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Abstract:

Despite the volume of literature afforded knowledge work and innovations in information and communications technologies (ICTs), few studies have examined the importance of ICTs to firms in knowledge industries. This study will develop spatial econometric models to examine the relative importance of the level of broadband provision to knowledge intensive firms in select U.S. metropolitan statistical areas (MSAs). Results demonstrate the need for both a spatial econometric and a metropolitan area specific evaluation of this relationship. They also suggest potential spillover effects to knowledge intensive firm location, which may explain why some regional economies are relatively more successful at stimulating firm growth in this increasingly important sector of the U.S economy.

Key words: firm location, knowledge intensive, broadband provision, ICTs, spatial econometrics, telecommunications

1. Introduction

As regional economies strive to remain competitive in the global information economy, economic development entities at the state and local levels are reevaluating important determinants of regional competitive advantage. One determinant of competitive advantage may be the level of information and communications technology (ICT) infrastructure within a region. ICTs are widely recognized as an important component of the growth of businesses and the development of regional economies (Abler, 1977; Richardson and Gillespie, 1996; Mansell and When, 1998; Prekumar, 2000; Hales et al., 2000). Despite this recognition, few quantitative studies exist regarding the impact of ICTs on firm location and the relative attractiveness of regions.

Over a decade after the privatization of the Internet and the subsequent explosion in Internet use, relatively little is known regarding the linkages between firm location and ICT infrastructure. The majority of studies attempting to evaluate this relationship remain largely theoretical and speculative in nature (Salomon, 1996; Atkinson, 1998; Moss, 1998; Audirac, 2002; Audirac, 2005). Thus, the impact of ICT deployment on firm growth and the related development prospects of regions remain somewhat enigmatic. Although the distribution of ICTs, like broadband, is perceived as increasingly ubiquitous, disparities persist in the level of infrastructure including the number of providers, and the speeds and platforms Internet access is available to end users (Grubesic and Murray, 2004). Of particular concern is whether locales with lower levels of ICT infrastructure are at a disadvantage for firm retention and attraction, and whether costly ICT deployment initiatives are capable of ameliorating this locational disadvantage.

The current lack of quantitative information combined with the largely invisible nature of ICT infrastructure, hampers the efforts of economic development officials and policy makers to generate effective strategies to stimulate regional growth. This is particularly important given the complicating factors surrounding ICTs and regional development. These include non-uniform adoption of ICTs by firms, which is related to a variety of spatial, organizational, and social factors (Gibbs and Tanner, 1997; Gibbs, 2001). Therefore, an understanding of the importance of this physical infrastructure, relative to other location factors such as transportation and labor force quality, is critically important for understanding the dynamic geography of regional competitiveness within the United States and the larger global information economy.

The purpose of this paper is to quantitatively evaluate the relative importance of broadband infrastructure to knowledge intensive firm location for select metropolitan areas within the United States. Knowledge intensive firms are the focus of this paper because they are more likely to use information and communications technologies (ICTs), to enhance business processes (Forman et. al., 2003), than are firms in other sectors of the economy, like manufacturing. These technologies are not only a key input to their production processes but, broadband Internet connections are also a key means of transmitting the outputs produced by these firms. The heavy usage of information technology, which allows firms to receive and transmit inputs and outputs at zero marginal cost, suggests knowledge-intensive firms may prefer to locate in areas with higher levels of these technologies, which are essential to the production of their final products. Further, the locational preferences of such firms are no longer a simple tradeoff between production and transportation costs (McCann and Sheppard, 2003) at the intra-national level, but must now include access to global markets, the transactions costs of information transmission (ibid), and the frequency of face-to-face contacts with local and global contacts. Thus, obtaining an understanding of the importance of broadband provision to knowledge intensive firms is a critical step to unraveling the relevant costs that factor into the location decisions of these firms.

A series of spatial econometric models constructed with ZIP code level data will be estimated to evaluate the importance of the level of broadband provision on knowledge intensive firm presence for the entire U.S and select metropolitan areas of interest. Results illustrate variation in the relative importance of this infrastructure and suggest that a one-size-fits all approach to broadband deployment is likely to have varying impacts for metropolitan regions, particularly with respect to their ability to attract firms in the knowledge intensive sector. This is an important consideration for metropolitan areas that are seeking to revitalize their industrial base (e.g. Detroit, MI) after the migration of manufacturing jobs to other places in the United States and around the world (Thomas, 1990; Digaetano and Lawless, 1999). The following two sections of this paper will provide an overview of the extant qualitative and quantitative work in this area. This will be followed by a discussion of the six selected metropolitan areas of interest and the data used in the models. The paper will conclude with a discussion of results and related policy implications.

2. Qualitative Studies

A majority of the research evaluating the impact of ICTs on firm location is qualitative in nature and takes either a theoretical or case-study approach to this topic. Previous interview-oriented research in Silicon Valley and Boston's Route 128 area (Saxenian, 1994; 2006) has provided case specific information about the intricacies of high-technology regions. Theoretical discussions of the eventual impact of these technologies on firm location also abound in the literature. In general, these studies hypothesize one of three reactions to advances in ICTs. The first hypothesis suggests firms will depart en masse from central city locations (Kutay, 1988a,b; Salomon, 1996; Moss, 1998) because the substitutability of these technologies for face-to-face interactions (Moss, 1998; Steinfield, 2004) and transportation (Salomon, 1996 p. 79) will allow them to escape the diseconomies of central city locations (Kutay, 1988a,b). This school of thought presupposes a ubiquitous distribution of ICT infrastructure (Salomon, 1996 p.81) that allows firms to select the least cost location irrespective of the availability of this infrastructure. The second hypothesis suggests cities will retain their importance as commerce centers, which may be further reinforced because of the uneven distribution of this infrastructure (Grubesic and O'Kelly, 2002; Duffy-Deno, 2003). Central to both of these hypotheses is their assumption about the distribution of ICT infrastructure; it is either homogeneously distributed or clustered in central places.

However, the heterogeneous distribution of this infrastructure is a well-noted phenomenon in the literature and this heterogeneity is present at a variety of scales, including urban and rural areas (Strover, 2001; Grubesic and Murray, 2004), between metropolitan areas (Moss and Townsend, 2000; Grubesic and O'Kelly, 2002), and within cities (Graham, 1999; Graham, 2002; Grubesic and Murray, 2002). Given this uneven distribution of infrastructure and the unique characteristics of metropolitan areas, a third hypothesis posits the impact of ICTs on firm location will be heterogeneous. One important source of variation in impacts is firm industry membership (Atkinson, 1998; Moss, 1998; Audirac, 2005), which suggests the varied industrial legacies of metropolitan areas may impact ICT deployment initiatives.

3. Quantitative Studies

Quantitative work in the technology adoption literature further supports the expectation that the impact of ICTs on firm location will be heterogeneous. These studies suggest impacts will vary by firm size, industry, and metropolitan area size (Forman et al., 2005b). For example, empirical comparisons of manufacturing oriented industries and service oriented industries indicate these sectors utilize ICTs in different ways (Forman et al., 2005a). The adoption literature also finds the geographic distribution of an industry (Forman et al., 2003a; Forman et al. 2003b, Forman et al., 2005c) plays a role in the use of ICTs by firms. These findings are corroborated by exploratory analyses of the coincidence of knowledge intensive firm location and broadband provision which find urban biases in both the locations of these firms and broadband (Mack and Grubesic, 2009). In sum, these studies are of particular interest to this analysis because of their focus on industry and metropolitan area specific impacts regarding the relative importance of broadband to firm location. These studies suggest broadband deployment initiatives such as the national level Broadband Technology Opportunities Program (BTOP) (NTIA, 2009), which has designated funds from the American Recovery and Reinvestment Act of 2009 (H.R. 1) to help provide underserved communities with broadband, are likely to have heterogeneous impacts across metropolitan areas.

Outside of the adoption literature, there is a limited amount of work examining the impact of ICTs on firm location (Sohn et al., 2002; Sohn et al., 2003; Sohn, 2004; Hackler, 2003a). Although these studies represent important initial contributions to this topic, several methodological gaps are evident. One gap is the use of linear regression models estimated via ordinary-least squares (OLS). This modeling approach is problematic for several reasons. First, business data are made available in the form of counts, and the use of untransformed count data in linear models violates the normality assumption of linear-normal models (Wu, 1999). Second, the results of this study and those prior demonstrate the presence of autocorrelation in both broadband provision (Grubesic, 2006; Grubesic, 2008a) and firm data (Maoh and Kanaroglou, 2007; Carroll et al., 2008; Mack and Grubesic, 2009; Banasick et. al., 2009) The estimation of linear regression models in the presence of spatial autocorrelation produces two major problems. First, it generates biased and inconsistent estimators when the model specification should include a spatial lag of the dependent variable (Anselin, 1988). Second, it can produce unbiased but inefficient coefficient estimates when spatial structure is present in the error term because the variance matrix of the disturbance is heteroskedastic (ibid, p. 59). Third, theory suggests that feedback exists between firm location and broadband provision, or the presence of endogeneity between these two variables. The problem of endogeneity, which produces inconsistent coefficient estimates if left unaddressed (Greene, 2000), is recognized in several quantitative studies related to broadband. This literature suggests the presence of an endogeneous relationship between broadband and several variables including: GDP growth and broadband demand (Holt and Jamison, 2009), broadband deployment and firm productivity (Majumdar et al., 2009), and broadband and economic activity (Van Gaasbeck, 2008). A final issue with previous empirical work on this topic is the use of proxies for ICT infrastructure such as bandwidth capacity (Hackler 2003a, b) and the number of information intensive businesses (Sohn, 2004) in place of actual infrastructure data. Although these proxies may capture aspects of *potential* ICT use, they cannot replace real metrics of ICT provision. The use of some of these proxies, such as the number of information intensive businesses (Sohn, 2004) is also not feasible for the purposes of this study since this proxy represents the dependent variable of interest.

The spatial econometric models estimated in this study will fill many of these methodological gaps in the current literature regarding the impacts of ICTs on firm location. Although the framework presented in the following analysis is not capable of resolving all of the data and statistical problems associated with the proposed econometric analysis, it certainly represents a significant methodological improvement over prior work, and presents a good foundation for future research in this area.

4. Study Area

This study is concerned with metropolitan level differences in the relative importance of broadband provision to knowledge intensive firms. Six metropolitan areas were selected for further analysis based on their unique location, industrial composition, and/or urban morphology. These metropolitan areas include: the Atlanta-Sandy Springs-Marietta, GA, Boston-Cambridge-Quincy, MA-

NH, Columbus, OH, Dallas-Fort Worth-Arlington, TX, Detroit-Warren-Livonia, MI, and the San Jose-Sunnyvale-Santa Clara, CA metropolitan areas.

The Boston and San Jose metro areas are of specific interest because of their high-technology clusters; Route 128 in Boston and Silicon Valley in San Jose. Despite this industrial similarity however, it is hypothesized that broadband provision will be more important to knowledge intensive firms in the San Jose region than the Boston region. This hypothesis is based on Saxenian's (1994) finding that San Jose experienced greater economic growth in the 1980s and 1990s than did Boston because of the flexible organizational structure of its firms, which promoted entrepreneurial activity and adaptation to an increasingly dynamic global business environment. Broadband is therefore anticipated to be of greater importance to San Jose's small entrepreneurial start-ups and supporting knowledge intensive firms than to the established large firms in Boston who have historically contracted with large government agencies (ibid).

Broadband is also expected to be of key importance to knowledge intensive firms in the Dallas metropolitan area for several reasons. First, Dallas is home to six of the largest telecommunications services companies in the United States including GTE, Nortel, Ericsson, Fujitsu, and Alcatel (Devol, 1999). Second, this region is one of the top metropolitan areas in the United States in terms of the number of knowledge workers per million people and its ability to attract high technology industry (Florida, 2000). Finally, Dallas has been recognized in previous studies as a node of key importance on the Internet backbone (Moss and Townsend, 2000; Grubesic and O'Kelly, 2002) and a core broadband area (Grubesic, 2006) that has experienced growth over time (Grubesic, 2008a).

Metropolitan areas where broadband is anticipated to be of moderate importance to firms include Columbus, OH and Atlanta, GA. Columbus was selected because of its relatively long track-record of empirical evaluation in the literature (Grubesic and Murray, 2002; Grubesic, 2002; Grubesic, 2003;

Grubesic, 2008a), and its location in a state with a diverse landscape and industrial mix. Atlanta was chosen because of its urban morphology. It is considered a classic example of urban sprawl, and has subsequently been the subject of numerous case studies (Wheeler, 1986; Walcott, 2000; Fujii and Hartshorn, 1995). The suburban location tendencies of business and professional services (which are categorized as knowledge intensive in this study) have also been studied for this metropolitan area (Gong and Wheeler, 2002). These prior studies suggest broadband may be a particularly important communication tool for businesses and individuals within this metropolitan area because of the congestion costs associated with frequent face-to-face contacts in an area with a sprawling urban morphology.

Finally, the Detroit-Warren-Livonia, MI area was chosen because it is an area historically dominated by manufacturing and currently characterized by a decaying industrial base. This metropolitan area also suffers from its singular focus on, automobile manufacturing, and subsequent deindustrialization in the post-1970 period (Digaetano and Lawless, 1999). Given these characteristics, and the results of previous studies which demonstrate Detroit has a competitive disadvantage in the growth and attraction of knowledge firms (Mack, 2010), broadband is expected to be of lesser importance to firms in this area.

5. Data

2004 ZIP code areas and associated data were obtained from TeleAtlas[1]. This data source contains 2001 and 2006 estimates for a variety of demographic and socioeconomic variables, including population, income, and housing units. However, only the 2006 estimates were used in the analysis. Table 1 contains additional information about the variables used in the construction of the models.

Appendix A provides the descriptive statistics for all variables of interest and Appendix B contains their correlation coefficients.

2003 metropolitan statistical area boundary files from the U.S. Census Bureau were used to delineate the spatial extent of the six metropolitan areas of interest. Using these geographic base files, ZIP code area membership in a metropolitan area was determined by an intersection procedure in a desktop geographic information system (GIS). This selection method was chosen over other methods because of the irregular shape of ZIP code area polygons. For example, the use of another procedure such as the "center within" approach would have left gaps in the spatial coverage of metropolitan areas of interest.

For the research question considered in this study, the relevant universe of ZIP code area polygons is those ZIP codes with both knowledge intensive businesses and broadband providers. This subset of ZIP codes is considered in place of all ZIP codes because the paper is primarily interested in evaluating the impact that the *level* of broadband provision has on the *level* of knowledge intensive businesses in an area. It is not concerned about the impact of an infusion of broadband to an area that contained no broadband providers previously. The evaluation of such a presence/absence relationship is a separate research question that merits an entirely different modeling approach, and is thus considered beyond the scope of this paper.

5.1 Knowledge Intensive Firm Data

Industry level establishment counts by ZIP code area for 2004 were obtained from ZIP Code Business Patterns of the U.S Census Bureau (2009b), and the information for firms in knowledge intensive industries extracted. This study defines knowledge intensive firms as the sum of all establishments[2] pertaining to the following two-digit NAICS industries: Information (51), Finance and

Insurance (52), Professional, Scientific, and Technical Services (54), Management of Companies and Enterprises (55), and Educational Services (62). Firms in this sector are the focus of the study for several reasons. First, given the results of prior research, which discovered manufacturing and service industries utilize ICTs in different ways (Forman et al., 2005a), it is likely firms of a knowledge intensive nature use these technologies more intensively than other sectors of the economy. Second, the production function of these firms is different than more traditional service and manufacturing firms because knowledge is both a primary input and output. This is an important distinction because the use of knowledge as a production input has been recognized as a different kind of input to a production process than the typical inputs of land, labor, and capital (Audretsch, 1998). Third, advances in ICTs have enabled businesses to obtain inputs and send outputs at zero marginal cost. These characteristics of knowledge intensive firms suggest transportation costs may not be the driving force behind the location decisions of these firms. Therefore, an evaluation of the role broadband provision plays in their location decisions is an important step in evaluating changes in the locational preferences of firms and the extent to which traditional location theory may need to be revised to include the relevant costs of these firms.

5.2 Broadband Provider Data

The *independent variable* of interest is the level of broadband provision in a ZIP code area. These data were obtained from the Federal Communications Commission (FCC) Form 477 database (FCC, 2009) which includes information for facilities-based providers[3] with 250 high speed lines (or more) in each state. Despite some minor imperfections in this database, which include the inability to ascertain the platform through which broadband is provided[4] and a relatively nebulous definition of what connection speeds constitute broadband[5], these data are a direct measure of the level of broadband infrastructure present in an area. Thus, the inability to pinpoint the exact speed and platforms at which broadband is provided in a given ZIP code area are only minor drawbacks given this data source eliminates the need to rely on proxies for broadband to answer the research question of interest. For more details on the use of these data and their limitations, see Grubesic and Murray (2004) or Grubesic (2006).

5.3 Other Independent Variables

Other independent variables believed to be important to the number of knowledge intensive businesses in a ZIP code area include: transportation infrastructure, the presence of an educated labor pool, the relative "urbanness" of an area, and the presence of urbanization economies. Airport and highway data were obtained from the Bureau of Transportation Statistics (BTS). From these data two variables were computed, aggregate highway mileage in a ZIP code area and the shortest distance (in miles) of a ZIP code area from a commercially served airport. Highway miles are expected to have a positive impact on knowledge intensive firm location; places with more highway miles are more accessible than those with fewer highway miles. The ability to travel, particularly via airplane, is well noted as important to firms of a knowledge intensive nature, particularly those requiring "face-to-face contact and direct collaboration" (Debbage and Delk, 2001 p. 166; Grubesic, 2010). Therefore, distance from an airport is anticipated to have a negative impact on knowledge intensive firm location given the heavy usage of air travel by these firms. However, the sign on this variable may change from metropolitan area to metropolitan area, depending on the location of the airport relative to the downtown area. Metropolitan areas with airports located in or near central city locations like Chicago's Midway Airport and Atlanta's Hartsfield-Jackson Atlanta International Airport are likely to have a negative coefficient on this variable. Larger distances from these airports detract from knowledge intensive firm presence in a ZIP code. Metropolitan areas with airports located in less central, suburban areas far from the city center are likely to have a positive coefficient on this variable. Larger distances from these airports correspond with the historical preference of firms to locate in central areas.

The presence of an educated labor pool is described by two variables, median household income, which is a proxy for education, and the growth of the population of persons aged 18 to 65, which is meant to characterize the size of a metropolitan area's labor pool. The relative urbanness of a ZIP code area is described by a dummy variable, which indicates whether a ZIP area intersects a Census delineated urban area[6]. Previous studies have shown broadband provision has a traditional urban bias (Strover, 2001; Grubesic and Murray, 2004) and the use of an urban area dummy variable is designed to capture this bias. The subtleties of trends in urban morphology are captured by additional measures of urbanness including: average household size, percent of renter occupied housing units, and percent white. These variables were selected for their potential to capture knowledge intensive location trends in both central city and suburban areas. A negative coefficient on household size and a positive coefficient on renter occupied suggest a central city preference for knowledge intensive firms while a positive coefficient on percent white would suggest a suburban location preference. The sign on percent white is hypothesized to be of greater importance in places that have experienced rapid suburbanization like Columbus and Detroit.

The final independent variable of interest is the level of urbanization economies. This variable was calculated by interacting the dummy variable for urban area with the sum of the natural log of broadband provision and aggregate highway mileage in a ZIP code. It is designed to capture the impact of both kinds of critical infrastructure on the presence of knowledge intensive firms. The extant literature on ICTs and firm location in the global knowledge economy suggests the sign on this coefficient is expected to vary across metropolitan areas. A positive sign on this variable is expected given the findings of previous studies which demonstrate knowledge firms have an urban bias similar to broadband, which may be related to the presence of more infrastructure in urban areas (Mack and Grubesic, 2009). There is also a well noted traditional urban bias for producer services firms[7], who prefer to locate in downtown areas near other firms who provide complementary services or key inputs (Sassen, 1991). However, the same literature also suggests there is reason to believe the coefficient on this variable may also be negative, representing urbanization diseconomies. These diseconomies are related to high rents and traffic congestion in central city locations, which may encourage firms to locate in less expensive suburban locales (Kutay, 1988a,b).

6. Methods

This study represents a major departure from previous work in this area not only because of its use of the FCC Form 477 data, which resolves the issues associated with the use of ICT proxies discussed earlier, but its methodological approach to the research question of interest. As mentioned previously, there are a variety of issues associated with the use of OLS models to evaluate the impact of ICTs on firm location. The analysis that follows seeks to resolve several of the methodological issues from prior studies including endogeneity in the regressors, spatial autocorrelation, and heteroskedastic errors.

6.1 Instrumental Variables

Previous research examining the relationship between broadband and GDP growth and broadband demand (Holt and Jamison, 2009) found an endogenous relationship between broadband and these variables. Given these findings, the current study follows the approach of prior broadband studies (van Gaasbeck, 2008; Majumdar et al., 2009), and uses an instrumental variables approach to account for endogeneity in the regressors. The selection of instruments was made by specifying two structural equations, one for broadband and one for knowledge intensive firms. These equations were specified as follows (Greene, 2000):

(1) $$y_1 = \alpha x + \gamma_1 y_2 + \varepsilon_1$$

(2) $$y_2 = \beta z + \gamma_2 y_1 + \varepsilon_2$$

Where y_1 = natural log of knowledge establishments
y_2 = natural log of broadband provision
x = vector of independent variables for knowledge firms
z = vector of independent variables for broadband provision
ε_1, ε_2 are error terms for knowledge firms and broadband respectively

After specifying these equations, it became evident household density was a viable instrument for broadband provision[8]. Not only was household density significant in the equation for broadband and not significant in the equation for knowledge firms, but this variable has been demonstrated to be a significant explanatory variable for broadband in prior studies (Mack and Grubesic, 2009). Unfortunately, post-estimation testing via the Wu-Hausman test (Wu, 1973; Hausman, 1978) found endogeneity was not an issue. This counterintuitive result is likely the result of a weak instrument (Hahn and Hausman, 2003), which is widely documented in the econometrics literature (Staiger and Stock, 1997; Stock et al., 2002; Dufour, 2003). Therefore, the natural log of broadband providers in 1999 was included as an additional instrument. Further post-estimation testing via the Wu-Hausman test with these two instruments verified endogeneity was a problem[9]. Therefore, all models were initially estimated via two-stage least squares (2SLS) using household density and the natural log of broadband providers in 1999 as instruments for the natural log of broadband providers in 2004.

6.2. Spatial Autocorrelation

A preliminary analysis of spatial autocorrelation trends in the dependent variable and independent variable of interest suggest that autocorrelation is present (in addition to endogeneity), although the amount varies across metropolitan areas. Table 2 contains the results of a global Moran analysis[10] (Moran 1948) of knowledge intensive firms and broadband provision. This table also contains the results of a bivariate global Moran analysis (Anselin et al., 2002)[11] where the *y* variable is the natural log of knowledge establishments within a metropolitan area and the *x* variable is the natural log of broadband provision of neighboring ZIP code areas.

Positive and significant[12] z-values for the global Moran computed with broadband and knowledge firm data separately suggest positive spatial autocorrelation. Broadly interpreted, this suggests similarities in the level (low or high) of broadband provision and the level of knowledge firms in nearby ZIP code areas. The multivariate global Moran's *I* analysis also demonstrates similarities in the spatial distribution of broadband and knowledge firms, or, that ZIP code areas with a given level of knowledge establishments are surrounded by ZIP code areas with similar levels of broadband provision. These results suggest spatial structure to the data that will need to be accounted for in the estimation process.

Both spatial lag and spatial error models estimated via spatial two-stage least squares S2SLS (Anselin, 1988; Kelejian and Robinson, 1993; Kelejian and Prucha, 1998) were considered to model the spatial structure in the data. These models are specified as follows (Anselin, 1988):

(3) $$y = \rho W_1 y + X\beta + \mu$$

where $\mu \sim N(0, \Omega)$ and ρ is a coefficient estimate of the amount of spatial dependence in the dependent variable

(4) $$y = X\beta + \lambda W_2 \varepsilon + \mu$$

where λ is a coefficient estimate of the amount of spatial dependence in the error term and μ is the uncorrelated portion of the error term and is independently and identically distributed (i.i.d) (Odland, 1988). While the spatial lag model in equation (3) deals specifically with autocorrelation in the dependent variable, the spatial error model in equation (4) deals with unknown causes of autocorrelation such as an omitted variable or functional form misspecification (ibid). Specifically, spatial lag models will be estimated via the generalized spatial two-stage least squares (GS2SLS) procedure proposed by Kelejian and Prucha (1998). This procedure produces a consistent and asymptotically normal estimator with specified large-sample properties (ibid). The spatial two-stage least squares estimation method for spatial error models will utilize the generalized moments estimator proposed by Kelejian and Prucha (1999). The estimator is consistent under certain conditions and does not require the assumption of normality (ibid). Further, their estimator of ρ is nearly as efficient as the ML estimator typically used for SAR models (ibid).

The selection of an aspatial model estimated via two-stage least squares versus a spatial lag or spatial error model will be based on an evaluation of spatial autocorrelation in model residuals via the Anselin-Kelejian Test for Residual Spatial Autocorrelation (Anselin and Kelejian, 1997). This is a test for spatial autocorrelation in models that have been estimated via procedures such as two-stage least squares (Anselin and Kelejian, 1997). The test is also a test for remaining autocorrelation if the model in question contains a spatial lag, and is therefore able to detect whether a spatial error model may be more effective at removing autocorrelation than a spatial lag model (Anselin and Kelejian, 1997). Use of this diagnostic test will be used to avoid the pitfalls associated with model misspecification related to unaccounted for spatial dependence.

6.3 Heteroskedasticity

A final statistical problem considered in the model estimation process was heteroskedastic errors. Post-estimation tests for heteroskedasticity were conducted after obtaining two-stage least squares estimates and suggested non-constant variance was an issue for some metropolitan areas. Given these results from the Pagan-Hall test statistic (Pagan and Hall, 1983) three corrections for heteroskedasticity were considered. The White correction (White, 1980), which produces a heteroskedasticity-consistent covariance matrix irrespective of the source of the heteroskedasticity. The HAC estimator [13] (Kelejian and Prucha, 2007) which produces errors that are robust to unknown forms of heteroskedasticity and autocorrelation, and the Kelejian-Prucha consistent estimator for heteroskedastic error terms (KP-HET) (Kelejian and Prucha, forthcoming). The White and HAC estimators were used in conjunction with spatial lag models estimated via S2SLS and the KP-HET correction was used in conjunction with spatial error models estimated via the Kelejian and Prucha generalized moments estimator.

6.4 Specification of Weights Matrices

The spatial econometric techniques discussed in the previous section require the selection of a weights matrix, which is a way to specify spatial structure in the data. Several options for weights matrices are available[14] and the selection of a weights matrix is an attempt to best represent the influence of the variable values of surrounding observations on the observation of interest (Anselin, 1988). A binary distance-based weights matrix was used to estimate each of the metropolitan-specific regression models. The use of this kind of weights matrix is based on precedent from previous broadband studies using ZIP code level data (Mack and Grubesic, 2009) and the highly irregular nature of ZIP code area polygons.

At the national level, a 6 nearest neighbor weights matrix was selected over other options (i.e. rook, queen, distance) due to the irregular nature of ZIP code areas and the research question of the study, which requires the dependent variable and independent variable in their original form be greater than zero. This data restriction produced an irregular distribution of ZIP code areas at the national level with gaps between the observations of interest (Figure 1). The number of nearest neighbors was determined by analyzing the average number of neighbors in the queen weights matrix[15 16] for each of the metropolitan areas of interest. This analysis computed a weighted average of the number of neighbors in each metropolitan area where the weights are the number of ZIP code areas with a given number of neighbors.

7. Estimation Results

Stata and an alpha version of GeoDaSpace (Anselin and Lozano, 2009) were used to generate the output displayed in Tables 2-5 and Appendices C-H. Stata was used to generate the ordinary least squares and two-stage least squares results while GeoDaSpace was used to generate all of the spatial econometric model results. The latter of these two programs is a cutting edge, menu driven interface for advanced spatial econometric techniques such as the generalized spatial two-stage least squares estimator (Kelejian and Prucha, 1998) and the HAC estimator (Kelejian and Prucha, 2007) mentioned previously. Models were estimated in a sequential manner (OLS, 2SLS, etc.) and post-estimation tests for autocorrelation and heteroskedasticity run to ensure the unique statistical problems of each area were considered in the construction of the models.

7.1 National Model

Table 3 contains the results of the models estimated for the universe of relevant national level ZIP codes. The results of the Anselin-Kelejian test suggest remaining spatial autocorrelation despite the inclusion of a spatial lag. Given the insignificance of the spatial lag and the issue of remaining spatial autocorrelation, two different approaches were taken to modeling the autocorrelation, a model estimated via two-stage least squares with errors that are robust to unspecified heteroskedasticity and spatial autocorrelation (HAC standard errors), and a model that incorporates a lagged error term estimated via the Kelejian-Prucha GM estimator. The latter model was deemed the best model given the large value of lambda estimated (0.4908). This model explains 64% of the variation in knowledge intensive firm location across the United States, and produces a national average elasticity for broadband of 2.0. Results also suggest knowledge intensive firms prefer to locate in urban areas with smaller households and a larger number of renter occupied housing units. The growth of an educated labor pool has a positive impact on provision, as do a greater number of highway miles in a given ZIP code area. These firms also prefer to be located in close proximity to airports, which is not surprising given the findings in the airline literature, which find specific industries, like professional, scientific, and technical services (PSTS) have a positive impact on airport activity (Alkaabi and Debbage, 2007).

Two particularly interesting results produced by this model are the coefficient estimates for percent white and urbanization economies. Despite a general urban area preference of these firms, slight urbanization *diseconomies* do exist. The percent white also suggests that knowledge intensive firms may prefer more suburban areas within metropolitan regions. These apparently conflicting results for percent white and urban area may be related to the concentration of knowledge intensive firms in both central city and suburban locations. A breakdown of global autocorrelation trends described previously via the local Moran (Anselin, 1995) in Figure 2 demonstrates two location trends for knowledge intensive firms, a tendency to locate in both central city locations and in more peripheral areas. This apparently contradictory trend may be related to sub-industry specific, firm specific, or firm size specific costs. For example, some firms may find it advantageous to make a decentralization decision to avoid the diseconomies of central locations, while other firms may decide to remain centrally located, despite the presence of these diseconomies, because the cost savings of suburban locations do not outweigh the benefits of central city locations.

The model estimation results also demonstrate the need to address endogeneity and spatial autocorrelation when estimating models to evaluate the importance of ICTs to firm location. Not only does the size of the coefficient on broadband for the spatial models vary dramatically from the OLS results, but so too do the sign and size of the coefficients for percent white and average household size. The applicability of the national level results to individual metropolitan areas however is questionable given the spatial error specification of the best model in Table 3. The specification is likely related to spatial heterogeneity in firm location for the knowledge sector across metropolitan areas. This suggests metropolitan specific evaluations of this relationship are preferable to a national model, where the metropolitan specific sources of autocorrelation end up in the error term. The following two sections provide more detailed results for the metropolitan areas of interest to better understand how the unique characteristics of metropolitan areas affect the relationship between knowledge intensive firm location and broadband provision.

7.2 Pooled Model for Metropolitan Areas of Interest

Given the likely heterogeneity across metropolitan areas, a pooled model for the six metropolitan areas of interest was constructed to obtain results that are perhaps more generalizable to the metropolitan areas of interest than are the national level results. Table 4 is a summary of these results, which illustrates the best model specification for all six metropolitan areas is a spatial lag model with HAC standard errors. This model was estimated with a block diagonal weights matrix constructed by combining the six metropolitan area specific distance-based weights matrices. This kind of weights matrix was selected, as opposed to other options such as a *k* nearest neighbor or a distance-based weights matrix, to preserve the neighbor structure within each of the individual metropolitan areas.

The national average elasticity for broadband is 2.0112 while the average for the pooled metropolitan area model is 2.4210, which is 20% higher than the national average. The relative size and sign on the coefficients of the other independent variables in the model are fairly consistent with those from the national model with some notable exceptions. Income, growth in the working age population, and distance from the nearest commercial airport do not significantly impact knowledge intensive firm presence. The size of the coefficient on percent renter occupied is less than half the size of the coefficient in the national model, while the impact of ZIP code area presence in an urban area is greater in the pooled metropolitan area model than the national level model. For the most part, these results are an average of the results for each metropolitan area, which will become evident in the examination of the metropolitan area specific results in the next section. Although an average for these metropolitan areas may not prove useful in the context of this study, given the a priori selection of the study areas for their divergent characteristics, this modeling approach may prove useful for established metropolitan area peer groups. The discussion of the metropolitan area results in the next section is the first step in establishing such peer groups, which are likely to prove more useful in benchmarking studies than are pooled results for dissimilar metropolitan areas or national level results.

7.3 Metropolitan Area Models

As mentioned previously, variation in the metropolitan area specific results is illustrated by examining the estimation results in Table 5, which provides a summary of the best models for knowledge intensive firm location. Detailed results for each of these metropolitan areas may be found in Appendices C-H. The most obvious difference in the results produced by these models is the variation in the size of the coefficient on broadband. The elasticity of broadband ranges from a low value of 1.2104 for Detroit to a high value of 3.8187 for Columbus. Figure 3 depicts the relative sizes of the coefficients on broadband with their respective confidence intervals for each of the six metropolitan areas, the national level model and the pooled metropolitan area model. A large amount of overlap in the bars for each of the metropolitan areas suggests no likely statistical difference in the relative importance of the level of broadband to knowledge intensive firms. An interesting aspect of this figure is its ability to highlight peer groups with respect to the primary relationship of interest; metropolitan areas with overlap in their confidence intervals possess similar coefficients on broadband. From this perspective, Atlanta, Columbus, Dallas, and San Jose form one peer group while Boston and Detroit represent two distinct peer groups with relatively lower coefficients than the first peer group. The coefficient on Boston is similar to the coefficient for the national model while the coefficients for the first peer group (Atlanta, Columbus, Dallas, and San Jose) are noticeably higher than the national average and the coefficient for the pooled metropolitan model. Detroit, as expected, has the smallest coefficient of all the metropolitan areas. Despite this result, it is important to note that broadband is still important to knowledge intensive businesses in the area. This suggests that places with similar industrial structures may derive some benefits from strategic plans or policies designed to attract broadband providers to their metropolitan areas.

Although these results are largely in line with expectations prior to estimation of the models, the results for two metropolitan areas are particularly interesting. The result for Boston compared to San Jose is noteworthy given the hypothesis generated from Saxenian's work (1994), which predicted broadband would have a greater impact on knowledge intensive businesses in San Jose than Boston. The Columbus result is also noteworthy given the size of its broadband coefficient, which is the largest of all the metropolitan areas, although broadband was anticipated to be of moderate importance to knowledge intensive businesses in this area. The larger than expected sign on this coefficient may be due to a metropolitan specific process at work that the current model is unable to capture despite the large adjusted R-squared of 0.76. This may result in elevated importance of broadband because the impact of other excluded variables is included in the broadband coefficient. The same rationale may also explain the large coefficients for the Atlanta and San Jose models, which also produce high adjusted R-squares but few independently significant variables. Further sensitivity analysis of these metropolitan area results is recommended as an area for future research, which will be elaborated upon further in the next section.

The diversity of results for each metropolitan area with respect to the other independent variables of interest suggests a metropolitan area specific approach is perhaps best for the research question of interest. One of the most obvious differences across the models is their specification. For example, the Boston and Detroit models incorporate a spatial lag in their specification while the others do not. This is an important difference and suggests spillover effects for knowledge intensive firm development may be present in surrounding ZIP codes. The potential presence of spillover effects in these metropolitan areas or equivalently, a spatial multiplier, means the impact of broadband deployment efforts or other development efforts targeting firms in the knowledge intensive sector will be greater for metropolitan areas where this impact is present as opposed to metropolitan areas with no spatial multiplier effect. The spatial econometric techniques utilized in this study are able to tease out this important subtlety that helps explain why knowledge intensive firm growth rates may be greater in some metropolitan areas than others. More importantly, the ability to estimate this spatial effect reduces the size of the coefficient on broadband, or the propensity to overestimate the importance of the level of broadband to knowledge intensive firm presence in a ZIP code. For example, the 2SLS results for Boston in Appendix D estimate the coefficient on broadband to be 2.5067 while the incorporation of a spatial lag reduces this coefficient by 15% to 2.1739.

Where the other independent variables are concerned, the size and significance of these variables are highly metropolitan area specific. For example, household income has a positive and significant impact on knowledge intensive firm development in Boston, Dallas, and Detroit but not Atlanta, Columbus, or San Jose. Percent renter occupied has a positive and significant impact on firms in this sector in Boston, Dallas, Detroit, and San Jose but not Atlanta or Columbus. The only variable besides broadband with a consistent positive and significant impact on knowledge intensive firm presence across metropolitan areas is highway miles. Although the variables in the models are able to jointly account for a large amount of the variation in the presence of knowledge intensive firms, the results suggest a detailed, metropolitan specific investigation of other independent variables to incorporate in the models, may yield results which provide more information regarding the marginal impacts of various factors related to knowledge intensive firm presence. Again, these results demonstrate a uniform approach to modeling this important relationship across metropolitan areas is unlikely to produce results that will inform economic development efforts or policies seeking to promote knowledge intensive firm growth.

8. Discussion and Conclusion

The spatial econometric models constructed from ZIP code level data seek to evaluate the relative importance of broadband provision to knowledge intensive firm location. The proposed modeling approach also attempts to address several methodological gaps in the current literature including estimation problems related to endogeneity, spatial autocorrelation, and heteroskedasticity. Results demonstrate the level of broadband provision in a ZIP code area is important to knowledge intensive firm presence, but that this importance exhibits marked variation across metropolitan areas. Of particular interest is the presence of spillovers in knowledge firm presence in specific metropolitan areas. These effects suggest policies designed to create knowledge intensive firm growth, including broadband deployment initiatives, are likely to yield more firm growth in areas with spillover effects than in areas lacking spillover effects. Metropolitan areas with spillover effects may also be more likely to change their industrial composition at a faster pace than places without these effects. This is a particularly salient point for places like Detroit which are seeking to transform their industrial, manufacturing-oriented economic base to one that is of a post-industrial or knowledge intensive focus.

Although the current availability of broadband data from the FCC, which does not contain information about specific providers, platforms, or speeds, prevents more stringent conclusions from being drawn from these data (Holt and Jamison, 2009), the methodological framework presented in this study certainly represents a viable framework from which sensitivity analyses of these results may be conducted. As more granular data become available from the FCC at the census tract level, sensitivity analyses with respect to the spatial scale of the data is of particular interest given the sensitivity of the metropolitan area results to the weights matrix used in the estimation of the models, and the further investigation of spillover effects at the metropolitan area level. The sensitivity of the results to weights matrix specification is likely due to the use of ZIP code area data, which are not based on nested geographical units, and are in fact polygons interpolated from linear and point features (Grubesic, 2008b). The use of these data also suggests the finding of spillover effects may be related to the spatial resolution of the data as opposed to a spatial process at work within the metropolitan areas of interest. Spillover effects may be present when measurement errors are the source of spatial dependence in a dataset (Anselin, 1988). Measurement errors of this nature are likely to occur when there is a mismatch between the spatial scale of the phenomenon of interest and the spatial scale for which the data are reported (ibid, p. 12). A sensitivity analysis of the current results using data collected at a different spatial scale will help evaluate whether the spillover effects uncovered in this paper are related to a metropolitan specific spatial process, or measurement error. Additional analysis that decomposes the results of this study by both sub-industry of the knowledge sector and firm size may also provide a clearer picture of the impacts of ICTs on knowledge intensive firm location.

Despite the current limitations of this study, its analytical results present both key methodological advancements and insights regarding the impact of space-time shrinking technologies on firm location. First, the spatial econometric results produced by this study are demonstrated to be an improvement over the standard OLS estimation of models typically employed in studies examining this research question. Second, findings recommend the use of metropolitan specific models in place of national level models to estimate the importance of ICTs, like broadband, to the presence of businesses in an area. This approach is particularly important given the demonstrated heterogeneity in this relationship across metropolitan areas. Third, the finding of potential spillover effects on regional economies may help explain why some places, ceteris paribus, may be relatively more successful at stimulating firm growth in this important sector of the economy. Certainly, the results of this study demonstrate a viable approach for examining the relationship between information and communications technologies and firm location. Results demonstrate this approach has the potential to provide a deeper understanding of the processes at work on businesses within metropolitan areas so that more effective strategies and policies for stimulating regional growth may be developed.

[1] TeleAtlas was formerly GDT.

[2] The U.S. Census Bureau refers to businesses as establishments and defines these as "a single physical location at which business is conducted or services or industrial operations are performed. It is not necessarily identical with a company or enterprise, which may consist of one or more establishments" (U.S. Census, 2009b). The Census database does not include information about the following: government entities, self-employed individuals, employees of private households, railroad employees, and agricultural production employees (ibid).

[3] The FCC (2009) defines a facilities-based provider as: "an entity (including subsidiaries and affiliates) that: 1) owns the portion of the physical facility that terminates at the end-user location as a broadband connection; 2) provisions/equips broadband wireless channels to end-user locations over licensed spectrum or over spectrum that the entity uses on an unlicensed basis; or 3) obtains unbundled network elements (UNEs), special access lines, or other leased facilities that terminate at end-user locations and provisions/equips them as broadband."

[4] The Form 477 FCC data reports combined information about cable, DSL, and wireless broadband providers (FCC, 2009).

[5] The FCC defines a broadband Internet connection as one that permits users to send and/or receive data using the Internet at transmission rates of *greater than* 200 kilobits per second (kbps) in at least one direction (FCC, 2009).

[6] The Census 2000 "classifies as 'urban' all territory, population, and housing units located within an urbanized area (UA) or an urban cluster (UC). It delineates UA and UC boundaries to

encompass densely settled territory, which consists of core census block groups or blocks that have a population density of at least 1,000 people per square mile and surrounding census blocks that have an overall density of at least 500 people per square mile" (U.S. Census, 2009a).

[7] Producers services firms, which are defined as firms that provide advanced services for other firms (Sassen, 1991: 11) are included under the umbrella of knowledge intensive firms, as defined in this study.

[8] This approach did not yield viable instruments for knowledge intensive businesses.

[9] In the global model and five of the six metropolitan area specific regressions, the null hypothesis in favor of OLS was rejected. The only exception was San Jose, which has the fewest observations of all the metropolitan areas. The small number of observations may explain the failure to reject the null hypothesis (Staiger and Stock, 1997).

[10] For the specification of the global Moran see Anselin (1995).

[11] For the specification of the bivariate global Moran see Anselin et al. (2002).

[12] Significance in this study refers to p-values of 0.05 or smaller.

[13] The HAC estimator for this paper considered the use of both Epanechnikov (1969) and Triangular kernels.

[14] For a more thorough discussion of weights matrices please see Anselin (1988).

[15] A queen weights matrix and a 6-knn weights matrix at the metropolitan area level result in similar neighbors.

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Appendix A: Descriptive Statistics for Variables of Interest

Variable Name	Obs	Mean	Std. Dev.	Min	Max
Urban Area	14,679	0.6219	0.4849	0.0000	1.0000
Average Household Size	14,679	2.5561	0.5646	0.0000	8.0000
Percent White	14,679	0.7925	0.2165	0.0000	1.0000
Percent Renter Occupied	14,679	0.2926	0.1727	0.0000	1.0000
Growth Population 18-65	14,679	-0.3411	0.1743	-1.0000	9.0000
Ln Broadband Provision	14,679	1.9201	0.4246	1.3863	3.0445
Ln Knowledge Intensive Firms	14,679	3.7267	1.4075	0.6932	7.9855
Household Density	14,679	1,034.3120	3,370.0690	0.0000	155,922.3000
Highway Miles	14,679	16.9507	17.3794	0.0000	244.9494
Distance from Airport	14,679	21.5594	15.8530	0.1366	165.3135
Ln Median Household Income	14,679	10.7176	0.4976	0.0000	12.8347
Urbanization Economies	14,679	8.9692	11.6158	0.0000	146.4890

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Appendix B: Correlation Matrix for Variables of Interest

	Urban Area	Average Household Size	Percent White	Percent Renter Occupied	Growth Population 18-65	Ln Broadband Provision	Ln Knowledge Intensive Firms	Household Density	Highway Miles	Distance from Airport	Ln Median Household Income	Urbanization Economies
Urban Area	1											
Average Household Size	0.1043	1										
Percent White	-0.3279	-0.1652	1									
Percent Renter Occupied	0.281	-0.2009	-0.5728	1								
Growth Population 18-65	-0.1381	0.0969	0.0747	-0.2764	1							
Ln Broadband Provision	0.5883	0.0376	-0.3636	0.3825	-0.1509	1						
Ln Knowledge Intensive Firms	0.5061	-0.1398	-0.2108	0.3808	-0.1367	0.7129	1					
Household Density	0.2237	-0.043	-0.2754	0.414	-0.1509	0.3023	0.2243	1				
Highway Miles	-0.3427	-0.0593	0.0661	-0.0841	0.0794	-0.1525	0.0834	-0.1783	1			
Distance from Airport	-0.5687	-0.0789	0.2841	-0.2764	0.1763	-0.4322	-0.3417	-0.2218	0.346	1		
Ln Median Household Income	0.1981	0.1678	0.2429	-0.2584	-0.0069	0.183	0.2176	-0.0122	-0.1135	-0.1115	1	
Urbanization Economies	0.6021	0.0938	-0.1428	0.0841	-0.055	0.3594	0.3927	-0.0053	0.2196	-0.2718	0.1136	1

All correlation coefficients are significant at the 1% level.

Appendix C: Model Estimation Results for Atlanta

	OLS	2SLS
Ln Broadband Provision	2.4646** (0.1674)	3.2045** (0.2786)
Ln Median Household Income	0.1033 (0.0725)	-0.0263 (0.0849)
Urban Area	0.9899** (0.2857)	0.4270 (0.3416)
Percent White	1.3240** (0.2967)	1.5795** (0.3197)
Average Household Size	-0.2806* (0.1307)	-0.1884 (0.1396)
Percent Renter Occupied	0.3484 (0.4482)	0.3522 (0.4695)
Growth Population 18-65	-1.0762* (0.5444)	-0.7729 (0.5773)
Highway Miles	0.0338** (0.0048)	0.0320** (0.0050)
Distance from Airport	-0.0031 (0.0062)	-0.0065 (0.0066)
Urbanization Economies	-0.0186* (0.0074)	-0.0162* (0.0078)
Constant	-4.2869** (.8792)	-4.4258** (0.9220)
Rho (Spatial Lag)	--	--
Lambda (Spatial Error)	--	--
Adjusted/Pseudo R-squared	0.7811	0.7793
Breusch-Pagan test statistic	9.44**	--
Pagan-Hall test statistic		16.404
Wu-Hausman F test		14.8821**
A-K Res. S.A. test statistic		0.17

**Significance at the 1% level.
*Significance at the 5% level.

Appendix D: Model Estimation Results for Boston

	OLS	2SLS	2SLS with a Spatial Lag	2SLS with a Spatial Lag and White Std. Errors
Ln Broadband Provision	1.4818** (0.1343)	2.5067** (0.3407)	2.1739** (0.3446)	2.1739** (0.2925)
Ln Median Household Income	1.6837** (0.1926)	1.4244** (0.2252)	1.2224** (0.2270)	1.2224** (0.2379)
Urban Area	0.6432** (0.2420)	0.9049** (0.2770)	0.6067* (0.2975)	0.6067* (0.2620)
Percent White	0.3556 (0.3860)	0.8094 (0.4449)	0.9114* (0.4139)	0.9114** (0.3216)
Average Household Size	-.1207 (0.1004)	-0.0483 (0.1123)	-0.0949 (0.1074)	-0.0949 (0.1000)
Percent Renter Occupied	2.3128** (0.4405)	1.6817** (0.5191)	1.5217** (0.4828)	1.5217** (0.4781)
Growth Population 18-65	0.1816 (0.3989)	0.2106 (0.4378)	0.1202 (0.4120)	0.1202 (0.3754)
Highway Miles	0.0502* (0.0219)	0.0640** (0.0244)	0.0585** (0.0229)	0.0585** (0.0174)
Distance from Airport	0.008 (0.0071)	0.0220** (0.0088)	0.0224** (0.0080)	0.0224** (0.0079)
Urbanization Economies	0.0165 (0.0230)	-0.0272 (0.0285)	-0.0115 (0.0274)	-0.0115 (0.0221)
Constant	-19.2373** (2.2161)	-18.9960** (2.4330)	-16.7682** (2.5134)	-16.7682** (2.6290)
Rho (Spatial Lag)	--	--	0.2150* (0.1035)	0.2150* (.1048)
Lambda (Spatial Error)	--	--	--	--
Adjusted/Pseudo R-squared	0.7123	0.6857	0.7039	0.7039
Breusch-Pagan test statistic	7.17**	--	--	--
Pagan-Hall test statistic	--	28.501**	--	--
Wu-Hausman F test	--	14.6722**	--	--
A-K LM test statistic	--	15.87**	1.95	1.95

**Significance at the 1% level.
*Significance at the 5% level.

Appendix E: Model Estimation Results for Columbus

	OLS	2SLS
Ln Broadband Provision	2.3287** (0.3328)	3.8187** (0.7977)
Ln Median Household Income	1.2161** (0.3711)	0.6743 (0.4831)
Urban Area	0.4471 (0.4120)	0.0741 (0.4873)
Percent White	0.2407 (0.7437)	1.2512 (0.9497)
Average Household Size	-0.297 (0.2522)	0.0288 (0.3181)
Percent Renter Occupied	1.3313 (0.8001)	1.1731 (0.8845)
Growth Population 18-65	0.6578 (0.9427)	1.4241 (1.1004)
Highway Miles	0.0432** (0.0069)	0.0367** (0.0081)
Distance from Airport	0.0124 (0.0102)	0.0279* (0.0134)
Urbanization Economies	0.0023 (0.0152)	-0.0009 (0.0168)
Constant	-15.1452** (3.8437)	-13.7769** (4.2834)
Rho (Spatial Lag)	--	--
Lambda (Spatial Error)	--	--
Adjusted/Pseudo R-squared	0.7845	0.7752
Breusch-Pagan test statistic	0.31	--
Pagan-Hall test statistic	--	10.364
Wu-Hausman F test	--	5.7319*
A-K LM test statistic	--	0.98

**Significance at the 1% level.
*Significance at the 5% level.

Appendix F: Model Estimation Results for Dallas

	OLS	2SLS
Ln Broadband Provision	1.9082** (0.1565)	2.8055** (0.3430)
Ln Median Household Income	0.8370** (0.1904)	0.5444* (0.2250)
Urban Area	0.3517 (0.2175)	0.1356 (0.2426)
Percent White	1.0134** (0.3199)	0.8858** (0.3433)
Average Household Size	-0.3479** (0.1051)	-0.2869** (0.1137)
Percent Renter Occupied	1.7489** (0.3818)	0.9600* (0.4845)
Growth Population 18-65	0.9713* (0.4253)	0.5506 (0.4742)
Highway Miles	0.0280** (0.0044)	0.0233** (0.0050)
Distance from Airport	-0.0109* (0.0052)	-0.0005 (0.0065)
Urbanization Economies	-0.013 (0.0071)	-0.0178* (0.0077)
Constant	-9.5094** (2.0280)	-8.2420** (2.2003)
Rho (Spatial Lag)	--	--
Lambda (Spatial Error)	--	--
Adjusted/Pseudo R-squared	0.7968	0.7856
Breusch-Pagan test statistic	3.48	--
Pagan-Hall test statistic	--	8.165
Wu-Hausman F test	--	13.5566**
A-K Res. S.A. test	--	0.00

**Significance at the 1% level.
*Significance at the 5% level.

Appendix G: Model Estimation Results for Detroit

	OLS	2SLS	2SLS with a Spatial Lag
Ln Broadband Provision	1.1963** (0.1497)	1.7402** (0.2729)	1.2104** (0.2852)
Ln Median Household Income	1.7552** (0.1719)	1.4759** (0.2118)	1.5507** (0.1926)
Urban Area	0.4327 (0.2499)	0.3395 (0.2610)	0.2673 (0.2554)
Percent White	-0.5955* (0.2486)	-0.4743 (0.2617)	-0.3536 (0.2624)
Average Household Size	-0.5122** (0.1028)	-0.3981** (0.1162)	-0.4679** (0.1096)
Percent Renter Occupied	2.0283** (0.4337)	1.7274** (0.4649)	1.9682** (0.4472)
Growth Population 18-65	2.1455** (0.5128)	2.0501** (0.5312)	2.1325** (0.5116)
Highway Miles	0.0352* (0.0154)	0.0357* (0.0159)	0.0444** (0.0159)
Distance from Airport	0.0029 (0.0034)	0.0054 (0.0037)	0.0054 (0.0035)
Urbanization Economies	0.0077 (0.0165)	-0.0005 (0.0174)	0.0010 (0.0166)
Constant	-16.0803** (1.7177)	-14.4378** (1.8998)	-15.3943** (1.7973)
Rho (Spatial Lag)	--	--	0.3075* (0.1511)
Lambda (Spatial Error)	--	--	--
Adjusted/Pseudo R-squared	0.7729	0.7718	0.7801
Breusch-Pagan test statistic	1.15	--	--
Pagan-Hall test statistic	--	9.059	--
Wu-Hausman F test	--	7.2734**	0.44
A-K Res. S.A. test	--	7.85**	0.5088

**Significance at the 1% level.
*Significance at the 5% level.

Appendix H: Model Estimation Results for San Jose

	OLS	2SLS
Ln Broadband Provision	2.7203** (0.2734)	3.3271** (0.5025)
Ln Median Household Income	0.8313* (0.3526)	0.5257 (0.4212)
Urban Area	0.5684 (0.4209)	0.4600 (0.4429)
Percent White	-0.3307 (0.6050)	0.2330 (0.7364)
Average Household Size	-0.2641* (0.1320)	-0.2053 (0.1427)
Percent Renter Occupied	2.9557** (0.7077)	2.6090** (0.7713)
Growth Population 18-65	2.0147** (0.5647)	1.8853** (0.5924)
Highway Miles	0.0231** (0.0077)	0.0200* (0.0083)
Distance from Airport	0.001 (0.0130)	0.0120 (0.0155)
Urbanization Economies	-0.0032 (0.0094)	-0.0067 (0.0100)
Constant	-11.097** (3.8125)	-9.5029** (4.1018)
Rho (Spatial Lag)	--	--
Lambda (Spatial Error)	--	--
Adjusted/Pseudo R-squared	0.8434	0.8570
Breusch-Pagan test statistic	6.05*	--
Pagan-Hall test statistic	--	9.987
Wu-Hausman F test	--	1.2201
A-K Res. S.A. test	--	0.02

**Significance at the 1% level.
*Significance at the 5% level.

Table 1: Variable Descriptions

Variable	Status	Definition	Description	Hypothesized Sign
Ln Knowledge Establishments[1]	Dependent	Ln of the number of knowledge establishments in a ZIP code in 2004	Number of knowledge establishments in a ZIP code	N/A
LN Broadband Providers	Independent	Ln of the number of broadband providers in a ZIP code in 2004	Measure of broadband infrastructure	+
Ln Median Household Income	Independent	Ln of 2006 household median income	Proxy variable for educated labor force	+
Urban Area[2] *Membership*	Independent	ZIP code area intersects Census defined urbanized area (=1); ZIP code area does not intersect an urbanized area (=0).	Proxy variable for location (urban v. rural)	+
Percent White	Independent	Percent of white population	Proxy for suburban location preference	+
Average Household Size	Independent	Average number of people in a household	Proxy variable for central city location preference	-
Percent Renter Occupied	Independent	Percent of housing units that are renter occupied	Proxy variable for central city location preference	+
Growth Population 18-65	Independent	Growth of the population ages 18-65 between 2001 and 2006	Describes the growth in the size of the labor pool	+
Highway Miles	Independent	Aggregate number of highway miles	Measure of ease of travel via highways to a ZIP code area	+
Distance from Airport	Independent	Distance of a ZIP code (in miles) from the nearest commercial airport	Measure for ability to travel via airplane for local area businesses	-
Urbanization Economies	Independent	Interaction variable: urban area dummy multiplied by (Sum of the ln of broadband and aggregate highway miles)	Proxy for urbanization economies associated with infrastructure that is likely important to knowledge intensive firms	+

1. The number of knowledge establishments in a ZIP code is the sum of establishments in the following two-digit NAICS industries: Information (51), Finance and Insurance (52), Professional, Scientific, and Technical Services (54), Management of Companies and Enterprises (55), and Educational Services (62).

2. An urbanized area consists of core census block groups or blocks that have a population density of at least 1,000 people per square mile and surrounding census blocks that have an overall density of at least 500 people per square mile (Census Bureau, 2002).
For more information, see http://www.census.gov/geo/www/ua/ua_2k.html

Table 2: Global Moran and Bivariate Moran Analysis

	Global Moran[1]		Multivariate Moran[1]
	z-value (ln Knowledge Intensive Firms)	z-value (ln Broadband Provision)	y (ln Knowledge Intensive Firms), x (ln Broadband Provision)
Atlanta	16.75**	27.37**	22.97**
Boston	14.43**	14.77**	14.00**
Columbus	7.32**	14.86**	11.63**
Dallas	18.12**	29.40**	25.39**
Detroit	12.09**	17.01**	15.05**
San Jose	4.20**	-8.15**	7.32**
All ZIPs	84.32**	138.98**	100.85**

1. Results were obtained by using a distance-based weights matrix for each of the metropolitan areas of interest. The results for All ZIPs were obtained via a 6knn weights matrix.
**Significance at the 1% level.

Table 3: Model Estimation Results for All Continental U.S. ZIP Codes

	OLS	2SLS	2SLS with a Spatial Lag	2SLS with a Spatial Lag and HAC Std. Errors	2SLS with a Lagged Error Term
Ln Broadband Provision	1.8316** (0.0218)	2.4443** (0.0447)	2.3989** (0.0458)	2.3989** (0.0458)	2.0112** (0.0447)
Ln Median Household Income	0.4141** (0.0160)	0.3164** (0.0175)	0.3264** (0.0172)	0.3264** (0.0172)	0.2893** (0.0175)
Urban Area	0.6977** (0.0269)	0.4830** (0.0307)	0.5090** (0.0313)	0.5090** (0.0313)	0.5256** (0.0307)
Percent White	.7247** (0.0443)	0.8820** (0.0466)	0.8681** (0.0462)	0.8681** (0.0462)	0.8448** (0.0466)
Average Household Size	-.3463** (0.0137)	-0.3371** (0.0140)	-0.3378** (0.0140)	-0.3378** (0.0140)	-0.3365** (0.0140)
Percent Renter Occupied	1.5896** (0.0570)	1.2713** (0.0619)	1.3002** (0.0609)	1.3002** (0.0609)	1.8415** (0.0619)
Growth Population 18-65	0.1967** (0.0420)	0.2111** (0.0432)	0.2081** (0.0432)	0.2081** (0.0432)	0.2630** (0.0432)
Highway Miles	0.0235** (0.0005)	0.0226** (0.0005)	0.0226** (0.0005)	0.0226** (0.0005)	0.0235** (0.0005)
Distance from Airport	-0.0046** (0.0005)	-0.0029** (0.0006)	-0.0031** (0.0006)	-0.0031** (0.0006)	-0.0061** (0.0006)
Urbanization Economies	-0.0038** (0.0009)	-0.0042** (0.0009)	-0.0043** (0.0010)	-0.0043** (0.0010)	-0.0029** (0.0009)
Constant	-5.0145** (0.1692)	-5.0783** (0.1738)	-5.0717** (0.1733)	-5.0717** (0.1733)	-4.0616** (0.1738)
Rho (Spatial Lag)	--	--	-0.0092 (0.0161)	-0.0092 (0.0161)	--
Lambda (Spatial Error)	--	--	--	--	0.4908
Adjusted/Pseudo R-squared	0.6437	0.6323	0.6345	0.6345	0.6391
Breusch-Pagan test statistic	492.52**	--	--	--	--
Pagan-Hall test statistic	--	269.480**	--	--	--
Wu-Hausman F test	--	298.7689**	--	--	--
A-K LM Test Statistic	--	3450.06**	586.73**	--	--

**Significance at the 1% level.
*Significance at the 5% level.

Table 4: Model Estimation Results for Pooled Metropolitan Areas of Interest

	OLS	2SLS	2SLS with a Spatial Lag	2SLS with a Spatial Lag and HAC Std. Errors
Ln Broadband Provision	1.8572** (0.0688)	2.8132** (0.1400)	2.4210** (0.1198)	2.4210** (0.1402)
Ln Median Household Income	0.4977** (0.0571)	0.2352** (0.0698)	0.2899** (0.0646)	0.2899** (0.2036)
Urban Area	1.0234** (0.0994)	0.8587** (0.1094)	0.8831** (0.1030)	0.8831** (0.1103)
Percent White	0.7391** (0.1284)	1.1840** (0.1493)	1.1052** (0.1395)	1.1052** (0.1887)
Average Household Size	-0.3020** (0.0515)	-0.1884** (0.0574)	-0.2347** (0.0538)	-0.2347** (0.0567)
Percent Renter Occupied	0.9704** (0.1819)	0.5277** (0.2041)	0.7642** (0.1912)	0.7642** (0.2518)
Growth Population 18-65	0.1703 (0.2152)	0.3210 (0.2335)	0.3276 (0.2204)	0.3276 (0.2350)
Highway Miles	0.0304** (0.0025)	0.0278** (0.0027)	0.0286** (0.0026)	0.0286** (0.0028)
Distance from Airport	-0.0003 (0.0023)	0.0033 (0.0025)	0.0026 (0.0023)	0.0026 (0.0025)
Urbanization Economies	-0.0103** (0.0037)	-0.0211** (0.0043)	-0.0167** (0.0040)	-0.0167** (0.0040)
Constant	-6.3871** (0.6220)	-5.8440** (0.6759)	-6.7441** (0.6494)	-6.7441** (1.8743)
Rho (Spatial Lag)	--	--	0.2954** (0.0543)	0.2954** (0.0625)
Lambda (Spatial Error)	--	--	--	--
Adjusted/Pseudo R-squared	0.7175	0.6930	0.7036	0.7036
Breusch-Pagan test statistic	88.78**	--	--	--
Pagan-Hall test statistic	--	69.21**	--	--
Wu-Hausman F test	--	82.40**	--	--
A-K LM Test Statistic	--	40.37**	4.35*	--

**Significance at the 1% level.
*Significance at the 5% level.

Table 5: Best Models for Knowledge Intensive Firm Location

	All ZIPS	Pooled Metros	Atlanta	Boston	Columbus	Dallas	Detroit	San Jose
	2SLS with a Lagged Error Term	2SLS with a Spatial Lag and HAC Std. Errors	2SLS	2SLS with a Spatial Lag and White Std. Errors	2SLS	2SLS	2SLS with a Spatial Lag	2SLS
Ln Broadband Provision	2.0112** (0.0447)	2.4210** (0.1402)	3.2045** (0.2786)	2.1739** (0.2925)	3.8187** (0.7977)	2.8055** (0.3430)	1.2104** (0.2852)	3.3271** (0.5025)
Ln Median Household Income	0.2893** (0.0175)	0.2899** (0.2036)	-0.0263 (0.0849)	1.2224** (0.2379)	0.6743 (0.4831)	0.5444* (0.2250)	1.5507** (0.1926)	0.5257 (0.4212)
Urban Area	0.5256** (0.0307)	0.8831** (0.1103)	0.4270 (0.3416)	0.6067* (0.2620)	0.0741 (0.4873)	0.1356 (0.2426)	0.2673 (0.2554)	0.4600 (0.4429)
Percent White	0.8448** (0.0466)	1.1052** (0.1887)	1.5795** (0.3197)	0.9114** (0.3216)	1.2512 (0.9497)	0.8858** (0.3433)	-0.3536 (0.2624)	0.2330 (0.7364)
Average Household Size	-0.3365** (0.0140)	-0.2347** (0.0567)	-0.1884 (0.1396)	-0.0949 (0.1000)	0.0288 (0.3181)	-0.2869** (0.1137)	-0.4679** (0.1096)	-0.2053 (0.1427)
Percent Renter Occupied	1.8415** (0.0619)	0.7642** (0.2518)	0.3522 (0.4695)	1.5217** (0.4781)	1.1731 (0.8845)	0.9600* (0.4845)	1.9682** (0.4472)	2.6090** (0.7713)
Growth Population 18-65	0.2630** (0.0432)	0.3276 (0.2350)	-0.7729 (0.5773)	0.1202 (0.3754)	1.4241 (1.1004)	0.5506 (0.4742)	2.1325** (0.5116)	1.8853** (0.5924)
Highway Miles	0.0235** (0.0005)	0.0286** (0.0028)	0.0320** (0.0050)	0.0585** (0.0174)	0.0367** (0.0081)	0.0233** (0.0050)	0.0444** (0.0159)	0.0200* (0.0083)
Distance from Airport	-0.0061** (0.0006)	0.0026 (0.0025)	-0.0065 (0.0066)	0.0224** (0.0079)	0.0279* (0.0134)	-0.0005 (0.0065)	0.0054 (0.0035)	0.0120 (0.0155)
Urbanization Economies	-0.0029** (0.0009)	-0.0167** (0.0040)	-0.0162* (0.0078)	-0.0115 (0.0221)	-0.0009 (0.0168)	-0.0178* (0.0077)	0.0010 (0.0166)	-0.0067 (0.0100)
Constant	-4.0616** (0.1738)	-6.7441** (1.8743)	-4.4258** (0.9220)	- 16.7682** (2.6290)	-13.7769** (4.2834)	-8.2420** (2.2003)	-15.3943** (1.7973)	- 9.5029** (4.1018)
Rho (Spatial Lag)	--	0.2954** (0.0625)	--	0.2150* (.1048)	--	--	0.3075* (0.1511)	--
Lambda (Spatial Error)	0.4908	--	--	--	--	--	--	--
Adjusted/Pseudo R-squared	0.6391	0.7036	0.7793	0.7039	0.7752	0.7856	0.7801	0.8570
Breusch-Pagan test statistic	--	--	--	--	--	--	--	--
Pagan-Hall test statistic	--	--	16.404	--	10.364	8.165	--	9.987
Wu-Hausman F test	--	--	14.8821**	--	5.7319*	13.5566**	--	1.2201
A-K LM test statistic	--	--	0.17	1.95	0.98	0.00	0.5088	0.02

**Significance at the 1% level.
*Significance at the 5% level.

Figure 1: ZIP codes (2004) and Metropolitan Area Boundaries (2003)

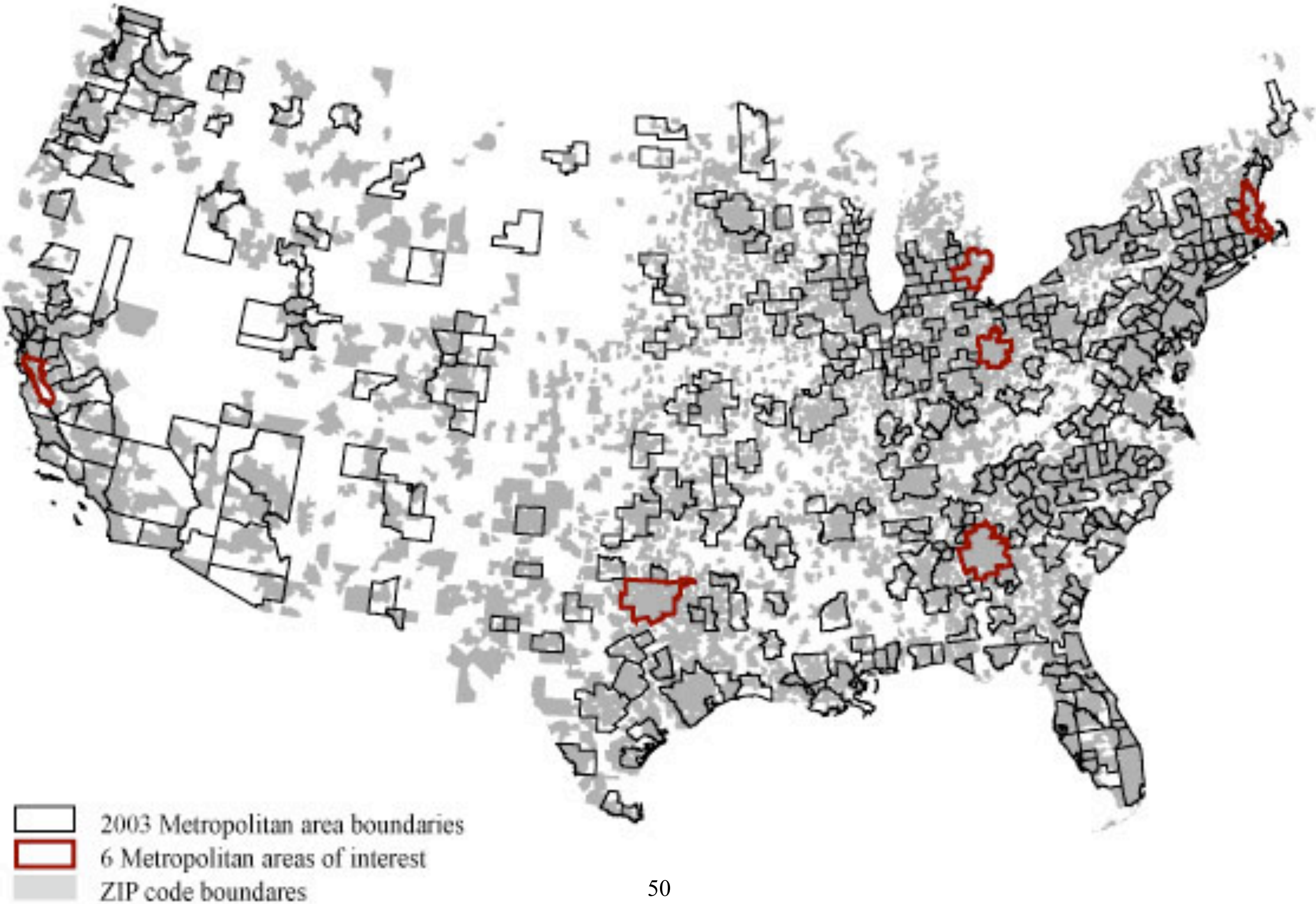

Figure 2: Local Indicators of Spatial Association for Knowledge Intensive Firms by Metropolitan Area

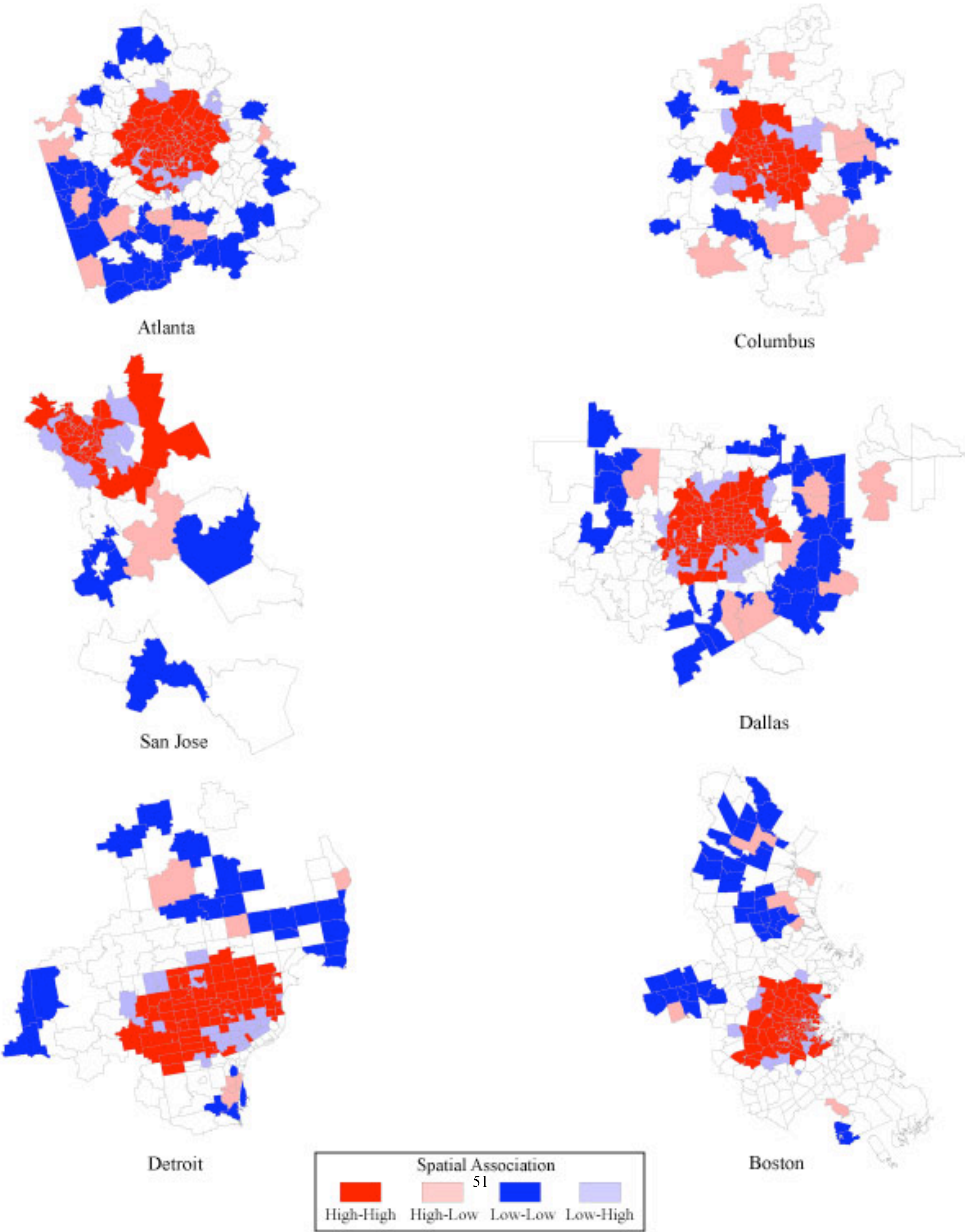

Figure 3: Broadband Coefficients with their Confidence Intervals