Broadband Provision and Knowledge-Intensive Firms: A Causal Relationship?

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Broadband provision and knowledge intensive firms: a causal relationship?

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Abstract

Despite the discussions about the importance of the digital economy, we are still far from understanding how Information and Communication Technologies (ICTs) affect economic activity in space. Recent studies have started untangling the spatial economic impact of ICTs, highlighting the potential use of ICTs as a local development tool. This paper contributes to this domain by exploring whether broadband Internet provision can act as an attractor for knowledge intensive business services in the US. Using Granger causality tests, this paper addresses the simultaneity issue between broadband Internet demand and supply at the very detailed spatial level of the US counties.

Keywords: internet, broadband, knowledge intensive business services, Granger causality

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1. Introduction

Despite the intensive discussions about the importance of the digital economy, we are still far from being able to understand if and how Information and Communication Technologies (ICTs) affect economic activity in space. This can be partially justified by the 'black box' nature of ICTs. Indeed, ICTs, the supporting layer of the digital economy, consist of various layers, the technicality of which makes it difficult to comprehend their structure and, moreover, the spatial economic impact that they might generate. These layers are important to deconstruct however, given the general-purpose technology (GPT) status of ICTs, which means that they provide opportunities for downstream complementarities and new business opportunities (BRESNAHAN and TRATJENBERG, 1995).

The impact of ICTs on physical activity presumes a ubiquitous distribution of the requisite infrastructure. However, studies suggest that the decentralization opportunities for firms provided by broadband are hindered by the well-noted uneven distribution of Internet infrastructure (MOSS and TOWNSEND, 2000; GRUBESIC and MURRAY, 2004; TRANOS and GILLESPIE, 2009; TRANOS, 2011). From a regional perspective, there is also widespread discussion regarding the developmental role of broadband Internet infrastructure. Given the fact that ICTs not only perform a GPT role and affect productivity, but they are also unequally distributed across space, recent studies have questioned the regional development impacts of the Internet's hardware. Kolko (2012) identified a positive relationship between broadband expansion and employment growth in the US. At a different scale, Tranos (2012) indicated an almost north-south divide in Europe, regarding city-regions' abilities in utilizing Internet infrastructure. In more detail, northern city-regions, which are characterized by knowledge intensive economies, are more capable of leveraging digital infrastructure. A similar study focusing on China (SHIU and LAM, 2008) identified a causal relationship running from teledensity to economic development only for the affluent eastern regions, concluding that ICTs alone are not sufficient for economic development.

An underexplored aspect of the determinants of broadband access is how businesses factor into the equation. This is particularly important to address if we are to unpack the impact of broadband and other ICTs on regional economic growth. Most of the work on broadband to date has focused on the demand of residential consumers (NORRIS, 2001; GABEL and KWAN, 2001; GRUBESIC, 2004; HU and PRIEGER, 2007) rather than business demand for services. Businesses are perhaps overlooked because of their ability to lease private fiber high-speed lines (HANSEN, 2005). However, there is evidence to suggest that small businesses rely on the quality of existing infrastructure and do not lease private lines (CENTER FOR AN URBAN FUTURE, 2004).

Given the comparatively underexplored link of the relationship between broadband and businesses, from both the supply and demand perspectives, the goal of this paper is to evaluate the relationship between broadband Internet provision and knowledge intensive business presence across the United States counties. Therefore, Granger causality tests in a panel framework are employed, the results of which highlight the spatially heterogeneous causal relation between knowledge intensive business presence and broadband provision. Moreover, further light is shed on the spatiality of these patterns with the use of an auxiliary multinomial logit model.

The paper is organized as follows. Section 2 discusses the location decisions of producer services and knowledge intensive businesses and Section 3 the impact of ICTs on these location decisions. Section 4 presents the data and Section 5 the methodology we employ for this paper. Section 6 presents the results and the paper ends with a discussion and conclusions section.

2. The Location of Producer Services and Knowledge Intensive Business Services (KIBS)

This study examines the linkages between broadband provision and KIBS because of their likely intensive use of information technology, which has been well noted in the producer services literature (COFFEY, 1989; GOE ET AL., 2000; MULLER and DOLOREUX, 2009). These businesses are also of particular interest because they deal with intangible knowledge and knowledge-based products (HARRIS, 2001), rather than tangible assets like their manufacturing counterparts. Because of this production and trade in informational products, it is anticipated that these firms may be comparatively more footloose than firms dealing with tangible products.

The evolution of the global economy from a manufacturing orientation to a services and informational orientation, particularly in industrialized countries (COFFEY and BAILLY, 1991), prompted widespread interest about the production processes and location decisions of these firms. Studies present somewhat contradictory evidence however regarding the comparative decentralization tendencies of these firms. Several studies note a decentralization trend away from central locations in large metropolitan areas towards smaller metropolitan areas (KIRN, 1987; ÓHUALLACHÁIN and REID, 1991; GONG, 2001). Kirn (1987) calls this movement to smaller locales, down-filtering of producer services and suggests that policies focused on these services are likely to benefit small metropolitan areas as well as non-metropolitan areas. Coffey and Shearmur (1997) note however that in a Canadian context, producer services are biased towards large urban areas because of their need for a highly educated labor force and because of the presence of backward and forward linkages which help these firms obtain the necessary inputs and sell their outputs to nearby businesses.

Additional producer services work suggests several explanations for these apparently contradictory location trends. Some studies suggest that the trend towards centralization or decentralization may be temporally specific (POLÉSE and SHEARMUR, 2006; SHEARMUR and DOLOREUX, 2008) and related to technological trends and industrial mix (SHEARMUR and ALVERGNE, 2002; POLÉSE and SHEARMUR, 2006). For example, within sub-sectors of producer services Shearmur and Alvergne (2002) find patterns of both dispersal and concentration that are likely related to each sub-sector's market orientation, internal structure, and technical orientation.

In the context of this paper, prior studies that emphasize the location of producer services in more remote locations are particularly important. Beyers and Lindahl (1996) suggest for example, that high quality of life which is related with non-central locations might attract KIBS. Wernerheim and Sharpe (2003) assert that producer services industries are not as footloose as policymakers have anticipated because they locate in places where their services are complementary to the existing industrial composition. They also suggest that these compositional needs are unlikely to make producer services responsive to public policies designed to promote migration to more peripheral regions (WERNERHEIM and SHARPE, 2003).

3. Information and Communications Technologies (ICTs) and KIBS

The Internet is widely recognized as a GPT (BRESNAHAN and TRAJTENBERG, 1995; HARRIS, 1998; ATKINSON and MCKAY, 2007). This means there are numerous opportunities for downstream "innovational complementarities" and economic growth (BRESNAHAN and TRAJTENBERG, 1995). Due to this perceived importance, an extensive amount of effort has been dedicated to unpacking the impact of ICTs on economic growth (CRONIN ET AL., 1993; CZERNICH ET AL., 2011; KOUTROUMPIS, 2009; HOLT and JAMISON, 2009; GREENSTEIN and MCDEVITT, 2011) and productivity (JORGENSON and STIROH, 2000; JALAVA and POHJOLA, 2002; MARTINEZ, RODRIGUEZ, and TORRES, 2010). Early work evaluating the impact of telecommunications on economic growth finds a bi-directional, causal relationship between telecommunications investment and economic activity (CRONIN ET AL., 1993). More recent work on broadband specifically also finds a positive link between broadband and economic growth (KOUTROUMPIS, 2009; HOLT and JAMISON, 2009). There is likely a lagged effect to these impacts however because businesses require time to experiment with applications and reorganize operations (Holt and Jamison, 2009). While valuable, these studies do not evaluate whether noted spatial disparities in broadband availability may impact business presence, which is a critical ingredient to economic growth.

Some studies have begun to evaluate the linkages between firms and ICTs. These studies have found that the central city bias of the relevant infrastructure may restrict locating outside of core, central city areas (SOHN ET AL., 2003; MACK and GRUBESIC, 2009). They also find that the strength of the linkages between ICTs and KIBS varies across metropolitan areas (MACK ET AL., 2011; MACK and REY, 2014) and industries (KANDILOV and RENKOW, 2010). Prior evaluations of industrial variations in dial-up adoption rates have found that industries such as Information (NAICS[1] 51), Professional Scientific and Technical Services (NAICS 54), Finance and Insurance (NAICS 52), and Management of Companies and Enterprises (NAICS 55) had the highest adoption rates amongst other industries for both basic and advanced uses (FORMAN ET AL., 2003). To date however, no causal link between ICTs and firms has been established.

4. Data

This study examines the causal nature, or lack thereof, between broadband and KIBS for the 1999-2004 period. Although more recent broadband data have become available from the National Telecommunications and Information Administration (NTIA) through the National Broadband Mapping Project, these data correspond to a time when broadband is more widespread than previously. The goal of this particular piece is to examine the causal nature of this relationship in the initial years of broadband availability when access to this novel infrastructure was perhaps a defining feature of the regional business climate. While this paper focuses on historical impacts, prior research highlights that past diffusion trends of older telecommunications infrastructure are indicative of diffusion trends in more recent advancements in telecommunications such as the Internet (Perkins and Neumayer, 2011). Thus, examining the initial impacts of broadband infrastructure on KIBS is likely important for understanding the impacts of next generation Internet technologies on KIBS.

4.1 Broadband Data

Broadband data were obtained from the Federal Communications Commission (FCC) Form 477 database. This database is the only publicly available source of broadband data for the study period of interest. It contains information obtained from private companies that provide service over at least 250 broadband lines (FCC, 2014). Data from individual providers are aggregated to the ZIP code area level and made available to analysts and policymakers through

[1] NAICS stands for North American Industrial Classification System.

the FCC's Wireline Competition Bureau website (FCC, 2014). These ZIP code area data contain the raw count of the number of providers for all ZIP code areas across the United States[2].These data were aggregated to the county level. While these counts do not speak to the number of unique companies that provide broadband service in a particular county, counts are important in the context of broadband markets, because it is assumed that markets with more providers are more competitive (KOLKO, 2012). Instead of focusing on the levels, the growth rate of the number of broadband providers is utilized in this paper to better capture the causal nature of the relationship between broadband provision and KIBS. Table A1 in the Appendix provides the descriptive statistics of all the data used here including the growth rates of broadband providers and Figure A1 maps these data.

4.2 Establishment Data

Business data obtained for this study are actually establishment counts reported for U.S counties. These data were obtained from County Business Patterns of the U.S. Census Bureau. Establishments are different from firms, businesses, or companies although these terms are often used interchangeably (BLS, 2014). An establishment is actually one location at which business takes place (U.S. CENSUS BUREAU, 2014). Thus, establishments differ from firms, which may be comprised of multiple establishments (U.S. CENSUS BUREAU, 2014; BLS, 2014).

To obtain the count of the number of knowledge intensive establishments in each county, data from several industries were collected. These industries include the following two-digit North American Industrial Classification Systems (NAICS) industries: Information (51), Finance and Insurance (52), Professional Scientific and Technical Services (54), Management of Companies and Enterprises (55), and Educational Services (61). This definition is taken from prior work evaluating the relationship between broadband provision and knowledge intensive establishment presence (MACK ET AL., 2011; MACK, 2014). A defining characteristic of KIBS in the context of this study and other studies (MACK, 2014) is that knowledge is a key primary input and the primary output of these sectors. The growth rates of KIBS are used for this paper and the descriptive statistics are presented in Table A1 in the appendix. Figure A2 in the Appendix provides the relevant maps.

5. Methodology

The main methodological tool employed for this paper is the Granger causality test. This test will enable us to address the research question regarding the direction of causality between broadband provision and knowledge intensive firms. Granger causality tests are based on a bivariate model such as model (1) where the dependent variable y is regressed against k lagged values of y and k lagged values of x. Using such a model, the null hypothesis can be tested according to which x does not cause y. If the test proves to be significant then the null hypothesis can be rejected, and it can be concluded that x Granger-causes y (HOOD III et al., 2008). The latter signifies that y is better predicted if all the information (i.e. both the lagged values of y and x) is included in the model than if the lagged values of x are excluded (HURLIN and VENET, 2003). In order to evaluate both directions of causality between broadband provision and

[2] For these data information about provision in ZIP code areas with fewer than three providers is suppressed. To address the suppression issue in these data, ZIP code areas with fewer than three providers are conservatively assumed to have one provider in that ZIP code per the precedent set by prior studies (GRUBESIC and MURRAY 2002, 2004). Previous work has shown this assumption has no impact on econometric studies (MACK and GRUBESIC, 2009).

knowledge intensive firms, this model is run twice, interchanging the dependent with the independent variable. As mentioned above, both for broadband provision and KIBS establishments, instead of using the levels variable, the focus here is on the growth rates. The latter is equivalent to the natural log of the levels variable minus the natural log of the lagged levels variable[3]. This approach enables us to eliminate possible unit roots and to reach time stationarity.

$$y_{i,t} = \sum_{k=1}^{\rho} \gamma^{(k)} y_{i,t-k} + \sum_{k=1}^{\rho} \beta_i^{(k)} x_{i,t-k} + \mu a_i + \varepsilon_{i,t} \qquad (1)$$

For each cross-sectional unit *i*, and for all *t* [1,T], the regressors are lagged values of the dependent variable ($y_{i,t-k}$) and lagged values of the independent variable ($x_{i,t-k}$). α_i represents the fixed effects, $\varepsilon_{i,t}$ the error term, *k* the lags, and ρ the number of lags (HOOD III et al., 2008). In order to maintain sufficient degrees of freedom, it is assumed that γ^k are constant and β_i^k identical for all $k \in [1, \rho]$. While the former assumption prevents variation in the autoregressive coefficient among cross-section units from time period to time period, the latter only prevents variation in the regression coefficients from time period to time period to address spatial heterogeneity (HOOD III et al., 2008; HURLIN and VENET, 2003).

Granger causality tests were initially introduced for time series (GRANGER, 1969). However, recent advances enable their application to panel models (HOFFMANN et al., 2005). Hood III et al. (2008) suggest that Granger causality tests work better with panel data because: (a) panel data increases flexibility in modelling the cross-section units in comparison to time-series analysis individually for each cross-section; (b) panel data increases the number of observations and consequently the degrees of freedom in comparison to time-series data; (c) lastly and also because of (a) and (b) above, Granger causality tests are more efficient with panel data (HURLIN and VENET, 2003).

An important distinction in the literature with regard to the different Granger causality applications for panel data is based on the treatment of the autoregressive and slope coefficients as equal for all the cross-section units. Hurlin and Venet (2003) addressed the heterogeneity of the casual relations between the different cross-section units by not having such a restriction, and by testing the causality direction for each cross-section unit. Applications of this method include, among others, the work of Hood III et al. (2008), Tervo (2009), Mukkala and Tervo (2013) and Tranos (2012). Others (SHIU and LAM, 2008; HARTWIG, 2010) assumed the equality of the coefficients across the different-cross section units, and addressed the heterogeneity issue indirectly by splitting the panel into smaller and theoretically homogeneous panels.

This method tests for three potential causal scenarios (HOOD III et al., 2008):

1. A homogeneous causal relationship running from *x* to *y* for every cross-section unit;
2. No causal relationship running from *x* to *y* for any cross-section unit;
3. A causal relationship running from *x* to *y* only for a subset of cross-sectional units. Hurlin and Venet (2003) further distinguish two possible sub-cases: (a) different types of causal

[3] For instance, if $y_{i,t}$ in equation (1) is the growth rate and $\dot{y}_{i,t}$ is the levels variable of either broadband provision or KIBS establishments then $y_{i,t} = ln\dot{y}_{i,t} - ln\dot{y}_{i,t-1}$. Similarly, if $x_{i,t}$ is the growth rate and $\dot{x}_{i,t}$ is the levels variable of either KIBS establishments or broadband provision then $x_{i,t} = ln\dot{x}_{i,t} - ln\dot{x}_{i,t-1}$.

relationships across cross-sections; and (b) no evidence of any causal relationship for at least one cross-section unit.

Figure 1 illustrates the different steps of this method. As it will be analyzed in detail in the next section, each step is based on the validation or rejection of the different hypotheses using a relevant Wald statistic.

The results of the Granger causality tests are fed into a multinomial logit model in order to better explain the resulting causality spatial patterns. Simply put, the results of the Granger causality tests will be used to create a categorical variable reflecting whether there is a causal relationship between the rate of broadband provision and the rate of knowledge intensive businesses for each US county. This variable will reflect the four possible outcomes of the third step of the Granger causality test: (i) a causal relationship running from broadband provision rate to KIBS establishment rate; (ii) a causal relationship running from KIBS rate to broadband provision rate*;* (iii) a bidirectional causal relationship; and (iv) no significant causal relationship. Then, this variable will be regressed against socio-economic and geographical characteristics of the US counties in order to better understand the nature of places for which causal relationships exist. More details for both of these steps are presented in the next section.

Insert Figure 1

6. Results

6.1 Broadband provision and KIBS: Granger causality tests

Granger causality tests are introduced in this section in order to empirically test the nature of the relationship between broadband provision and KIBS establishments. Following the methodology in the previous section, the first step is to test whether a homogenous causal relationship exists between *x* and *y* for all cross-section units.

In order to evaluate the first scenario (a homogeneous causal relationship between *x* and *y* for all cross-section units), the following hypothesis is tested:

H_1: For all *i*, *x* does not cause *y* (HOOD III et al., 2008).

To test this hypothesis, the following Wald test is used:

$$F_1 = \frac{(RSS_2 - RSS_1)/N\rho}{RSS_1/[NT - N(1+\rho) - \rho]} \quad \text{(HURLIN and VENET, 2003)} \qquad (2)$$

This Wald test inspects if the inclusion of the lagged independent variable increases the explanatory power of model (1) in predicting the dependent variable. To do so, the model described in (1) is run twice: the first time, no restrictions are introduced; the second time a restriction referring to the nullity of the regression coefficients for all the lags is introduced. Such a restriction makes the prediction of the dependent variable reliant only on the fixed effects, and on the lagged version of the left hand-side variable (HOOD III et al., 2008). The sum of the squared residuals for the unrestricted (RSS_1) and the restricted model are calculated (RSS_2), and the F_1 test is calculated using (2). For its significance, the *F* distribution is used, with $N\rho$ and $NT - N(1+\rho) - \rho$ degrees of freedom for the nominator and the denominator (TRANOS 2012).

This hypothesis is tested in both directions, i.e. whether the one-year lag of the rate of broadband provision Granger-causes changes in the rate of knowledge intensive firms, and vice versa. A one year time lag is used ($\rho=1$ and $k=1$) due to the dynamic landscape of broadband provision from year to year, particularly in locales that have benefitted from spillover effects to provision in more central locations (GRUBESIC, 2006), and also the limited temporal dimension of the panel (6 years). According to the results of these tests[4], hypothesis H_1 is rejected. This means that the presence of the independent variable in both models increases the explanatory value of the models in predicting the left hand-side variable, and, that for the one-year lag period there is a bidirectional causal relationship between the two variables.

Following the diagram in Figure 1, the next step is to examine the nature of these causal relationships. As discussed before, the F_1 test cannot determine whether these relationships exist for a subset of the US counties or for all cross-sectional units. To study this scenario, a second hypothesis is tested:

H_2: *x* causes *y* for all *i* (HOOD III et al., 2008).

This hypothesis is tested using the following *F* test:

$$F_2 = \frac{(RSS_3 - RSS_1)/\rho(N-1)}{RSS_1/[NT - N(1+\rho) - \rho]} \text{ (HURLIN and VENET, 2003)} \qquad (3)$$

Again RSS_1 refers to the sum of the square residuals of the unrestricted model, while RSS_3 refers to the sum of the square residuals of a new restricted model based on (1). The new restriction introduced in this step is the equity of the regression coefficients for each cross-sectional unit (HOOD III et al., 2008). Such a restriction allows the assessment of the homogeneous nature of the causal relationship. As before, the F_2 test's significance is based on the *F* distribution with $N\rho$ and $NT - N(1+\rho) - \rho$ degrees of freedom. The F_2 test for the causal relationship from the one-year lagged rate of broadband providers to the rate of BIBS establishments is 1.553, and 1.338 for the reverse relationship; both of these test statistics are significant at $p<0.01$. This outcome leads to the rejection of the H_2 hypothesis and translates to a bi-directional and non-homogeneous causal relation across the cross-section units. In other words, a causal relationship might only exist for a subset of the 2993 US counties.

In order to investigate for which US counties these causal relationships are true, a third hypothesis is tested:

H_3: For *i*, *x* does not cause *y* (HOOD III et al., 2008).

$$F_3 = \frac{(RSS_{2,i} - RSS_1)/\rho(N-1)}{RSS_1/[NT - N(1+\rho) - \rho]}, \text{ (HURLIN and VENET, 2003)} \qquad (4)$$

To calculate the F_3 test, model (1) is estimated 5986 times separately, once for each of the 2993 cross-section units, and for relationships in both directions. Then, the significance of these 5986 F_3 tests is examined, and the presence and the direction of a causal relationship for each

[4] The F_1 test for the impact of broadband on KIBS is 1.556 and the test for the reverse direction is 1.351. Both of the tests are significant at $p < 0.01$.

cross-section unit is discussed[5]. The series of models estimated consist of the left hand-side variable (e.g. KIBS establishment rate), a one-year time lag for this variable, fixed effects for each cross-sectional unit, and interaction terms between the primary independent variable of interest (e.g. broadband rate) and the fixed effects for each cross-sectional unit. The restriction here has to do with the exclusion of the interaction term for one cross-sectional unit at a time only to evaluate if the relationship of interest is statistically significant for a particular county. In other words, the restriction introduced here is the nullity of the coefficient of the interacted explanatory variable for each cross-sectional unit (i.e. $\beta_i^{(k)} = 0$).

Figure 2[6] presents the results of the three Granger causality tests. It presents four categories of counties: counties where the growth rate of broadband provision Granger-causes changes in the growth rate of knowledge intensive firms, counties where the growth rate of KIBS Granger-causes changes in the growth rate of broadband provision, counties where the direction of causality runs in both direction, and finally, counties for which the relation between the two variables is not significant. This figure highlights that the counties where the supply of broadband is an enabling factor that attracts KIBS are prominent in the center of the country and in more remote counties in states such as Colorado, Texas, Wyoming, and Montana. The concentration of counties with such linkage is highest however in Nebraska, Kansas, New Hampshire, and Massachusetts. This relationship in New Hampshire and Massachusetts likely reflects the intensity of KIBS activity in both of these states. The Route 128 area of Boston is well-known for its technical orientation (SAXENIAN, 1994). New Hampshire is also home to several technical companies such as the IT services firm WEI.com which was founded in 1989 (INC, 2014). Interestingly, both Nebraska and Kansas have a history of federal investments in Internet development efforts. Both were members of MIDnet and the Great Plains Network (GPN).

MIDnet was funded by the National Science Foundation (NSF) and was the first fully operational regional Internet network (REICHENBACH and FINKELSON, 2011). The hub for MIDnet was located at the University of Nebraska-Lincoln (REICHENBACH and FINKELSON, 2011). In addition to this government investment in Nebraska, several private companies have also been noted to contribute to infrastructure development in the state. For example, Metropolitan Fiber Systems (MFS) Communications, located in Omaha, Nebraska, was instrumental to commercial network access by constructing several network access points in the state (REICHENBACH and FINKELSON, 2011). Omaha is a well-recognized financial services and insurance headquarters and is home to globally renowned companies such as Berkshire, Hathaway, Mutual of Omaha, and Ameritrade. Ameritrade is particularly notable because it is recognized for helping to popularize online stock trading (REICHENBACH and FINKELSON, 2011).

In Kansas, the Kansas Research and Education Network (KanREN), which was originally founded in 1991 to provide the institutions of higher education in the state with Internet access, invested heavily in Internet2 technology (KANSAS RESEARCH AND EDUCATION, 2012). KANREN received NSF funds in 1993 to fund this network (NIEBAUM, 2013). Kansas was

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[5] The computational intensity of this exercise should be highlighted here, as each of these 5986 regressions (2993x2) includes 5986 right hand-side variables (the lagged version of the *y* variable – see equation 1, 2993 fixed effects and 2992 interaction terms of the fixed effects with the variable *x*. The estimation of these models was only possible with the use of a super-computing facility.

[6] This figure is available online in color.

also a member state involved in another NSF grant entitled "Great Plains Network for Earth Systems Science" (NIEBAUM, 2013). The goal of this proposal was to connect seven states: North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Arkansas with a high speed Internet network that would enhance and support earth systems science (NIEBAUM, 2013). As a result of these efforts, Kansas University was the first institution to have access to a fully functional Internet2 (I2) connection (KANSAS RESEARCH AND EDUCATION, 2012).

Insert Figure 2

Figure 2 also presents the counties for which a reverse causal relationship exists: these are the counties for which an increase in KIBS results in an increase in broadband provision. In other words, KIBS demand for broadband facilitates the deployment of broadband infrastructure. A breakdown of counties where a change in KIBS Granger-causes change in broadband provision highlights that most of these counties are located in adjacent and non-metro, non-adjacent counties: just over forty percent of these counties are adjacent to metropolitan areas and thirty two percent of these counties are neither metropolitan areas nor adjacent to metropolitan areas. A state-by-state analysis of the counties where KIBS impacts broadband provision reveals that metropolitan counties have a southeast orientation and are located in states such as Texas, Georgia, Tennessee, and Illinois.

A majority of counties in non-metropolitan and non-adjacent counties are located in the Great Plains area of the country in states such as Kansas, Iowa, Nebraska, North Dakota and South Dakota. Several of these states (Iowa, Kansas, Nebraska, and South Dakota) were original recipients of NSF MIDnet funds, which created a regional Internet network in these states (REICHENBACH and FINKELSON, 2011). As discussed above, Kansas and Nebraska have also been the recipients of additional public and private funds over the years. Aside from this prevalent pattern however, there also appears to be a spillover pattern to these counties; counties where this relationship is present have several neighbors. This pattern suggests that the presence of KIBS may stimulate the build out of broadband in neighboring counties. A similar trend to broadband deployment has been noted in prior studies in response to suburbanization trends and associated household demand (GRUBESIC, 2006).

The third relationship illustrated by Figure 2 is the counties for which the direction of the causality works in both directions, broadband causes changes in the growth rate of KIBS and vice versa. This bi-directional relationship highlights that there are likely feedback effects between broadband and KIBS. The figure clearly highlights spatial patterns in these counties with Kansas City and Nebraska accounting for the bulk of these places. Other states where this relationship is present include California, Texas, Georgia, and Arkansas and New Mexico. Unlike the spatial pattern to counties where KIBS have a causal impact on broadband providers, counties where a bi-directional relationship is present are quite patchy and located in specific areas of the country. Additional analysis of these counties reveals that they are nestled between metropolitan areas, which coincides with the spatial patterns uncovered in Mack (2014).

6.2 Granger causality spatial patterns: an auxiliary explanatory analysis

In order to better understand the spatial patterns of the above results and also to extract some policy recommendations regarding the characteristics of the places for which a causal relationship exists, a multinomial logit model is estimated. This model, which is presented in equation (5), enables us to capture the socio-economic and geographic factors that affect the probability for each distinct direction of causality between the rate of broadband provision and the rate of KIBS exists for a particular county.

$$\Pr(Y_i = j) = \frac{exp^{X_i \beta_j}}{\sum_{j=1}^{m} exp^{X_i \beta_j}} \begin{cases} i = 1, 2, 3, \dots, N \\ j = 1, 2, \dots, J \end{cases} \quad (5)$$

The identification strategy is as follows. Based on the Granger Causality tests presented in the previous section we can identify $J = 4$ distinct cases for the direction of causality between the rate of broadband provision and the rate of KIBS establishments: (i) changes in broadband provision Granger cause changes in KIBS establishments; (ii) changes in KIBS establishments Granger cause changes in broadband provision; (iii) a bidirectional Granger causal relation between changes in broadband provision and changes in KIBS establishments; and (iv) no significant causal relation between changes in broadband provision and changes in KIBS establishments. In addition, X_i is a vector of covariates which will be regressed against the nominal variable which represents the above four different causal relations. The variables included in this vector are described here. ln(*broadband1999)*$_i$ and ln(*kibs1999)*$_i$ denote the natural logarithm of the level of broadband providers and KIBS establishments respectively in 1999 in county *i*. These variables are introduced in order to test potential saturation or early adoption effects. To better capture such effects, two more variables are introduced. *Point of Presence*$_i$ is a dummy variable which takes the value 1 for the counties which hosted a Point of Presence (PoP) in 1997 using data from Grubesic and O'Kelly (2002) and 0 otherwise. PoPs are nodal points in the Internet network topology, where the backbone links are connected with local and regional networks. This variable can help us test the early adoption argument or the possible saturation effect as cities which were facilitated by that infrastructure in the early years of the commercial Internet might have experienced some relevant effects. In order to include potential spillover effects of this initial digital infrastructure, we assigned the value 1 not only to these counties which hosted a PoP in 1997, but also to their surrounding counties. The underlying argument is that the location of a PoP could have also affected the neighboring counties too. In addition, we control here for regulatory effects. Then, the variable *municipal restriction*$_i$ is another dummy variable which takes the value 1 if a county is located in a state that has some sort of restriction on municipal broadband provision (MUNINETWORKS, 2014). Then, the variable ln(*population)*$_i$ denotes the natural logarithm of the population of county *i* in 2000; ln(*population density)*$_i$ represents the natural logarithm of population density, *population 18-24*$_i$ the percentage of population between 18-24 years old in 2000, ln(*skilled occupations)*$_i$ is the natural logarithm of highly skilled occupations in 2000 in county *i*, *bachelor's*$_i$ is percentage of population with a bachelor's degree in 2000 in county *i* and *agriculture*$_i$ is the share of agricultural establishments in 2000. *research universities*$_i$ is another dummy variable which represents the research intensive universities. Just like with the PoP variable, we also assigned the value 1 to the surrounding counties in order to capture potential spillover effects. Finally, we test here for the effect of the census regions and we introduce dummy variables to capture such effects.

Insert Table 1

Table 1 presents the results for model (5). The variables described above have been inserted incrementally to the model in three stages. Columns 1, 4 and 7 contain the coefficients of the multinomial logit model for the three distinct directions of causality (broadband provision rate affects KIBS rate, KIBS rate affects broadband provision rate and bidirectional causality between broadband provision rate KIBS rate), while the fourth category (no significant causal relation) is the reference category. Columns 2, 5 and 8 as well as 3, 6 and 9 present the same model with more covariates.

Starting from the first direction of causality, the model results that the level of broadband provision in 1999 increases the likelihood that a county will experience such a causal effect. This is a clear indication for a positive early adoption effect. In other words, probability is higher for counties to be able to transform an increase in broadband providers to an increase in KIBS establishments if these counties had better Internet provision in the early period.

The exact opposite is observed for the initial level of KIBS establishments. When all the other covariates are included (column 3) the variable ln*(kibs1999)* has a significant negative coefficient. This indicates that chances are lower for a county to be able to convert an increase of broadband providers to an increase of KIBS establishments if the initial level of KIBS establishment is high in this county. In other words, the counties for which an increase in broadband providers led to an increase in KIBS establishments are these counties with a lower level of KIBS in the early period indicating a saturation effect for the KIBS establishments.

Then, in column 3, the early adoption argument is tested again with an alternative variable, the PoP. This variable does not have a significant impact on the chances that a county is characterized by a significant causal relationship running from the rate of broadband provision to the rate of KIBS establishments. Apart from the current version of that variable, we also tested the original variable provided by Grubesic and O'Kelly (2002) which only includes the location of PoPs and not the neighboring counties and the result was the same. However, it needs to be highlighted here that this variable tested the effect of early adoption in a broader sense as depicted by access to the backbone networks of the US Internet. In the same column, the effect of state level restrictions to municipal broadband provision was tested, which also proved to be non-significant.

Moreover, the probability that a county can leverage an increase in broadband provision to increase the presence of KIBS establishments is negatively related to population size and positively related to population density and human capital, as reflected in the percentage of the population with a bachelor's degree, and the share of employment in agriculture. In other words, the likelihood of a county to be part of this group of counties for which an increase in broadband provision resulted in an increase of KIBS establishments is higher in small and densely populated counties with high quality human capital and at the same time, with a rather high share of agricultural activities. In addition, chances are higher if the county is located in the North Atlantic and New England or West North Central region.

Columns 4-6 present the coefficients for the reverse direction of causality, where an increase in KIBS establishments resulted in an increase in broadband provision. A saturation effect is present here as both the initial level of broadband provision and the location of PoPs have significant negative coefficients. The same applies for the municipal broadband provision restriction variable. To put it briefly, for counties with an early adoption attitude towards digital infrastructure, the chances that an increase in KIBS establishments led to an increase in broadband provision are lower. Apart from the saturation effect, the counties for which an increase in KIBS did not result in an increase in broadband provision are counties that are characterized by lower population densities, lower levels of human capital, and a lack of research-intensive universities. On the other hand, these counties are characterized by younger populations and the presence of highly skilled occupations.

Lastly, the last three columns of Table 1 present the coefficients for the bidirectional causality. As only 139 counties are characterized by such a relationship, there are hardly any significant variables here. There are some indications of a saturation effect as far as it concerns the broadband provision, but this effect is not significant throughout the different specifications. The same applies to population size (negative effect) and the highly skilled occupations (positive). In addition, the probability to observe such a relation is higher for counties located in West North Central region, an effect which was also observed for the cases where causality runs from broadband provision rate to KIBS establishment rate (column 3). In a nutshell, the counties for which bidirectional causality exist do not resemble a group of counties with concrete characteristics.

To summarize, the above analysis enables us to draw some concrete insights regarding the characteristics of the counties and the different causal relations between broadband provision and KIBS. It seems that causal relations running from changes in broadband provision to changes of KIBS establishment are related with early adoption effects regarding Internet and saturation effects regarding KIBS. Moreover, chances are higher to identify such relations in small and densely populated counties with high quality human capital, and intense agricultural activities. On the contrary, a reverse causal relation is affected by a saturation effect of broadband provision. In addition, such a causal relation more often appears in small and not densely populated counties, with low level of human capital and absence of research-intensive universities. These counties are also characterized by young population and also by the existence of highly skilled occupations.

7. Discussion and Conclusion

The goal of this paper was to evaluate the causal nature of the relationship between changes in broadband provision and changes in KIBS establishments given the comparatively understudied nature of this relationship. By adopting a Granger causality framework, which understands causality as a notion of temporal precedence between two variables, it was possible to extract some interesting and policy relevant results regarding the causal relationship, which connects these two variables.

The results of this analysis find a bidirectional causal relationship between the change of broadband providers and the change of KIBS establishments. What is important though is the spatial heterogeneity of these causal relationships. As the auxiliary analysis points out, there are specific elements that characterize the counties for which such causal relationships exist. From a policy perspective, the most important finding is that early adoption of digital technologies is related with an increase of KIBS. Of course, this relationship is affected by other geographic and socio-economic conditions including, among others, the low saturation level of KIBS. Interestingly, these Granger causality results suggest that government investments in Internet infrastructure in the fledgling years of Internet development have facilitated broadband deployment, and the ability of locales to retain and attract KIBS, which are likely intensive users of the Internet (Forman et al., 2003).

From a policy perspective, the results speak to the unique development history of the Internet. They also support government investments in broadband deployment initiatives. In recent years, the Broadband Technology Opportunities Program and the State Broadband Data and Development Program were government initiatives funded by $7.2 billion dollars of

American Recovery and Reinvestment Act funds (NTIA, 2013). These initiatives are designed to ameliorate disparities in Internet access and Internet service quality that have emerged since the transfer of the governmentally developed Internet backbone to private companies in 1995 (ABBATTE, 1999). In the hands of private, profit-oriented companies, poorer and rural areas remain underserved in an infrastructure that is increasingly critical to several facets of residential life and business competitiveness (FCC, 2010).

Unfortunately, in the current U.S. political climate, where government spending is hugely controversial, future government investments may not be possible even though these outlays represent a miniscule portion of the budget. This means that alternative mechanisms for stimulating broadband deployment in underserved areas may be necessary. It is likely that these initiatives will need to move beyond the current aim of national policy, the goal of which is to reduce regulations and stimulate competition in order to provide consumers with lower costs and better service quality (TA, 1996). Instead, policies may need to consider ways to ensure providers that the demand for broadband in underserved areas is there by either stimulating demand or aggregating demand (GILLETT ET AL., 2004).

That said, more research is necessary to expand upon this initial look at the causal nature of the relationship between businesses and broadband. For example, more work is required to understand how these results translate to other time periods and industries. While prior research suggests that the trends highlighted in this paper are likely indicative of future impacts of next generation Internet technologies (Perkins and Neumayer, 2011), more research is needed to verify this. The time period in this study is a period in which broadband may have been a relatively novel technology, and perhaps a differentiating factor between places for businesses. As this technology diffused over time, this novelty perhaps expired, and the causal impact of the infrastructure dissipated. Another extension to this study is the use of occupational data within the NAICS industries identified given the emphasis of prior studies on the role of occupations in regional growth (Florida, 2002; McGranahan and Wojan, 2007) and the uneven distribution of particular occupations across the United States (Scott, 2009; Scott and Mantegna, 2009).

In addition to extending this methodological framework to other time periods, it is also recommended that it be extended to evaluate this relationship for other industries. KIBS are not the only knowledge intensive businesses; manufacturing, wholesaling, and other industries also are knowledge- and IT-intensive. KIBS are *relatively more* technology intensive and footloose than other industries, thus the presence of a causal impact on businesses with other characteristics may be weaker, or even absent. An evaluation of variations in causal linkage by industry is particularly important to understanding the impact of broadband on the compositional dynamics of regions. If broadband is important to businesses in specific industries, such as KIBS, places that are comparatively broadband poor may have difficulty in retaining and attracting these businesses.

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Figure 1: Granger Causality Steps

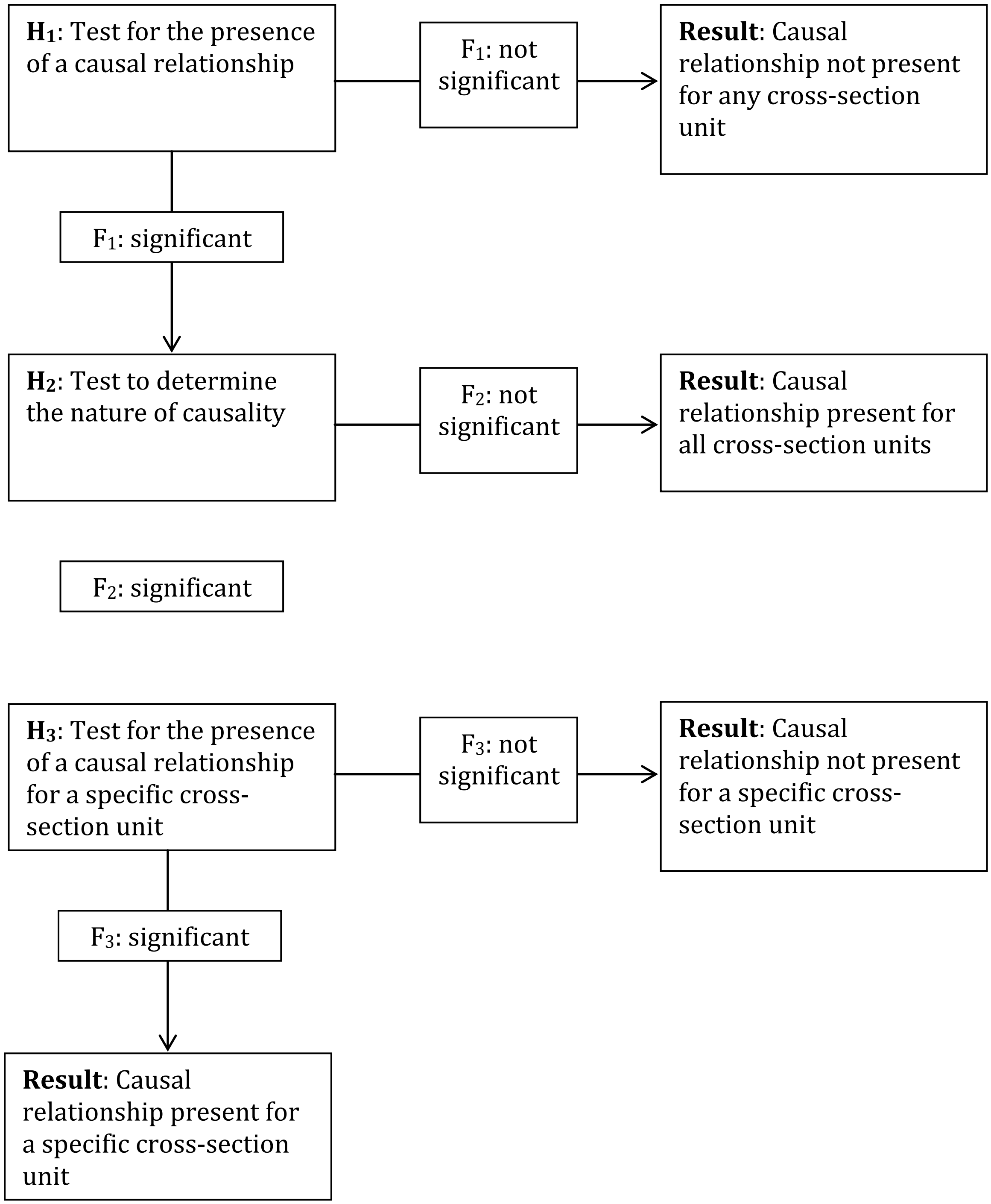

Figure 2: Granger Causality Results

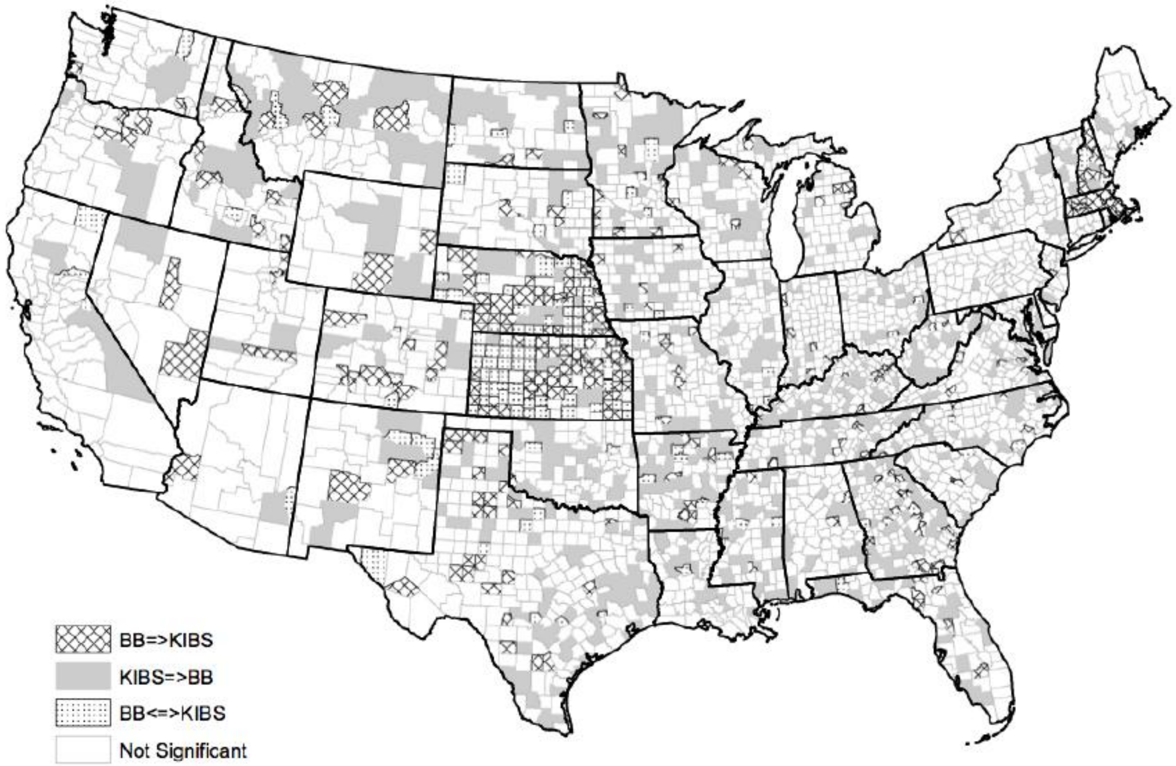

Table 1: Multinomial logistic regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
dep. Var.: direction of GC		**broadband ➡ KIBS**			**KIBS ➡ broadband**			**broadband ⇆ KIBS**	
ln(broadband1999)	0.248		0.324	-0.399		-0.325	-0.353		-0.222
	(0.125)**		(0.128)**	(0.0826)***		(0.0862)***	(0.152)**		(0.157)
ln(kibs1999)	-0.285		-0.561	0.0682		0.0366	0.0209		-0.340
	(0.193)		(0.200)***	(0.156)		(0.160)	(0.261)		(0.268)
Point of Presence		0.0280	0.118		-0.406	-0.331		-0.242	0.163
		(0.296)	(0.309)		(0.187)**	(0.191)*		(0.476)	(0.487)
municipal restriction		0.0285	-0.0956		-0.0587	-0.188		-0.176	-0.274
		(0.139)	(0.151)		(0.0921)	(0.101)*		(0.187)	(0.201)
ln(population)	-1.643	-1.615	-0.0880	-0.738	-0.772	-0.795	-2.214	-2.327	-0.210
	(0.435)***	(0.424)***	(0.486)	(0.329)**	(0.320)**	(0.366)**	(0.566)***	(0.555)***	(0.643)
ln(population density)	0.273	0.309	0.250	0.0518	0.0236	-0.165	0.157	0.139	0.0907
	(0.0993)***	(0.0996)***	(0.128)*	(0.0654)	(0.0644)	(0.0885)*	(0.133)	(0.132)	(0.175)
population 18-24	1.463	0.914	0.807	3.805	4.662	2.831	1.105	1.988	0.0484
	(2.401)	(2.375)	(2.498)	(1.483)**	(1.443)***	(1.532)*	(3.310)	(3.244)	(3.442)
ln(skilled occupations)	0.689	0.431	-0.574	0.649	0.601	0.974	1.246	1.254	-0.319
	(0.440)	(0.421)	(0.479)	(0.339)*	(0.324)*	(0.363)***	(0.580)**	(0.554)**	(0.653)
bachelor’s	0.0456	0.0493	0.0946	-0.0397	-0.0387	-0.0408	0.0133	0.00627	0.0709
	(0.0262)*	(0.0255)*	(0.0285)***	(0.0218)*	(0.0212)*	(0.0231)*	(0.0347)	(0.0340)	(0.0392)*
research universities	0.152	0.236	0.123	-0.334	-0.361	-0.227	0.0897	0.0248	0.124
	(0.174)	(0.178)	(0.186)	(0.117)***	(0.119)***	(0.122)*	(0.249)	(0.254)	(0.261)
agriculture	5.173	5.654	7.621	1.442	0.751	1.420	1.642	1.230	4.434
	(2.765)*	(2.730)**	(2.832)***	(2.362)	(2.348)	(2.490)	(4.164)	(4.167)	(4.253)
East North Central			-0.235			-0.435			-0.630
			(0.347)			(0.180)**			(0.560)
East South Central			-0.374			0.133			-0.717
			(0.345)			(0.177)			(0.568)
North Atlantic and New England			1.105			-0.920			0.178
			(0.363)***			(0.276)***			(0.695)
Mountain			-0.0659			-0.670			-0.158
			(0.329)			(0.234)***			(0.456)
Pacific			-0.404			-1.149			0.409
			(0.515)			(0.339)***			(0.592)

South Atlantic			-0.178			0.176			0.0151
			(0.308)			(0.167)			(0.445)
West North Central			1.269			-0.130			1.597
			(0.252)***			(0.170)			(0.336)***
Constant	7.945	8.848	2.653	1.779	2.085	0.879	9.274	9.913	2.201
	(1.704)***	(1.295)***	(1.897)	(1.260)	(0.927)**	(1.415)	(2.201)***	(1.669)***	(2.465)
Observations (for each direction of causality)	268	268	268	677	677	677	139	139	139
Observations (total)	2,986	2,986	2,986	2,986	2,986	2,986	2,986	2,986	2,986
Pseudo R-squared	0.0815	0.0752	0.110	0.0815	0.0752	0.110	0.0815	0.0752	0.110

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The base outcome is the non-significant causal relation (1,909 observations)

broadband and KIBS are the grwoth rates of broadband provision and KIBS establishments; arrown indicate direction of causality based on the Granger causality tests

Figure A1: Growth in Broadband

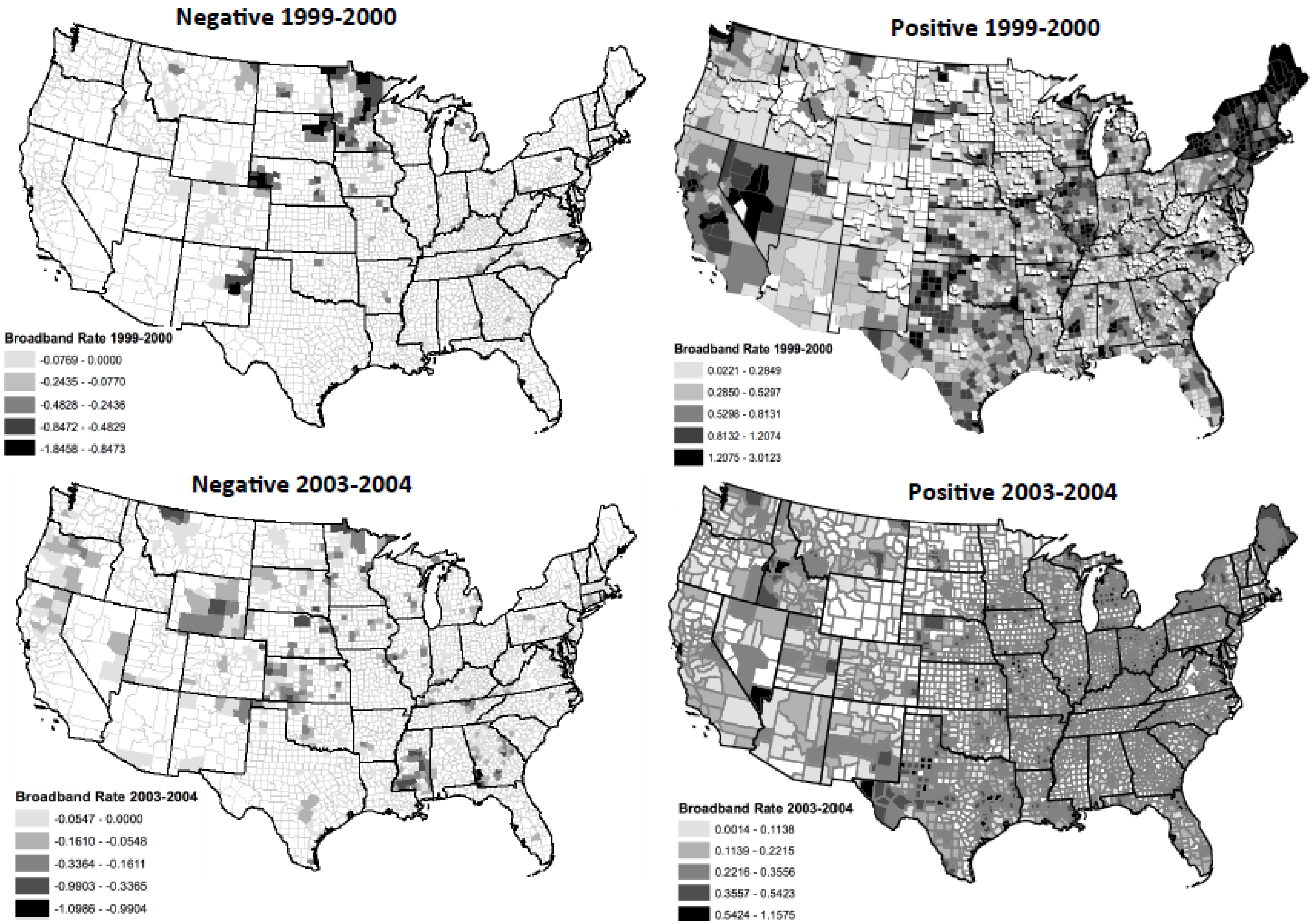

Figure A2: Growth in KIBS

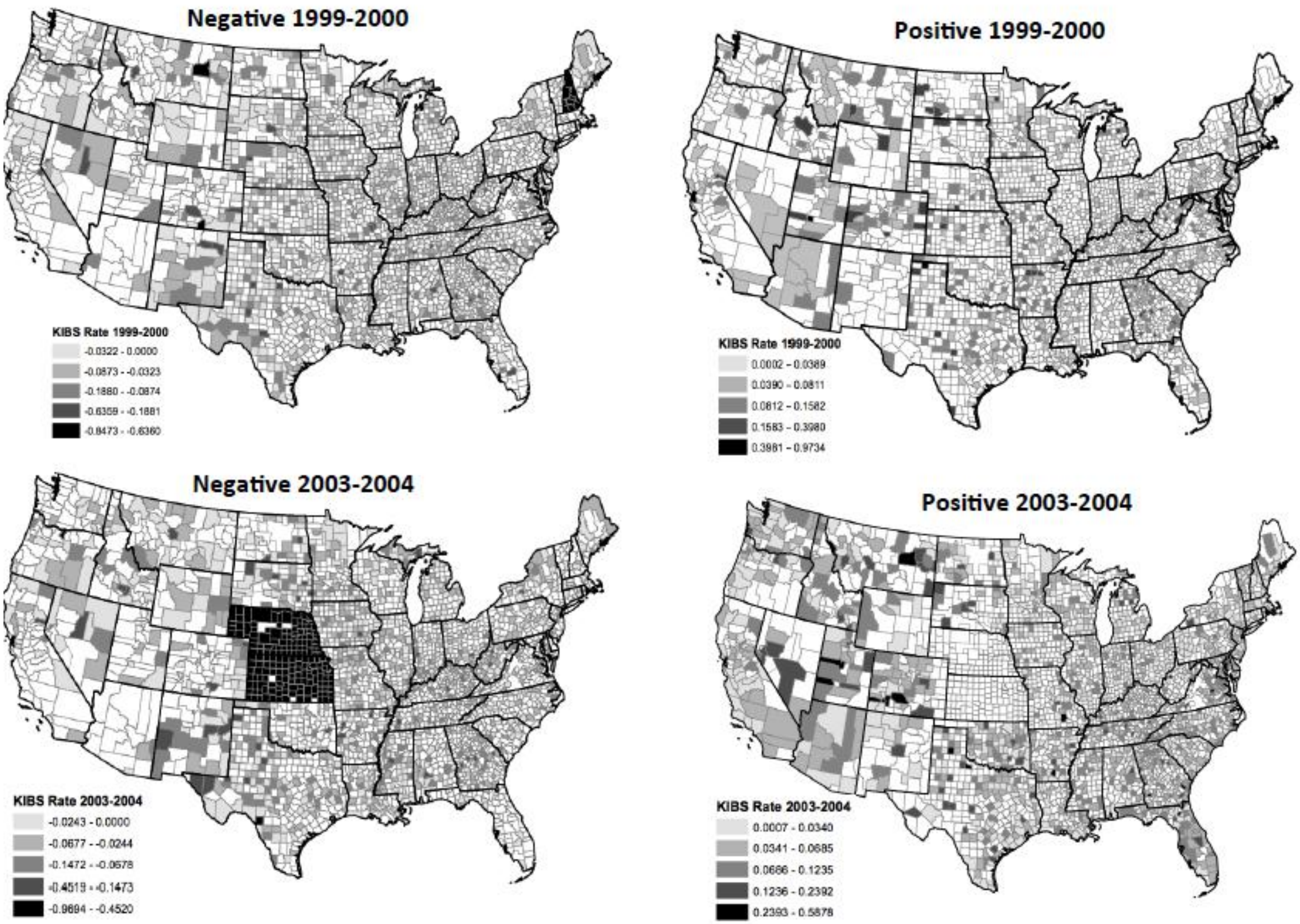

Table A1: Variables and descriptive statistics

Variable	Description	Source	Obs	Mean	Std. Dev.	Min	Max
broadband provision rate, 1999-2004	= ln (broadband provision in 2004) - ln (boradband provision in 1999)	Federal Communications Commission (FCC)	14965	0.323	0.344	-1.846	3.012
KIBS establishment rate, 1999-2004	= ln (KIBS establishments in 2004) - ln (KIBS establishments in 1999)	County Business Patterns, U.S. Census Bureau	14965	0.015	0.142	-1.609	1.099
population 18-24	Percentage of the total population	National Historic Geographic Information System (NHGIS)	2993	0.089	0.033	0.034	0.399
bachelor’s	Percentage of the population with a bachelor's degree or higher in 2000.	U.S. Census Bureau	2993	10.881	4.870	2.470	40.020
ln(skilled occupations in 2000)	Natural logarithm of people employed in management, professional, and related occupations in 2000.	National Historic Geographic Information System (NHGIS)	2993	8.162	1.467	4.625	14.120
ln(population density)	Natural logarithm of population density in 2000.	U.S. Census Bureau	2993	3.696	1.571	-1.333	10.726
research universities	Dummy variable that indicates whether a county contains a research I university, as defined by the Carnegie Classification System in 2000.	Integrated Post-Secondary Education Data System (IPEDS)	2993	0.330	0.470	0.000	1.000
ln(broadband1999)	Natural logarithm of broadband provision in 1999	Federal Communications Commission (FCC)	2993	2.186	0.993	0.000	7.239

ln(kibs1999)	Natural logarithm of KIBS establishments in 1999	County Business Patterns, U.S. Census Bureau	2993	4.527	1.550	0.000	10.758
ln(population)	Natural logarithm of population in 2000	National Historic Geographic Information System (NHGIS)	2993	10.271	1.376	6.096	16.067
agriculture	Share of agricultural establishments in 2000	County Business Patterns, U.S. Census Bureau	2986	0.013	0.021	0.000	0.241
Point of Presence	Dummy variable that indicates counties which hosted or are adjacent to a county which hosted a Point of Presence in 1997	Grubesic and O'Kelly 2002	2993	0.140	0.347	0.000	1.000
municipal restriction	Dummy variable that indicates whether a county is located within a state that has some sort of restriction on municipal broadband provision	MUNINETWORKS, 2014	2993	0.492	0.500	0.000	1.000