Forman, Goldfarb, and Greenstein (2009) look at the effect of business Internet adoption and county-level wage growth, and they do include interactions between their Internet measure and county-level start-year income, education, and share of businesses in information-technology-intensive industries. Their main conclusion is that business information technology usage raised wages more in counties that started with higher incomes and therefore contributes to the divergence of wages across counties.

more pronounced in more "footloose" industries—those whose location is not tied to local customers or inputs. Additionally, broadband expansion could lead to declines in both employment and economic output in local businesses that begin to face competition for customers from online businesses located elsewhere, depending on how easily their customers can switch from local brick-and-mortar businesses to their online counterparts.[6]

Heterogeneity with respect to location could arise if broadband offers greater benefit for places that are smaller or more isolated, helping local businesses or households to connect with larger markets: This line of thinking lies behind popular predictions that rural areas might benefit disproportionately from Internet technology, though it is also plausible that electronic communication is a complement to the face-to-face interactions that dense cities facilitate.[7] Other examples include areas that have access to a more highly educated labor market (if the more educated workers are better able to use advanced information technologies) and areas with more favorable climates and recreational opportunities (if broadband access allows firms to move further away from suppliers and customers toward locations appealing to employers and workers).[8]

Of course, a positive relationship between broadband expansion and economic growth does not, in itself, mean that broadband expansion *causes* economic growth. The reverse might be true if broadband providers choose to offer or expand service where employment is growing faster. Alternatively, population growth could cause both broadband expansion and employment growth. Broadband expansion might follow population growth since more than 60 percent of broadband subscribers are households, according to the most recent FCC broadband report. Once again, this effect could vary by industry: Population growth would

[6] Retail and entertainment are plausible examples of industries where local providers could suffer in competition with national online stores and services.

[7] Gaspar and Glaeser (1998) suggest this complementarity. Kolko (2000) and Kolko (2010c) both find that information technology substitutes for longer-distance proximity but not for the short-distance proximity that cities facilitate. Kolko (2000) shows that commercial Internet usage arose first in larger though more geographically isolated cities; Kolko (2010c) shows that IT-using service industries that trade with each other are less likely to co-locate within a state but *more* likely to co-locate within a ZIP code.

[8] "Why Wall Street Is Losing Out To 40 Acres and a Modem," *New York Times,* December 27, 1998, highlights the relocation of some financial operations to idyllic recreation areas like Jackson Hole and Nantucket.

lead to employment growth in industries whose customers are local residents. Assessing causality is, of course, essential for predicting whether policies to expand broadband will lead to economic development.

A positive relationship between broadband and local employment growth begs the question of who benefits. Whether employment growth actually raises the likelihood of employment among residents or raises wages depends, in part, on labor mobility: If people follow jobs, and population grows in response to employment growth, residents' likelihood of employment and wages might not change, even though increases in land values and the tax base could still benefit some residents.[9] Employment growth with population growth could still meet the policy objective of economic development, though it has different implications for households than employment growth that significantly exceeds population growth.

Finally, broadband could change the location of economic activity by making it easier to telecommute, bring work home informally, or operate a home-based business. Incorporating these measures of home-based work into the analysis of broadband and economic development provides a fuller picture of how broadband affects the range of business and household behaviors and outcomes.

This paper answers four questions about broadband expansion and economic growth raised by this theoretical discussion:

1. Does employment grow faster in areas with greater broadband expansion?
2. Is the relationship between broadband and employment heterogeneous across industries or places?
3. If there is a positive relationship between broadband expansion and employment growth, does broadband expansion *cause* this growth?
4. If broadband does boost employment growth, what does the effect on other household outcomes tell us about who benefits?

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[9] This paper does not assess the relationship between broadband expansion and property values because the time period studied (1999–2006) coincides with the large and varying house price bubbles in many local housing markets. The geographic variation in price changes during this time is probably too noisy to be a reliable measure of the geographic variation in the capitalization into land values of potential local productivity enhancements such as broadband expansion.

IV. Data Description

The analysis combines broadband data from the FCC's Form 477 report; employment and business data from the National Establishment Time-Series; demographic data from the Census; and household data on telecommuting and other forms of working at home from Forrester Research. This section describes each data source, and the Appendix describes the process for linking them together using ZIP codes and ZCTAs (Census ZIP Code Tabulation Areas).

The FCC's Form 477 data report the number of broadband providers with subscribers in each ZIP code, semiannually back to 1999. Providers offering broadband services at 200 kilobits per second or faster are included, which covers telephone-line-based DSL, cable modems, wireless, satellite, and power-line technologies. The FCC uses these data to assess the extent of broadband rollout in the United States, but these data have numerous limitations. First, the FCC data reflect geographic patterns in subscriptions, not availability. Provider counts, therefore, could understate availability in areas where service is available but no one subscribes. This situation describes satellite broadband, which is available to nearly every household with a clear view of the southern sky but accounts for a very small share of high-speed subscriptions.[10] Second, many ZIP codes cover large geographic areas, and providers with a subscriber in a ZIP code might not offer service throughout the ZIP code. This could overstate broadband availability if the FCC data are interpreted to mean that an entire ZIP code is served by a provider. Third, the FCC data include providers who serve business or residential customers (or both), which could overstate the level of availability if the data are interpreted to mean availability for residential customers. Fourth, providers reporting service include those that buy or lease telecommunications facilities from wholesalers who might themselves offer

[10] Satellite accounts for less than 1 percent of all high-speed lines (FCC 2006). Because satellite offers slower speeds for higher monthly fees and requires costlier hardware, satellite is not considered an adequate substitute for the main wireline broadband technologies (cable and DSL); and satellite subscriptions might be more prevalent where cable and DSL are unavailable.

retail service as well. Thus, the provider counts might reflect the level of market competition better than the extent of physical infrastructure if that infrastructure is shared among multiple providers.[11]

The FCC ZIP code provider counts, therefore, are hard to interpret. They are, at best, an imperfect measure of some combination of the deployment of broadband infrastructure, the extent of residential availability, and the depth of market competition. Furthermore, the published FCC ZIP code data include no information on price or speed of service, which would be essential for understanding geographic differences in broadband markets within the United States.[12] Nonetheless, "there is no practical alternative to using the FCC data in assessing broadband availability" (Flamm, 2006). Policymakers use the FCC data to describe the broadband landscape, and although some reports are careful to mention that the FCC data do not reflect whether broadband is available to every residence in a ZIP code, the data are nonetheless used as a measure of broadband deployment (California Public Utilities Commission, 2006). Numerous academic papers have relied on the FCC Form 477 data, both to assess the effects of broadband on other outcomes and also to describe the factors that affect broadband availability.

Despite these difficulties of interpretation, the ZIP code provider count data provide useful information on the extent of broadband availability over time. Kolko (2010b) shows that there is a relationship between the number of providers in a ZIP code and the estimated extent of residential broadband availability. Based on residential adoption data and adjusting for household characteristics, availability increases with the number of providers, especially at low numbers of providers. ZIP codes with multiple providers could have more widespread availability if not every provider covers all parts of the ZIP code. Also, if providers within a ZIP code do overlap geographically, then the number of providers could also reflect the extent of competition. Since the FCC does not publicly report on price, speed, or quality of service at the ZIP code level, one cannot identify the

[11] The Government Accountability Office (2006) offers a fuller description and assessment of the FCC Form 477 data.
[12] Data on price and speed are also essential for understanding international differences in broadband services. Ultra-high-speed fiber service, for instance, is far more prevalent in Korea and Japan than in the U.S., as reported by the Organisation for Economic Co-operation and Development, www.oecd.org/sti/ict/broadband.

mechanism by which introducing an additional broadband provider affects the market for broadband services.[13] But since broadband policies often work by adding providers to an area—sometimes directly with public provision and sometimes indirectly through subsidization or regulation—using the number of providers as a proxy for broadband availability is meaningful in a policy context.

Kolko (2010b) shows that the relationship between provider count and availability is neither binary nor linear: The marginal provider implies a bigger increase in the share of households within a ZIP code with broadband availability at low provider counts than at higher provider counts, suggesting that a logarithmic model is more appropriate. Other studies have used different functional forms of the provider count measure. Gillett et al. (2006), Prieger (2003), and Flamm (2006) construct a binary availability measure using FCC provider counts to indicate whether a ZIP code had any broadband subscribers. Grubesic (2006) and Grubesic and Murray (2004) use the FCC provider count as a continuous variable and assume a linear relationship between broadband provider count and outcome variables; Stenberg et al. (2009) use provider count as a continuous variable and, in one model, include both a linear and squared term.

These provider count data suggest that broadband is widely available. By December 2006, essentially all ZIP Code Tabulation Areas (ZCTAs) in the United States, including those in rural areas, had at least one provider offering service.[14] This simple metric overstates broadband availability because providers do not always offer service throughout an entire ZIP code. Inferring availability based on adoption patterns and FCC provider counts, Kolko (2010b) estimates that broadband was available to 85 percent of U.S. households and 92 percent of California households in December 2005. Looking at the number of providers, broadband availability increased substantially between 1999 and 2006. The average number of providers per ZCTA grew from 3.4 in 1999 to 11.2 in 2006, weighted by employment (Table 1).

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[13] Kolko (2010b) finds that broadband monthly subscription price does not vary with the number of providers in a ZIP code.
[14] ZCTAs are U.S. Census Bureau approximations of U.S. Postal Service ZIP codes. ZCTAs are better suited to data analysis than ZIP codes. See the appendix for more detail about how ZCTAs and ZIP codes compare and how ZIP code data were converted to ZCTAs. "Rural" means outside a metropolitan area and accounts for roughly 20 percent of the U.S. population.

Broadband availability varies across places because the costs and benefits of providing broadband depend on local factors. Broadband provision requires fixed costs to extend service to an area: Much of the cost to install or upgrade telecommunications infrastructure is required up front, regardless of the number of eventual subscribers served by that infrastructure. Thus, in order to spread the fixed costs across more subscribers, providers are more likely to serve areas with high demand for broadband. In addition, infrastructure is more expensive to deploy in some areas, such as those with steep terrain or fewer roads, as broadband lines often follow existing transportation rights-of-way. Finally, broadband availability can vary because most areas in the United States are served by a dominant telephone provider and a dominant cable television provider, and each can make different strategic decisions about when to introduce broadband service to their regions. State policies about regulating or subsidizing broadband could also affect the level of availability.[15]

Broadband availability in 2006—equal to the log number of broadband providers —is positively correlated with residential density (0.50), share college degree (0.40), and road density (0.42), and negatively correlated with slope of terrain (-0.14). All of these correlations are statistically significant at the 1% level.[16] Below, the first-stage instrumental variable results show the relationship between broadband availability and each independent variable conditional on the other independent variables.

Data on employment and businesses come from the National Establishment Time-Series (NETS) database, a longitudinal panel of business establishments based on the Dun & Bradstreet register of nearly all U.S. businesses. The NETS includes employment, 6-digit NAICS industry, and exact street address for establishments, covering the entire United States over the period 1992–2006. The NETS has important advantages over other data sources used to estimate the effect of broadband on economic

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[15] I do not attempt to measure the effect of state policies on broadband availability because telecommunications regulations are difficult to quantify in a consistent way across states.

[16] Flamm (2006), GAO (2006), Grubesic (2003), Gillett and Lehr (1999) and others also find greater broadband availability in higher-density and higher-income areas. Prieger (2003) reports no statistically significant effect of income on broadband availability when education and numerous other controls are included.

development. Because the NETS reports exact street address and is not based on confidential government data, one can generate exact employment counts by ZIP code and detailed industry. Government sources like County Business Patterns suppress information for many industry-county and industry-ZIP code cells to preserve business confidentiality. Also, because the data are establishment-level and longitudinal, one can decompose employment changes into those due to births and deaths of establishments, relocations, and the expansion and contraction of existing establishments, to assess whether any observed relationship between broadband and growth is due solely to jobs moving around from migration.[17]

Data on telecommuting come from Forrester Research, a technology consultancy. Forrester surveys 60,000–100,000 households annually by mail about technology adoption and behaviors, with approximately one-sixth of respondents participating in successive years' surveys. Between 2001 and 2007, the surveys ask respondents whether they "bring work home to do outside normal business hours"; "have a formal arrangement with an employer to work from home one or more days per week" (i.e., as a telecommuter); and have a home-based business. The surveys also report respondents' ZIP codes, as well as standard household demographic variables.

Numerous other data sources provide information at the ZCTA and county level:

- Educational attainment, median household income, and population are available at the ZCTA level in the 2000 Census. In 1990, the Census did not report summary data for ZCTAs. To estimate 1990 ZCTA Census data, I assign year-2000 Census tracts to ZCTAs using Mable/Geocorr (http://mcdc2.missouri.edu/websas/geocorr2k.html). Then, I use the Neighborhood Change Database—which recalculates 1970, 1980, and 1990 Census summary data using year-2000 tract definitions—to construct tract-based estimates of ZCTA-level summary data for the 1990 and 2000 Censuses.
- Climate variables at the county level come from the USDA Economic Research Service.
- Employment at businesses, employment among residents, working-age population, payroll, and household income at the county level come from the U.S. Bureau of Labor Statistics and Census Bureau.

[17] See Kolko and Neumark (2007) for a longer description and quality assessment of the NETS database.

- Population, income, education, and housing characteristics at the county level come from the 1990 and 2000 Census and the 2006 American Community Survey, as well as from Census Bureau mid-decade estimates.
- Slope and road density at the ZCTA level are generated using ESRI mapping data in ArcGIS software.

V. Analytical Approach

The analysis uses three baseline empirical specifications:

1. ZCTA-level employment changes based on business location, using NETS data.
2. County-level household labor market outcomes, including employed residential population, total population, working-age population, the employment rate, median income, and average pay per employee, using Census and other data.
3. Individual-level analysis of changes in telecommuting and operating a home-based business, using Forrester data.

Each specification relates the dependent variable to the change in the number of broadband providers, from the FCC Form 477 data. This section presents the ZCTA-level specification with employment growth as the dependent variable in detail. The subsequent analyses involve only minor modifications to this first specification and are discussed later in the paper.

The first specification looks at the relationship between employment growth and broadband availability.

(1) $$ln\left(\frac{emp_i^{t+1}}{emp_i^t}\right) = \alpha + \beta \ln(BB_i^{t+1} - BB_i^t + 1) + \Phi X_i^t \ln(BB_i^{t+1} - BB_i^t + 1) + \Psi X_i^t + \Lambda Z_i^t + \mu ln\left(\frac{emp_i^t}{emp_i^{t-1}}\right) + \tau \ln(BB_i^t - BB_i^{t-1} + 1) + \varepsilon_i$$

The dependent variable is employment growth, and BB refers to the number of broadband providers in a ZCTA at a point in time. The independent variable of interest is the change in broadband providers in log form to proxy for broadband availability, following Kolko (2010b) as explained above (plus one so as not to drop from the logged value those ZCTAs where the number of providers stayed constant between *t* and *t+1*). Employment growth in ZCTA *i* between time *t* and time *t*+1 is a function of the change in the number of broadband providers in ZCTA *i* and ZCTA-level controls, some of which (the Xs) are interacted with the change in broadband providers and others of which (the Zs) are not. Lagged values of employment growth and broadband expansion are also included as controls.

The analysis focuses on the time period 1999–2006 for several reasons. The FCC reports ZIP code provider counts starting in 1999, and Forrester surveys about home-based work are available starting in 2001. The NETS covers the entire time period 1992–2006, and Census/BLS data on employment, pay, income, and population are available for years prior to 1999. Focusing on the 1999–2006 period makes it possible to use prior trends in employment growth from the NETS. Furthermore, this period is more relevant than earlier years (1992–1999) as a guide to what broadband expansion facilitated by current policies means for economic development. The relationship between broadband (or any technology) and economic outcomes could change over the course of the technology's diffusion.[18] Policies designed to bring broadband to still-underserved areas are at the end of the diffusion process of broadband at current broadband speeds, so the most recent historical experience is a better guide to what might happen in the future than earlier historical experience.

Because the FCC began reporting provider counts at the ZIP code level in 1999, the number of broadband providers in 1992 is assumed to be zero in all ZCTAs, so the level of providers in 1999 is assumed to equal the change in providers from 1992 to 1999.[19] This assumption will make it possible to control for earlier trends in broadband expansion, check for a lagged effect of broadband on employment growth, and check for whether broadband expansion in the earlier period appeared to anticipate later employment growth. I also use this specification for the 1992–1999 period to assess how broadband

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[18] It is ambiguous whether the economic effects, theoretically, might be bigger earlier or later in the diffusion process. Early adopters, by taking advantage of a technology first, could grow to a scale that is hard for later adopters to compete with. However, the cost of adopting a new technology can fall over time with technological improvements and knowledge from lessons learned by the earlier adopters, which could make economic benefits higher for later adopters.

[19] The FCC reports the number of high-speed lines in use (i.e., broadband subscribers, residential and business) back only to December 1999, when there were 2.5 million, compared with 82.5 million in December 2006 and 132.8 million in June 2008. Kolko (2000) reports that the initial growth of commercial Internet usage began around 1994: In January of that year, only 6,653 ".com" Internet domain names were registered, compared with over one million four years later. Forman, Goldfarb, and Greenstein (2009) also argue that commercial Internet usage most likely did not affect local economic activity before 1995. Gillett et al. (2006) note that few communities had broadband before December 1996 (p. 14).

expansion in its early stages related to economic development. But with *t*=1992 and *t*+1=1999, one cannot control for lagged employment growth because the NETS begins in 1992.

Controls include factors (the Xs) that could influence the relationship between broadband provision and growth. ZCTA-level population density, ZCTA-level median household income, and the log of metropolitan area population (or county population for ZCTAs outside metropolitan areas) are included in the Xs; these interactions are potentially important from a policy perspective since lower-income and rural areas are less well-served by broadband providers and are the main focus of efforts to close the digital divide. County-level education attainment—measured as the percent of adults 25 years or older with a bachelor's degree—is also included to assess whether broadband availability is a complement for the skill level of the local workforce. Because ZCTAs are almost always smaller than a labor market, and firms draw their workforce not just from within their ZCTA but from the local labor market, I use county-level rather than ZCTA-level education. Finally, the model includes interactions to assess whether broadband encourages businesses or households to locate in places that are desirable: These measures include (1) a county-level climate index from the USDA that captures mild temperatures, sunny winters, and dry summers; and (2) a county-level measure of the share of housing that is vacation or seasonal homes, reflecting how recreation-oriented a place is.

Additional controls include several measures from the urban growth literature to predict local economic growth. One control is a shift-share measure intended to predict employment growth between *t* and *t+1*, calculated as the weighted average of 3-digit NAICS industry growth (indexed by *j*) in the rest of the country (i.e., excluding ZCTA *i*), where the weights are industry shares in ZCTA *i* at time *t*. $Emp_{i,j}$ equals employment in ZCTA *i* in industry *j*, and emp_i equals employment in ZCTA *i* across all industries.

$$predictedgrowth_i^{t \to t+1} = \sum_j \left(\frac{\sum_{k \neq i} emp_{k,j}^{t+1}}{\sum_{k \neq i} emp_{k,j}^{t}} * \frac{emp_{i,j}^{t}}{emp_i^{t}} \right)$$

Intuitively, this predicted growth measure reflects the level of employment growth in ZCTA *i* if each industry within the ZCTA grew at the same rate as in the rest of the country. In addition, the model includes the diversity of ZCTA employment as measured by the similarity of the ZCTA's industry mix to that of the nation, and the average establishment size in the ZCTA.[20] These employment variables are all generated from the NETS database. The model also includes the density of major roads in the ZCTA as a proxy for transportation costs: Areas with better transportation could grow faster, and since broadband infrastructure often follows existing transportation rights-of-way, omitting road density could bias the relationship between broadband and employment growth. Models for the 1999–2006 period include further controls (in the Zs) for the log of broadband providers in 1999 and 1992–1999 employment growth. The lagged growth variable captures the prior trend in employment growth: If past ZCTA-level growth is positively correlated with future growth due to a pre-existing growth trend, and if broadband providers expand service in areas exhibiting persistent growth, then omitting lagged growth would bias the relationship between broadband expansion and employment growth upward.

The results are weighted by employment in ZCTA *i* at time *t*. ZCTAs have no inherent economic meaning (they don't approximate a labor market, for instance) and no political meaning, so there's no justification for giving them all equal weight, particularly since many ZCTAs have very little employment. Standard errors are clustered at the county level to reflect likely correlation of errors between nearby ZCTAs.

In addition to looking at overall employment growth for all ZCTAs in each time period, I also look at growth in specific industries or sectors; growth due to relocation, expansion and contraction, and births and deaths of establishments; and growth over the period 1999–2006 in ZCTAs with 0 or 1–3 providers in 1999. This set of ZCTAs excludes the early adopters of broadband and better represents the unserved and underserved areas that are the target of government programs to support broadband infrastructure.

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[20] Glaeser et al. (1992) and Henderson, Kuncoro, and Turner (1995) use diversity measures in their classic studies of local industry growth. Glaeser et al. (1992) also include average establishment size as a measure of competition as another explanatory factor affecting local industry growth.

In an improvement over earlier work on broadband and economic development, this paper investigates causality using an instrumental variable strategy. A good candidate instrument for broadband must be correlated with broadband availability without being independently correlated with economic growth, aside from its indirect effect through the relationship between broadband availability and economic growth.

As an instrument for broadband availability, I use the average slope of the land in ZCTA *i*. Broadband providers face higher costs to extend service in areas with steeper terrain.[21] The results section, below, confirms that slope and provider count have a statistically significant, negative relationship over the period 1999–2006, holding constant other explanatory variables used in the model. The exclusion restriction holds if slope has no direct effect on economic growth independent of its relationship with broadband availability. Several possibilities arise as to why slope might affect economic activity outside of an indirect effect on broadband availability. First, workers might increasingly be valuing steeper terrain as an amenity offering views or recreational activities (due to changing tastes, or -- assuming positive income elasticity of demand for the amenity -- rising incomes), thus lowering wages and raising employment growth in steeper areas. To handle this potential source of bias, I control for two amenity measures—climate and share of housing that is vacation homes: Mountainous areas have drier climates, which enters positively into the climate index, and mountain areas that are high-amenity due to recreational opportunities (e.g., skiing) would have a higher share of housing as vacation homes. Second, steeper terrain might raise transportation costs, lowering the level or growth of employment relative to flatter areas. To handle this potential source of bias, I control for road density as a proxy for transportation costs. Third, slope could affect the economic base: Steeper areas tend to be farther from coasts, where transportation, warehousing, and other goods-related industries often cluster. Slope could also be correlated with the location of natural resource industries such as mining or

[21] Personal communication with Mark Guttman of CostQuest, a consultancy whose practice includes modeling the costs and benefits to telecommunications firms of providing broadband service, August 15, 2008. Prieger (2003) notes that the FCC's Hybrid Cost Proxy Model considers terrain as a factor that influences the cost of providing local telecommunications services. The Government Accountability Office (2006) reports that broadband providers, state regulators, and other stakeholders said "infrastructure build-out can be difficult in mountainous and forested areas because these areas may be difficult to reach or difficult on which to deploy the required equipment. Conversely, we were told that "flat terrain constitutes good geography for telecommunications deployment" (p.19).

forestry. I control for the local industry mix using the shift-share predicted-growth measure, which captures local employment growth differences due to exogenous national shifts in the growth rates of local industries.[22]

VI: Results: Employment Growth

The analysis of broadband and employment growth—following model (1) above – appears in Tables 2 through 6. The baseline specification is a regression of employment growth in 1999–2006 on the change in broadband providers 1999–2006 (Table 2, column 1). To interpret the magnitude of the coefficients, keep in mind that a one-unit change in the log of the difference in providers corresponds roughly to an increase from zero to 1–3 providers or from 1–3 providers to 4 providers; a two-unit change corresponds roughly to an increase from zero to 7 providers. A one-unit change is associated with employment growth that is 6 percentage points higher over the seven-year period, which corresponds to the coefficient of 0.0636 in column 1. Standardizing this coefficient, a one-standard-deviation change in broadband corresponds to a 0.085 standard deviation change in employment.[23] The insignificant coefficient on broadband expansion in 1992–1999 indicates that there are not long lags in the relationship between broadband expansion and employment growth, controlling for the contemporaneous broadband expansion. Restricting the model to ZCTAs with zero or 1–3 providers in 1999, the 1999–2006 broadband expansion coefficient remains positive, significant, and of similar magnitude (column 2). Since this set of ZCTAs excludes the early broadband adopters, this coefficient represents the relationship between broadband and employment growth in the types of areas targeted by public broadband policy.

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[22] Kolko (2010b) shows that broadband subscription prices as reported by households are uncorrelated with the number of broadband providers in a ZIP code, so the relationship between slope and broadband availability is not driven by prices broadband providers charge.
[23] The standard deviation of the 1999–2006 provider count change is 0.36, and the standard deviation of employment growth 1999–2006 is 0.27—both weighted by 1999 ZCTA employment, as shown in Table 1.

The relationship between broadband expansion and employment growth in 1992–1999 is positive, statistically significant, and smaller than in the later period: 0.0350 in column 3 versus 0.0636 in column 1. Although the 1992–1999 model excludes prior employment growth as a control since the NETS data start in 1992, the exclusion of prior growth in the 1999–2006 model leaves the relationship unchanged (not shown); the 1999–2006 model also shows no significant lagged effect of broadband expansion.

The final two columns of Table 2 begin to explore the causality of the relationship between broadband expansion and employment growth. A plausible alternative to a causal effect of broadband on employment growth is that population growth could encourage both broadband provision—since residential customers are the bulk of broadband subscribers—and employment growth, since many industries serve local populations. Column 4 includes county population growth in 1999–2006 as a control.[24] Although employment growth and broadband expansion are measured at the ZCTA level, most businesses serving local populations probably have a larger customer footprint than a ZCTA, which in urban areas is often a small neighborhood and averages roughly 10,000 people.[25] Including population growth lowers the coefficient on broadband expansion by roughly one-fifth, remaining statistically significant: Population growth does not account for most of the relationship between employment growth and broadband expansion. The industry-level analysis in the next section explores this further.

The last point from Table 2 is that there is no relationship between employment growth in the later period and broadband expansion in the earlier period. Having already discounted the possibility of a long lagged effect of broadband expansion 1992–1999 on employment growth 1999–2006 from column 1, the lack of relationship between later employment growth and earlier broadband expansion in column 5 suggests that broadband expansion was not greater in areas with future employment growth. Although this does not

[24] County population for intercensal years are Census Bureau annual estimates, based on numerous administrative data sources.
[25] The Census has not published population estimates or any other data for ZCTAs after 2000.

establish the direction of causality between broadband expansion and employment growth, it is evidence that broadband expansion did not occur in anticipation of (accurately predicted) later employment growth.

Table 3 presents results for employment growth in specific industries and due to different employment dynamics, as well as for establishment growth. For the period 1999–2006, broadband expansion is positively associated with establishment growth as well as employment growth, while average establishment size is negative.[26] Across employment dynamics, broadband expansion has a positive, statistically significant relationship with growth due to births and deaths and expansions and contractions in 1999–2006. The magnitude of the coefficient in the cross-ZCTA moves regression is the smallest of the employment dynamics, suggesting that the broadband-growth relationship is not driven by the relocation of jobs from lower broadband areas to higher broadband areas.[27]

The relationship between broadband expansion and employment growth varies by industry. The lower portion of Table 3 presents the coefficients from separate regressions of growth in each sector on broadband expansion and the full set of controls. Column 1 does not include the control for county population growth and therefore corresponds to Table 2, column 1; column 2 includes the county population growth variable and therefore corresponds to Table 2, column 4. The relationship is strongest for utilities; information; finance and insurance; professional, scientific, and technical services; management of companies and enterprises; and administrative and business support services. In these sectors, the same increase in broadband availability is associated with at least 12 percentage point higher employment growth. The relationship was not statistically significant at the 5 percent level in mining and public administration. With

[26] The relationship between average establishment size and broadband expansion is positive in 1992–1999 (not shown in the tables), suggesting that the benefits of broadband might have favored larger firms earlier and smaller firms more recently, which could arise if early adopters of a technology face higher fixed costs of adoption whereas the cost of adopting the technology falls as the technology diffuses, raising the relative benefit to smaller firms.

[27] The cross-ZCTA migration employment change in 1999–2006 has the smallest magnitude of the three dynamics with standardized betas as well. The standard deviation of employment growth over the period is 0.17 for births minus deaths, 0.12 for expansions minus contractions, and 0.10 for migration. Employment growth for these dynamics is measured as the net employment change for the period divided by total ZCTA employment in the start-year. Cross-ZCTA migration is more common than cross-state migration, which Kolko and Neumark (2007) found to be minimal. The weaker relationship for migration does not, by itself, rule out the possibility that the growth associated with broadband expansion is a zero-sum game: Broadband expansion could theoretically change the geographical distribution of establishment births without changing the overall national level.

the population growth variable, the relationships with growth in manufacturing; educational services; and arts, entertainment, and recreation become insignificant.

The sectors whose growth is more strongly associated with broadband expansion are generally those that are more technology-intensive. I measure technology-intensity of industries in two ways: inputs and occupations. The input-based measure equals the ratio of the value of technology inputs to the value of industry output, where technology inputs include Internet publishing, telecommunications services, data processing, and related services (the output of NAICS industries 516–518). These data come from the 2002 Input-Output Use Tables, published by the Bureau of Economic Analysis. The occupation-based measure equals the share of industry workers in "computer specialist occupations" (Standard Occupational Code 15-1000, Bureau of Labor Statistics); these include programmers, software engineers, and database and network administrators, but not workers involved in physical computer assembly or telecommunications installation and repair. The correlation of the inputs-based and occupation-based measures of technology intensity across sectors is 0.72. Three sectors – management of companies and enterprises; professional, scientific, and technical services; and information – score high on both measures of technology intensity, and the relationship between broadband expansion and employment growth in these sectors is especially large, with regression coefficients of 0.12 or higher.[28]

To further investigate whether the relationship between broadband expansion and employment growth is primarily driven by population growth, the next analysis examines whether the strongest relationship between broadband expansion and employment growth is in sectors where growth is most tied to population growth. I create a dissimilarity index between the geographic distribution of a sector's employment and that of the population, measured as the sum of absolute values of the differences between a ZCTA's share of national sector employment and a ZCTA's share of population. The lowest values – sectors where the geographic

[28] Two industries – administrative and business support services and educational services – are technology-intense based on the inputs measure only; two other industries – utilities and finance and insurance – are technology-intense based on the occupation measure only. Except for educational services, these industries also have coefficients of at least 0.12.

distribution of employment most closely mimics the geographic distribution of population – are retail, construction, and "other services," which consists largely of personal services. Grouping together the sectors whose locations are most tied to the population – retail (NAICS 44–45) and consumer services (NAICS 6, 7, and 8) – moving from 0 to 1–3 broadband providers (or equivalent increases in the log change) is associated with a 6.3 percentage point increase in employment growth. (See Table 3, bottom rows.) For sectors whose locations are less tied to the population distribution – manufacturing (NAICS 3), wholesale trade (NAICS 42), and finance, information, real estate, and business services (NAICS 5) – broadband availability is associated with a 9.0 percentage point increase in employment growth.[29] The difference between these estimates is somewhat informative as a lower bound of the effect of broadband if the relationship between broadband and employment in retail and consumer services were entirely due to exogenous population growth that caused both broadband expansion and employment growth. However, this difference is only a lower bound. Even if broadband does not cause employment growth in retail or consumer services directly, a positive effect of broadband on employment growth in business services, manufacturing, and other industries could induce population growth (people follow jobs) and therefore indirectly cause some employment growth in retail and consumer services.

Up to this point, the analysis has not considered heterogeneous effects of broadband on employment growth based on ZCTA characteristics. Including interactions between the broadband provider count and ZCTA-, county-, and metropolitan-level variables reveals that broadband has a stronger relationship with employment growth in some areas than others. Table 4 shows that broadband expansion is associated with higher employment growth in lower-density ZCTAs, both in the later period (columns 1 and 2) and in the earlier period (column 3). The interaction coefficients in column 1 imply that a high-density ZCTA (density at the 90th percentile) with all other characteristics at their means would exhibit no statistically significant relationship between broadband

[29] For these estimates only, I omit sectors whose locations are strongly tied to the availability of natural resources or geographic features. Their geographic distribution often diverges from the population distribution, but that does not mean they are more "footloose" industries in the way that many business services are. I also omit public administration.

expansion and employment growth. However, density and metropolitan population are strongly positively correlated, and a ZCTA with density at the 90th percentile and metropolitan population typical for a high-density ZCTA would still exhibit a positive, statistically significant relationship between broadband expansion and employment growth.[30] The negative, statistically significant coefficient on the population density interaction is consistent with the claim that electronic communication, which broadband facilitates, can substitute for face-to-face communication, which is more prevalent and lower-cost in higher density areas.

The county education attainment interaction is statistically significant for the period 1992–1999 only, suggesting that the effect of broadband is a complement with general worker skills in fostering employment growth for areas where broadband was adopted earlier; below, the discussion of household outcomes includes an interpretation of this finding.

Results presented so far have been consistent with a causal relationship of broadband expansion leading to employment growth. Table 2 showed that earlier broadband expansion does not appear to anticipate later employment growth. Also, including population growth as a control did little to change the relationship between broadband expansion and employment growth, discounting the most plausible alternative to broadband expansion causing employment growth, which was that both could be caused by population growth. To assess causality in the contemporaneous positive relationship between broadband expansion and employment growth, I instrument for broadband expansion using slope. First-stage and second-stage results are presented in Tables 5 and 6, respectively.

In the first stage, the log change in broadband providers is regressed on slope (the instrument) and the full set of controls included in the second stage, which are shown in the results and notes to Table 5. Column 1 shows the relationship between broadband availability and the independent variables (including slope) over the entire 1992-2006 time period, whereas columns 2 through 5 are the first-stage of the 2SLS estimation

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[30] The estimated coefficient for density at the 90th percentile and other interacted variables at their means is 0.0089 with a standard error of 0.014; the estimated coefficient for density at the 90th percentile and metropolitan area population at the 75th percentile is 0.0340 with a standard error of 0.014, which is statistically significant at the 5% level. The correlation between log ZCTA population density and log metropolitan area (or county) population is 0.73.

where the dependent variable is the increase in broadband providers over the period 1999–2006; recall that the analysis focuses on this time period, rather than the entire 1992–2006 period. The coefficient on slope is negative and statistically significant, and although the p-value for the F-test is well-below .05, the F-statistic is small in column 2 relative to the subsequent columns. The relationship between slope and broadband expansion in 1999–2006 is quite sensitive to the weighting by ZCTA employment, as the comparison with column 3 shows: Unweighted, the magnitude of the slope coefficient is 2.5 times larger, and the F-statistic is much larger. As explained above, because ZCTAs have no inherent economic or political meaning, it makes more sense to weight by employment throughout the analysis, though this comes at the cost of some first-stage power because the ZCTAs with steep terrain and less broadband expansion in 1999–2006 tend to have low employment. The coefficient on slope becomes less sensitive to whether the regression is weighted if ZCTAs with low and high employment are removed: Looking only at ZCTAs with employment in 1999 between 200 and 7000 – roughly the 20th to 80th percentiles of ZCTAs by employment – the coefficient on slope is similar and the F-statistic is high regardless of weighting (see columns 4 and 5).[31]

Given the sensitivity of the first-stage results to weighting, it is unsurprising that the second-stage results are highly sensitive to weighting, too. The weighted, full-sample 2SLS estimate in Table 6, column 1, is positive, significant, but implausibly high: 0.636 is ten times the OLS estimate, and the standard error is twenty times that of the OLS estimate. The unweighted 2SLS estimate is essentially zero (column 2). Following the strategy in the first stage, I repeat the second-stage estimation, limiting the sample to ZCTAs with a narrower distribution of employment.[32] Columns 3 and 4 include only ZCTAs with employment between 200 and 7000, and – as in the first stage – the second-stage results are somewhat less sensitive to weighting. Weighted, the estimate with this restricted set is 0.325; the unweighted estimate is 0.127. Both

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[31] Another issue is that slope is not a valid instrument for broadband expansion for the 1992–1999 period because it is uncorrelated with the 1999 provider count in the weighted model (column 6) and *positively* related to broadband expansion in the unweighted model (column 7). However, the 1999–2006 period is more relevant for broadband policy and is the focus of the analysis.

[32] Excluding ZCTAs with little employment in an unweighted regression seems an appropriate balance between not giving undue influence to ZCTAs of little economic importance and choosing a model that gives slope more power as an instrument for broadband expansion.

estimates remain well above the OLS estimates for these samples, which are reported in the last row of the table.

The 2SLS results are suggestive—though by no means definitively—of a causal effect of broadband on employment growth. Aside from the unweighted full sample model, the 2SLS results are positive and statistically significant although the estimates balloon upward relative to the OLS estimates. As argued above, the most plausible source of upward bias in the 2SLS estimate would arise from slope being positively correlated with transport costs, transport costs being negatively correlated with employment growth, and slope being negatively correlated with broadband expansion over the 1999–2006 period: Thus, the portion of broadband expansion variation explained (positively) by flatness could bias the 2SLS upward, since flat land would have lower transport costs and therefore faster growth. But road density is included as a control, which reduces the possibility of this upward bias.

It is also possible that endogeneity could bias the OLS estimates downward during this time period since broadband expansion in 1999–2006 is negatively correlated with broadband expansion in 1992–1999 (see Table 5, columns 2–5). Areas expected to have higher employment growth might have induced more broadband expansion in 1992–1999 if broadband expanded first in the places that were expected to be most profitable. Broadband expansion in 1999–2006 would therefore have been in places where slower growth was anticipated, leading to a downward endogeneity bias. This would be consistent with the higher 2SLS estimates, though the magnitudes of the 2SLS estimates are still unconvincingly high.[33]

VII: Results: Household Economic Outcomes

Employment growth is only one of many possible economic effects of broadband. If broadband increases economic output in a ZCTA, households' employment and income outcomes could change throughout the

[33] The 2SLS results for sector employment growth (corresponding to the OLS results in Table 3) and for interactions with local characteristics (corresponding to the OLS results in Table 4) both had even higher standard errors relative to OLS and coefficient estimates with even less plausible magnitudes. While endogeneity is a concern not just for overall employment growth but also for other specifications, it appears that slope is not a sufficiently strong instrument to yield meaningful results for these other specifications.

labor market area. The analysis now turns to county-level relationships between broadband availability and economic outcomes, following specification (1) above but with the county as the unit of analysis rather than the ZCTA. I examine several labor market measures: employment from the NETS, and employed population, total and working-age population, the employment rate (employed population divided by working-age population), median household income, and average pay per employee from the Census Bureau and the Bureau of Labor Statistics. Employed population (Census) refers to the number of county residents who are employed anywhere, whereas employment (NETS) reflects employment by workplace location, not employee residence. Whereas the most geographically disaggregated analysis possible is appropriate for business location because businesses need broadband infrastructure at their exact location, county-level analysis is more appropriate for household outcomes because counties better approximate a firm's local labor market than smaller geographies like ZCTA's do.

For this county-level analysis, the only changes to the specification are as follows. The change in broadband availability is the employment-weighted average of ZCTA-level availability for ZCTAs in a county..The Xs include county-level education, median income, population density, metropolitan area population, climate, and housing share of vacation homes—the same variables as in specification (1). Instead of the predicted employment growth, average establishment size, and industrial diversity measures in specification (1), which are predictors specifically of employment growth, here the Zs include 2-digit NAICS sector shares, a more flexible specification for looking at a wider range of labor market outcomes.[34] As before, regressions for the 1999–2006 period include as controls the 1992–1999 change in the outcome variable and the 1999 provider count. Road density, like broadband provider count, is the employment-weighted average for ZCTAs in the county. The 1992–1999 regressions include prior trends of the dependent variable from 1979 or 1980 to 1990 or 1992, depending on data availability.

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[34] For outcomes other than employment growth, sector share controls are more appropriate than the predicted employment growth control used in model (1). When employment growth is the outcome, the predicted employment growth variable has the advantage of being constructed from 3-digit NAICS industries and, in effect, controls for detailed industry mix with a minimal loss of degrees of freedom.

Table 7 presents results for employment in businesses located in the county, employment among county residents, total population, the working-age population, the share of working-age adults employed (the employment rate), average pay per employee, and median household income. Employment in county businesses can differ from employment among county residents since some employees work at businesses outside their county of residence. For each outcome variable, Table 7 reports the coefficient estimate on contemporaneous broadband expansion for 1999–2006 – both for all counties and restricted to counties with on average 2 or fewer providers in 1999 – and for 1992–1999.[35]

The effect on employment from the NETS at the county level is positive, significant, and only slightly smaller in magnitude than the ZCTA-level analysis for 1999–2006: 0.0534 versus 0.0636 in Table 2, column 1, with a bigger gap for the county-level and ZCTA-level results for counties with low broadband availability in 1999. Turning to household outcomes, during 1999–2006 broadband expansion is associated with larger increases in employed residents, population, and the working-age population, but no statistically significant change in the employment rate or average pay.[36] Broadband expansion is associated with a decrease in household income despite no change in average pay per employee. The primary differences for counties with low broadband availability in 1999 (column 2) is that broadband expansion has no statistically significant effect on population employed and a negative relationship with the employment rate, significant at the 10 percent level.

The main difference between the later period and the earlier period is that broadband expansion in 1992–1999 is associated with a positive and statistically significant increase in the employment rate, average pay

[35] In the county model, the broadband provider count is a weighted average of the county's component ZCTAs. Since the ZIP code level provider count of 1–3 is coded as 2, the county-level cutoff of 2 or fewer corresponds to the ZCTA-level cutoff from earlier tables of zero and 1–3.

[36] As noted above, the effects on employment and employed residents could differ because the employment measure from the NETS is based on place of employment, and the employed-residents measure from the Census is based on place of residence. Some people commute across county lines and therefore would be included in different counties for employment in the NETS and employed residents in the Census. In counties with relatively little cross-county commuting – where more than 2/3 of employed residents work in the county and more than 2/3 of employment is county residents – the coefficient on employment (NETS) is 0.0384 and on employed residents (Census) is 0.0398, both statistically significant and nearly identical to each other. For counties where fewer than 2/3 of employed residents work in the county or where fewer than 2/3 of employment is employed residents, the coefficient on employment is 0.0752 (t-stat=3.7) and the coefficient on employed residents is 0.0194 (t-stat=0.99). This suggests that the employment growth due to broadband expansion in counties with cross-commuting does not necessarily benefit residents and is consistent with an elastic labor supply.

per employee, and median household income. The relationship with employment (NETS) is positive and significant in both periods. It may be that in the earlier years of broadband, computer-literate workers were in scarce supply, so employers paid more for the same skills earlier that they did in later years; furthermore, early adopting businesses might have demanded more advanced skills if, to integrate a nascent technology into their business processes, these early adopter businesses had to develop more applications in-house using in-house staff, whereas later adopters could rely more on off-the-shelf mass-market applications that workers with more modest technology skills could use. The stronger complementarity in the earlier period between broadband and higher-skilled workers, relative to the later period, is consistent with the positive interaction between county education level in 1992–1999 and broadband expansion, in Table 4, column 3, which could also reflect a greater benefit of broadband to businesses with access to higher-skilled labor.

The last outcomes the analysis covers are measures of home-based work, based on Forrester survey data of telecommuting, having a home-based business, bringing work home, and employment.

(2) $outcome_s^t = \alpha + \beta \ln(BB_i^t + 1) + \Phi X_i^t \ln(BB_i^t + 1) + \Psi X_i^t + \Lambda Z_s^t + \varepsilon_s$

Unlike specification (1), where the dependent variable is a change, here in specification (2) the dependent variable is the level of an outcome variable for individual *s*, who lives in ZCTA *i* at time *t*. Forrester data are matched to the ZCTA-level broadband provider count data and other ZCTA controls in X, which – as before – include ZCTA-level household income and population density, county-level educational attainment, climate score, housing share of vacation homes, and metropolitan area population. Here, the additional control variables – the Zs – include individual age, education, race and ethnicity, family structure variables, and household income and assets—all in categories using saturated sets of dummies. The Forrester data are an unbalanced panel: Many respondents participate in multiple years of the survey, though typically in just two or three years. Model (2) includes person-ZCTA fixed-effects in order to difference out time-invariant observed and unobserved individual characteristics, thus estimating for a given person the effect of the change in broadband provider count in their ZCTA on the likelihood of each outcome. The person-ZCTA fixed effects model identifies the relationship only off of households in the same location in multiple years (though including movers as well turns out not to affect the results). Also included are year dummies to capture general economic conditions and slight variations in survey-question wording in a couple of years. The outcomes include employment, having a formal telecommuting relationship with an employer, informally bringing work home, and having a home-based business. Each is a binary variable. Changes in the number of broadband providers have no effect on the likelihood of telecommuting, bringing work home, or having a home-based business (Table 8, first row). There is similarly no statistically significant effect for any of these outcomes when restricting the sample to people in ZCTAs with zero or 1–3 providers in 1999 (Table 8, second row). Even when restricting the sample to respondents with a bachelor's degree (row three) or in managerial or professional occupations (row four), who might be the respondents whose work is most conducive to working independently at home, broadband expansion has no relationship with changes in the likelihood of doing any of the home-based work activities. The likelihood of working for an employer, however, has a positive and statistically significant relationship with the number of broadband providers (Table 8, column 4), except for respondents in managerial or professional occupations. One cannot compare this with the lack of relationship between broadband expansion and the employment rate estimates at the county level in Table 7, for two reasons. First, the geographic level of analysis is different, so broadband expansion in one's own ZCTA might have different effects on household employment than broadband expansion in one's own county. Second, the individual-level analysis controls for individual characteristics and conditions on being in the same ZCTA in multiple years: Since broadband expansion was associated with both employment and population growth (Table 7), it may be that longer-term residents, who are overrepresented in the Forrester sample with fixed individual-ZCTA effects, have a better employment outcomes than newcomers who constitute the population growth that is also associated with broadband expansion.

VIII. Discussion

The findings indicate a positive relationship between broadband expansion and employment growth and suggest – though not definitively – that the relationship is causal. The relationship is strongest in more technology-reliant industries, and population growth does not appear to be the trigger, which was the most plausible alternative explanation to a causal relationship because most broadband subscribers are households, not businesses.

However, the large increase in employment growth associated with broadband expansion does not necessarily benefit local residents. Areas with faster broadband expansion between 1999 and 2006 experienced no greater increases in either the employment rate – employment as a share of the working-age population – or in average pay per employee, relative to other areas, and median household income declined. One possible explanation for this is that broadband does indeed lead to employment growth, which encourages people to move or commute to areas where employment opportunities have expanded, and this increase in the local labor supply prevents the increased demand for labor from raising either the employment rate or average pay. Employment growth might still raise local property values and tax bases, but in the absence of more direct benefits for residents, the economic development benefits of broadband are ambiguous.

These results are consistent with economists' expectations about "place-based policies," which target geographic areas, in contrast to policies whose benefits go to designated households or businesses. Winnick (1966) refers to place-based policies as "clumsy, expensive, and often inequitable," often capitalized into land values and possibly disadvantaging needy people who don't live in needy places.[37] Glaeser (2005, 2007) suggests that place-based policies may end up encouraging economic activity in places where that activity might not otherwise be economically sustainable, such as Buffalo, NY, and post-Katrina New Orleans. With

[37] The full quote from Winnick (1966), an economist and urban development expert: "Federal programs to change the geography of output are a kind of welfare device to redistribute personal income. But at best it is a clumsy, expensive, and often inequitable device. Not only are the gains to one locality offset by losses to another, but even in the locality of gain the added income frequently goes to the wrong people. … A disproportionately large share of the increased purchasing power goes to the owners of immobile resources [e.g. property owners] other than labor." Ladd (1994), in a review of research on enterprise zones, also notes that the benefits of place-based policies to non-landowning local residents are uncertain.

regard to place-based broadband policies that increase broadband availability in specific areas, many of the places that are unserved and underserved by broadband are so because terrain, remoteness, or low population density raises the cost of broadband provision. The ambiguous effect of expanding broadband availability for local residents begs the question whether public money designated for broadband infrastructure might have a larger effect on economic or social outcomes if the funds were allocated instead toward subsidizing broadband adoption or other needs of disadvantaged households, regardless of where they live.

The research strategy in this paper and the literature reviewed above is to compare local outcomes with local differences in broadband availability *relative to other areas*. Relevant as this approach is for assessing policies that raise broadband availability in unserved and underserved areas, it may not tell us about the relationship between broadband and national economic activity. On one hand, it is theoretically possible (though perhaps implausible) that broadband has no net effect on employment growth nationally, and the positive relationship between broadband expansion and local employment growth reflects a zero-sum game of economic activity shifting from broadband-poor to broadband-rich areas. On the other hand, it is possible (and quite plausible) that the economic benefits of broadband expansion are not limited to the immediate area where broadband expands: Network effects mean that broadband users everywhere may benefit when broadband availability expands and adoption increases in a specific location. Looking at local economic outcomes relative to other areas would therefore understate the aggregate economic benefits of broadband. Estimating the national economic value of broadband or the Internet generally requires different methods outside the scope of this paper, such as estimating consumer welfare from broadband access based on willingness-to-pay.[38]

Also outside the scope of this paper, broadband may also offer benefits not fully captured by measures of economic growth. People use broadband for a wide range of activities, some of which – like access to

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[38] The literature review above mentions examples of consumer welfare estimates based on willingness-to-pay studies.

news, remote medical services, or distance learning – might be important public policy goals. The 2010 FCC National Broadband Plan considers numerous potential benefits of expanded broadband access, including consumer welfare; health care; education; civic participation; government services; energy independence and efficiency; and public safety.

These findings have two important caveats. First is that the FCC's count of providers in a ZIP code, despite being the best publicly available data on broadband's diffusion, is an imperfect measure of availability. Although the provider count measure used in this paper is a good proxy for availability and is an improvement over previous studies, it does not take into account broadband speed, which can vary considerably across different locations. This limitation may be especially relevant for finding no association between broadband expansion and any of three types of home-based work, including telecommuting. While broadband service that meets the minimum speed in the FCC's historical definition of broadband may not raise the prevalence of telecommuting, future broadband services that support videoconferencing and other "telepresence" applications might do so. The FCC has already begun to collect broadband data at finer levels of geography and at various speeds, which will make the relationship between broadband speed and economic outcomes clearer in future research. However, these data improvements are not retroactive and will therefore not improve upon the existing ZIP code provider count data for assessing the first decade of broadband's diffusion.

The second caveat is that the effect of broadband expansion between 1999 and 2006 and local growth may be quite different from the economic effect of future expansions of broadband and other technologies. Between 1999 and 2006, broadband expansion consisted largely of cable and DSL service; by 2010, these technologies were available throughout most of the U.S., and future broadband expansions will include much faster wireline services like fiber-to-the-home as well as high-speed wireless services. Technologies offering higher speeds and greater mobility may facilitate applications whose benefits – economic and otherwise – are different from broadband applications that have dominated the Internet up to now – just as broadband services today and in recent years made possible many applications that earlier, slower dial-up modem Internet service could not support. The economic benefits of the Internet could yet turn out to be far different than what we are able to observe today.

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TABLE 1

Summary statistics

	(1)	(2)	(3)	(4)	(5)
	Source	Mean	Standard deviation	Minimum	Maximum
ZCTA-LEVEL VARIABLES (for tables 2-6)					
Log BB provider change, 1999–2006	FCC	2.12	0.36	0	2.89
BB provider level, 2006	FCC	11.24	3.38	0	21
BB provider level, 1999	FCC	3.42	2.11	0	10
Employment growth, 1999–2006	NETS	-0.03	0.27	-5.67	3.73
Slope (average vertical-horizontal ratio / 100)	ESRI	2.06	4.49	0	59.84
COUNTY-LEVEL VARIABLES (for table 7)					
Log BB provider change, 1999–2006	FCC	2.12	0.26	0	2.82
Employment growth, 1999–2006	NETS	0.01	0.11	-1.34	1.03
Employed residents growth, 1999-2006	BLS	0.08	0.11	-0.67	0.82
Population growth, 1999–2006	Census	0.06	0.10	-1.58	0.53
Working-age population growth, 1999-2006	Census	0.08	0.10	-1.35	0.61
Employment rate growth, 1999-2006	BLS/Census	-0.01	0.08	-0.57	0.92
Average pay per employee growth, 1999-2006	Census	0.22	0.07	-0.59	1.66
Median income growth, 1999-2006	Census	0.18	0.07	-0.08	0.37
INDIVIDUAL-LEVEL VARIABLES (for table 8)					
BB provider level (average level 2001-2006)	FCC	7.94	4.06	0	25
Telecommute (average level 2001-2006)	Forrester	0.03	0.16	0	1
Bring work home (average level 2001-2006)	Forrester	0.15	0.35	0	1
Home-based business (average level 2001-2006)	Forrester	0.11	0.31	0	1
Work for an employer (average level 2001-2006)	Forrester	0.64	0.48	0	1

TABLE 2
Employment growth and broadband, 1992–1999 and 1999–2006

Dependent variable: employment growth (NETS); OLS

	(1) Employment, 1999–2006	(2) Employment, 1999–2006	(3) Employment, 1992–1999	(4) Employment, 1999–2006	(5) Broadband, 1992–1999
BB provider change, 1999–2006	0.0636***	0.0601***		0.0499***	
	(0.0119)	(0.0180)		(0.0118)	
BB provider change, 1992–1999	0.0105	-0.00214	0.0350***	0.00773	
	(0.0101)	(0.0163)	(0.0126)	(0.00974)	
Population growth, county, 1999–2006				0.394***	
				(0.0647)	
Employment growth, 1999–2006					-0.00938
					(0.0193)
ZCTAs included	All	0 or 1–3 Providers in 1999	All	All	All
Observations	26721	23760	26717	26720	26717
R-squared	0.254	0.267	0.152	0.270	0.527

NOTES: Each column represents a separate regression. All columns include controls: predicted employment growth for the time period covered by the dependent variable, road density, percent bachelor's degree, population density, household income, and metropolitan/county population, climate, vacation home share, competition, and diversity, all as described in the text. Employment growth 1992–1999 included as a control for regression with 1999–2006 employment as dependent variable. Interactions are reported at the means of the control variables. Note that some 1990 control variables could not be generated for 4 ZCTAs using the consistent-tract-matching method described in the text. All regressions report robust standard errors clustered on county. *=10% level sig.; **=5% level sig.; ***=1% level sig.

TABLE 3
Employment growth in specified establishments, 1999–2006

Dependent variable: employment from NETS; all results OLS (each ROW is a separate regression)

	(1) Coefficient on BB provider change	Standard Error	(2) Coefficient on BB provider change	Standard Error
Employment growth in all establishments	0.0636***	(0.0119)		
Establishment growth	0.0547***	(0.00995)		
Average establishment size change	-0.0377***	(0.0101)		
EMPLOYMENT GROWTH IN:				
Establishment births and deaths	0.0441***	(0.00667)		
Establishment expansions and contractions	0.0112***	(0.00435)		
Establishment cross-ZCTA moves	0.00616*	(0.00315)		
INDUSTRY SECTORS (NAICS code):				
Agricultural, forestry, fishing, and hunting (11)	0.116***	(0.0422)	0.0918**	(0.0431)
Mining (21)	0.0657	(0.0590)	0.0339	(0.0604)
Utilities (22)	0.167***	(0.0592)	0.147**	(0.0601)
Construction (23)	0.118***	(0.0226)	0.0957***	(0.0229)
Manufacturing (31–33)	0.0625**	(0.0252)	0.0384	(0.0243)
Wholesale trade (42)	0.0708***	(0.0204)	0.0474**	(0.0213)
Retail trade (44–45)	0.0654***	(0.0157)	0.0443**	(0.0172)
Transportation and warehousing (48–49)	0.0862***	(0.0283)	0.0609**	(0.0287)
Information (51)	0.120***	(0.0236)	0.0995***	(0.0252)
Finance and insurance (52)	0.148***	(0.0241)	0.117***	(0.0236)
Real estate and rental and leasing (53)	0.102***	(0.0192)	0.0717***	(0.0198)
Professional, scientific, and technical services (54)	0.164***	(0.0193)	0.139***	(0.0182)
Management of companies and enterprises (55)	0.408***	(0.0765)	0.341***	(0.0763)
Administrative and business support services (56)	0.141***	(0.0272)	0.110***	(0.0265)
Educational services (61)	0.0610***	(0.0218)	0.0423*	(0.0227)
Health care and social assistance (62)	0.0736***	(0.0204)	0.0513***	(0.0198)
Arts, entertainment, and recreation (71)	0.0566**	(0.0259)	0.0367	(0.0275)
Accommodation and food services (72)	0.0993***	(0.0182)	0.0773***	(0.0208)
Other services (81)	0.0707***	(0.0167)	0.0497***	(0.0170)
Public administration (92)	0.00538	(0.0403)	-0.0163	(0.0397)
Sectors not tied to population (see below)	0.0899***	(0.0166)		
Sectors tied to population (see below)	0.0626***	(0.0105)		
Control for county population growth 1999–2006?	No		Yes	

NOTES: Each ROW and each pair of columns presents the coefficient estimate and standard error from a regression of employment growth on contemporaneous broadband expansion and controls, as described in the notes to Table 2. Note that the first row of Table 3 reports the same regression as the first column of Table 2. Controls also include employment growth 1992–1999 and employment share 1992 for the specified sector, in the industry-sector regressions.

TABLE 4

Employment growth and broadband: heterogeneous effects

Dependent variable: employment growth (NETS); OLS

	(1) 1999–2006	(2) 1999–2006	(3) 1992–1999
Broadband provider change, 1999–2006	0.0576***	0.0588***	
	(0.0116)	(0.0226)	
Broadband provider change, 1992–1999	0.00740	0.00106	0.0416***
	(0.01000)	(0.0162)	(0.0109)
Broadband provider change (1999–2006 for cols. 1 & 2) interacted with:			
Share bachelor degree (county)	0.103	0.161	0.326***
	(0.132)	(0.226)	(0.116)
Log population density (ZCTA)	-0.0314***	-0.0364***	-0.0105**
	(0.0101)	(0.0104)	(0.00490)
Median HH income (ZCTA)	0.0352	0.0636	0.00324
	(0.0291)	(0.0449)	(0.0244)
Log population (MSA or county)	0.0193*	0.0242*	-0.0262***
	(0.0114)	(0.0132)	(0.00589)
Climate desirability index	0.00514	0.00409	-0.000404
	(0.00341)	(0.00535)	(0.00312)
Share vacation homes (county)	0.0279	-0.0573	-0.366***
	(0.0964)	(0.101)	(0.122)
ZCTAs included	All	0 or 1–3 Providers in 1999	All
Observations	26721	23760	26717
R-squared	0.258	0.273	0.163

NOTES: Each column represents a separate regression. Main effect of broadband, plus interactions, shown in table. Main effects of the interaction variables are not shown but included in all models, as well as controls for road density, predicted employment growth, competition, and diversity, as described in the text. Employment growth 1992–1999 included as a control for regression with 1999–2006 employment as dependent variable. Interactions are reported at the means of the control variables. Education, density, income, and population measured in 2000 for 1999–2006 regressions and in 1990 for 1992–1999 regressions. All regressions report robust standard errors clustered on county. *=10% level sig.; **=5% level sig.; ***=1% level sig.

TABLE 5
Broadband providers and ZCTA characteristics (first stage for 2SLS)

Dependent variable: change in broadband provider count; OLS

	(1) 1992–2006	(2) 1999–2006	(3) 1999–2006	(4) 1999–2006	(5) 1999–2006	(6) 1992–1999	(7) 1992–1999
Slope (ZCTA)	-0.00398***	-0.00434***	-0.0114***	-0.00961***	-0.0119***	0.000212	0.00447***
	(0.00114)	(0.00162)	(0.000850)	(0.000955)	(0.000908)	(0.00127)	(0.000927)
Road density (ZCTA)	9.416***	5.539**	3.576	-6.613**	-5.615*	22.07***	15.14***
	(1.582)	(2.449)	(2.869)	(2.947)	(2.929)	(2.810)	(2.339)
Percent bachelor's degree (county)	0.629***	0.683***	0.514***	0.255**	0.211**	0.946***	0.524***
	(0.126)	(0.160)	(0.105)	(0.106)	(0.0945)	(0.169)	(0.114)
Log population density (ZCTA)	0.00311	0.0118	0.0278***	0.0312***	0.0200***	-0.00145	0.0554***
	(0.00532)	(0.00756)	(0.00493)	(0.00621)	(0.00543)	(0.00786)	(0.00555)
Log median HH income (ZCTA)	0.0759***	-0.0155	0.0196	0.0245	0.0855***	0.233***	0.192***
	(0.0159)	(0.0205)	(0.0158)	(0.0217)	(0.0202)	(0.0248)	(0.0192)
Log population (MSA/county)	-0.00915*	-0.0144**	-0.00335	-0.00860	0.000538	0.0350***	0.0107**
	(0.00532)	(0.00692)	(0.00489)	(0.00560)	(0.00478)	(0.00793)	(0.00462)
Broadband change (1992–1999)		-0.264***	-0.301***	-0.236***	-0.277***		
		(0.0249)	(0.0104)	(0.00979)	(0.00867)		
Employment growth (1992–1999)		0.146***	0.0812***	0.113***	0.0882***		
		(0.0305)	(0.0102)	(0.0138)	(0.0118)		
Weighted by employment?	Yes	Yes	No	Yes	No	Yes	No
ZCTAs included	All	All	All	Employment 200–7000	Employment 200–7000	All	All
Observations	26717	26721	26721	15210	15210	26717	26717
R-squared	0.479	0.268	0.445	0.239	0.279	0.527	0.503
F-test of slope=0	12.09	7.12	178.42	101.29	172.91	0.03	23.24
p-value for F-test of slope=0	0.0005	0.0076	0	0	0	0.86	0

NOTES: Each column represents a separate regression. Slope and road density from 2003 ESRI shape files. Percent bachelor's degree, population density, household income, and metropolitan/county population measured in 2000 for 1999–2006 regressions and in 1990 for 1992–1999 regressions. Additional controls included in all columns: predicted employment growth for the time period covered by the dependent variable, climate, vacation home share, competition, and diversity, all as described in the text. All regressions report robust standard errors clustered on county. *=10% level sig.; **=5% level sig.; ***=1% level sig.

TABLE 6
Employment growth and broadband, 1999–2006, second stage

Dependent variable: employment growth (NETS); 2SLS

	(1) Employment, 1999–2006	(2) Employment, 1999–2006	(3) Employment, 1999–2006	(4) Employment, 1999–2006
BB provider change, 1999–2006	0.636***	0.00925	0.325***	0.127***
	(0.238)	(0.0447)	(0.0649)	(0.0485)
BB provider change, 1992–1999	0.162**	0.00797	0.0835***	0.0515***
	(0.0692)	(0.0147)	(0.0183)	(0.0152)
Weighted by employment?	Yes	No	Yes	No
ZCTAs included	All	All	Employment 200–7000	Employment 200–7000
Observations	26721	26721	15210	15210
R-squared		0.150	0.130	0.165
BB provider change, 1999–2006 (OLS)	0.0636***	0.0566***	0.0823***	0.0654***
	(0.0119)	(0.00645)	(0.0103)	(0.00762)

NOTES: Each column represents a separate regression. Note that the OLS result in column 1 repeats the regression result from the first column of Table 2; the OLS results for other columns are not reported in other tables. All columns include controls: predicted employment growth for the time period covered by the dependent variable, road density, percent bachelor's degree, population density, household income, and metropolitan/county population, climate, vacation home share, competition, diversity, and employment change 1992–1999, all as described in the text. All regressions report robust standard errors clustered on county. *=10% level sig.; **=5% level sig.; ***=1% level sig.

TABLE 7
Broadband and household labor market outcomes

Dependent variable is change in: (all results OLS)	**(1)** **1999–2006**	**(2)** **1999–2006, county broadband provider count <=2**	**(3)** **1992–1999**
Employment (NETS)	0.0534***	0.0288**	0.0367**
	(0.0111)	(0.0121)	(0.0160)
Employed residents (Census)	0.0422***	0.0171	0.0654***
	(0.0131)	(0.0135)	(0.0121)
Population	0.0166**	0.0130**	0.0376***
	(0.00742)	(0.00542)	(0.00948)
Working-age population	0.0247***	0.0182***	0.0446***
	(0.00839)	(0.00628)	(0.0102)
Employment rate (Census)	-0.0118	-0.0143*	0.0199**
(employed residents/working age pop.)	(0.00947)	(0.00754)	(0.00796)
Average pay per employee	0.0110	0.0119	0.0488***
	(0.00846)	(0.00846)	(0.00846)
Median income	-0.0242**	-0.0166***	0.0499***
	(0.00984)	(0.00581)	(0.00954)
N (for all regressions in column)	3086	2772	3086

NOTES: The unit of observation is the COUNTY. Each CELL represents a separate regression. Shown is the coefficient on broadband provider count change for 1999–2006 (columns 1 and 2) or 1992–1999 (column 3). For income and poverty rate, column (3) represents the change 1989–1999. All regressions include controls for county-level road density, education, income, metro area (or county) population, the climate index, vacation home share, and employment shares in each 2-digit NAICS industry. Controls for 1999–2006 regressions include broadband change 1992–1999; controls for all regressions include lagged growth of the dependent variable, with the exception of the regression for NETS employment 1992–1999 since the NETS database begins in 1992. All regressions report robust standard errors. *=10% level sig.; **=5% level sig.; ***=1% level sig.

TABLE 8
Working at home and broadband, 2001–2006

Dependent variable (Forrester data): (all results OLS, respondent-ZCTA fixed effects)	**(1)** Telecommute	**(2)** Bring work home	**(3)** Have home-based business	**(4)** Work for an employer
Independent variable is log broadband providers; regression includes:				
All respondents	-0.000625	0.00451	0.00107	0.0144***
	(0.00157)	(0.00324)	(0.00268)	(0.00346)
Respondents in ZCTAs < 3 broadband providers in 1999	-0.000748	0.00414	0.00168	0.0112***
	(0.00170)	(0.00363)	(0.00312)	(0.00409)
Respondents with a bachelor's degree	0.00107	0.00824	0.000739	0.0103**
	(0.00323)	(0.00671)	(0.00463)	(0.00514)
Respondents in managerial or professional occupations	-0.000304	0.00511	-0.00365	0.00571
	(0.00337)	(0.00723)	(0.00488)	(0.00543)

NOTES: Each CELL represents a separate regression. For the full sample, N=166179; number of groups=68579. All regressions include controls (using saturated dummies) for individual- or household-level age, education, income, assets, household size, age of children, race, ethnicity, and year fixed-effects. All regressions include respondent-ZCTA fixed effects; only respondents participating in multiple years of the survey and reporting the same ZCTA contribution to the estimation. Respondents-ZCTAs that appear in only one annual Forrester survey are dropped from the count of observations and number of groups. Main effects of the interaction variables are differenced out because they are constant across years for each respondent-ZCTA observation.

Appendix: Combining Datasets

Most of the empirical analysis is at the ZCTA level; the individual-level analysis of telecommuting and home-based work activities also relies on ZCTA-level broadband availability. A major challenge of this research, therefore, was to combine data from multiple sources that use ZIP codes and ZCTAs, the Census approximation of ZIP codes.[39]

The NETS reports business addresses with United States Postal Service (USPS) ZIP codes. Forrester reports households' USPS ZIP codes. ZIP codes are a USPS designation intended to facilitate mail delivery, not data gathering and reporting, and they do not follow any of the geographies that the Census Bureau uses for reporting economic and demographic data (Census blocks, Census tracts, counties, etc.). USPS ZIP codes include standard, unique, and P.O. Box ZIP codes. Standard ZIP codes typically cover a neighborhood, region, or other geographic area and include numerous residences, businesses, or both. Unique ZIP codes serve a single institution, such as a large company or public institution, and typically include few or no residences. P.O. Box ZIP codes are often assigned to a post office location. Whereas standard ZIP codes are typically represented by a "polygon" shape (to use the Geographic Information System terminology), unique and P.O. Box ZIP codes are typically represented geographically by a "point" with no land area. Because residential measures like population density or median household income are important explanatory variables in the analysis of ZIP code-level data, unique and P.O. Box ZIP codes pose a problem if they have no residents or land area. USPS ZIP codes also pose a problem for research because they can split, merge, or be renumbered over time, and there is no comprehensive, public listing of ZIP code changes over time.

Because USPS ZIP codes do not correspond to Census blocks, tracts, or other geographic designations, the Census created ZIP code Tabulation Areas (ZCTAs) in 2000, which are groupings of Census blocks that

[39] Two studies discussed above also use FCC provider count data and faced similar challenges of combining ZIP code-level data with data reported at other geographic levels. Gillett et al. (2006) merge datasets based on FCC ZIP codes, USPS ZIP codes, and Census Bureau ZCTAs and analyze those that matched fully; it appears from their Appendix II that they do not include employment data in USPS ZIP codes (reported in ZIP code Business Patterns) that lacked a ZCTA with the same number, as well as unique and P.O. Box ZIP codes, and it is unclear how they handle employment changes in USPS ZIP codes that changed over time. Stenberg et al. (2009) aggregate the FCC ZIP code provider counts to the county level and match them to other data sources using counties.

approximate USPS ZIP codes. Most USPS unique and P.O. Box ZIP codes do not correspond to a Census ZCTA; most USPS standard ZIP codes do. The Census reports data for ZCTAs but not for USPS ZIP codes.

FCC Form 477 data report broadband provider count data for a proprietary ZIP code approximation that is based on USPS ZIP codes: the "TANA Inc./GDT Inc. Dynamap/ZIP code Boundary and Inventory Files," produced by TeleAtlas, a mapping company, for use with GIS software. These ZIP codes are not identical to either USPS ZIP codes or Census ZCTAs.

Research requires using a single geographic definition that is consistent over time and common to all data sources, in order to look at the same geographic area. It is therefore necessary to create a correspondence between (1) all USPS ZIP codes that appear in the NETS or Forrester data during the years 1992–2006, (2) all ZIP code designations that appear in the FCC data during the years 1999–2006, and (3) Census 2000 ZCTAs. Because ZCTAs do not change over time and because they all cover a geographic area, we use ZCTAs as our common geography and use the following steps described below to convert USPS ZIP codes, which are reported in NETS and Forrester data, and FCC ZIP codes over all years, to 2000 ZCTAs.

First, we use the NETS to identify all ZIP code changes and create a consistent ZIP code list over the time period 1992–2006. Without accounting for ZIP code redefinitions, employment changes will be incorrectly measured. For instance, if ZIP code A is split into two equally sized new ZIP codes, half of which is still called A and half is named B, then one must not misinterpret this as the movement of jobs from a declining neighborhood to a new, booming neighborhood. Fortunately the NETS allows an easy method for tracking ZIP code re-numberings, merges, and splits. Because the database is longitudinal, we can observe whether an individual establishment's ZIP code changes over time. A change in ZIP code could either reflect an establishment actually moving to a location with a different ZIP code or it could reflect the establishment remaining at an address where the ZIP code changed.[40] Using the NETS, we look at all establishments that existed over the

[40] Looking at street address changes could distinguish between actual moves and ZIP code changes, but matching millions of string variables (street addresses) is computationally demanding, and there are many misspellings and alternative spellings of street addresses in the database.

entire period of 1992–2006 and identify ZIP code changes based on whether (1) the plurality of establishments in a 1992 ZIP code reported a different ZIP code in 2006, or (2) the plurality of establishments in a 2006 ZIP code reported a different ZIP code in 1992. With this set of changes, we group together ZIP codes that appear to have been re-numbered, split, or merged over this time period. Of all ZIP codes for which the NETS reports some employment in 1992 or 2006, 7 percent of the ZIP codes are assigned to a ZIP code group of two or more ZIP codes. For instance, among establishments existing in 1992 and 2006, the vast majority of establishments with a ZIP code of 02146 in 1992 (Brookline, MA, just west of Boston) had ZIP codes of 02445 or 02446 in 2006. And the vast majority of establishments in ZIP codes 02445 and 02446 in 2006 were in ZIP code 02146 in 1992. A closer look at the NETS shows a sharp drop in establishments and employment between 1997 and 1998 in ZIP code 02146 and a correspondingly sharp rise in establishments and employment in ZIP codes 02445 and 02446 at the same time. Our algorithm groups ZIP codes 02146, 02445, and 02446 together in the same ZIP code group, and this ZIP code group is a much closer approximation to the same geographic area over time than any one of those ZIP codes individually. In this manner, we construct a set of consistent ZIP codes and ZIP-code groupings for the time period.

Second, we create a correspondence between USPS ZIP codes and Census ZCTAs using ESRI maps in ArcGIS. To do this, we overlay ZIP code and ZCTA maps using GIS software. We do this first for standard polygon ZIP codes and then for point P.O. Box and unique ZIP codes. For standard ZIP codes, we have ESRI polygon ZIP code maps for 1999–2006, except 2001, and a polygon map of 2000 ZCTAs. For each year, we combine that year's ZIP code map with the ZCTA map to determine, for each ZIP code, how much of its area is in which ZCTAs. We then use Census 2000 block group population data to weight these areas and determine, for each ZIP code, how much of its population is in which ZCTAs. We then combine this information across ZIP code groups – created using the NETS in the previous step – and across years to match each ZIP code group to a best match ZCTA. Each ZIP code group can only match to one ZCTA, though many ZIP code groups can match to the same ZCTA. For point ZIP codes, the method is very similar. We have ESRI point ZIP code maps for 1999–2006, excluding 2001, and the polygon ZCTA map. For each year, we again combine that year's ZIP code map with the ZCTA map; but since the ZIP codes are points, there is no need to calculate shares of ZIP codes in different ZCTAs; all of the ZIP code is necessarily in a single ZCTA. We then determine best matches as with polygon ZIP codes. Having matched ZIP code groups to best match ZCTAs separately for polygon and point ZIP code groups, we combine the results into a single ZIP code-ZCTA best match correspondence. With this method, 97–99 percent of ZIP codes in the NETS, depending on the year, are matched to ZCTAs; these successful ZIP code matches account for more than 99.99 percent of employment in every year. Our ZIP code-ZCTA correspondence also cover more than 99.5 percent of the ZIP codes that appear in any year in the FCC Form 477 data.

Third, we use several methods to assign the few still-unmatched ZIP codes from the NETS and FCC to ZCTAs. For ZIP codes that appear in the NETS, we have the street address, city, and state for most businesses in those ZIP codes, and we geocode those establishments using both ESRI's ArcGIS software and the Google Maps geocoding service. Overlaying the geocoded establishment points with the ZCTA polygon map allows us to assign some of the hitherto unmatched ZIP codes to the ZCTA with the greatest share of establishments in a ZIP code or a ZIP code group (from the first step). For ZIP codes that remain unmatched to a ZCTA, we check the place name associated with businesses in those ZIP codes; ZIP codes for which all place names correspond to the same ZCTA (according to the Mable/Geocorr engine) are matched that way. After all these steps, only a handful of ZIP codes remain unmatched, and we assign these last few ZIP codes to ZCTAs manually by looking up street names and places in ArcGIS and identifying the nearest ZCTA.[41] With these final matches, we arrive at a correspondence between ZIP codes and ZCTAs that allows us to assign nearly every ZIP code appearing in the NETS or the FCC data to a Census 2000 ZCTA.[42]

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[41] We use this manual process for all unmatched ZIP codes in the NETS with at least five establishments in any one year. We ignore ZIP codes that are unmatched by our algorithm and that have fewer than five establishments in every year because some of these ZIP codes may be data entry errors in the NETS and because the manual matching process is time-consuming. These ZIP codes account collectively for at most 2,000 employees in any one year out of total national employment of well over 100 million.

[42] See Census documentation on the relationship between ZCTAs and ZIP codes at www.census.gov/geo/ZCTA/zcta.html. Also, Gillett et al. (2006) offer a detailed explanation of reconciling the FCC and Census ZIP code definitions.