



Transportation Infrastructures and Socioeconomic Statuses: A Spatial Regression Analysis at the County Level in the Continental United States, 1970–2010

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Abstract

There is a large body of literature examining transportation impacts on population and employment growth. However, the possible impacts that transportation infrastructures have on socioeconomic statuses are less clear. This study fills the gap in the literature by associating education and income—two socioeconomic status measures—with transportation infrastructures. In specific, this study examines the associations of railroads, highways, and airports collectively with high school, Bachelor's degree, graduate degree, and income change in the continental United States for the period between 1970 and 2010. Data come from various sources, such as National Transportation Atlas Database, Decennial Census, Cartographic Boundary Shapefiles, and Land Developability Index. Standard regression and spatial analysis are conducted at decade levels and at the entire study period to test the consistency of the associations between transportation infrastructures and education and income. The study shows that railroads have a distributive and highways have a facilitative association with both education and income. Airports behave as a growth factor with education and as a facilitator with income. The findings clearly show the increased complexity of the roles performed by transportation infrastructures and do not show straightforward behaviors as has been considered for a long time. This study provides new insights into the role of transportation infrastructures for transportation planning and decision making.

Keywords Infrastructure · Socioeconomic impact · Spatial association

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1 Introduction

A large body of literature exists on the associations between transportation infrastructures and demographic and economic characteristics (Chi 2010; Levinson 2008a). Despite the large volume of literature, the associations of transportation with different socioeconomic characteristics is not adequately understood. One of the reasons for the poor understanding is the lack of a systematic study. In this manuscript, we have tried to address this issue by bringing three modes of transportation together—railroads, highways, and airports—in the analytical models and running spatial regression analyses at five periods—four separate decade levels and one at the entire study period. This manuscript examines the associations of the three transportation infrastructures collectively with education change and income change in the continental United States from 1970 to 2010 (Fig. 1).

Education and income have a complex relationship with population size, composition, and distribution. A high level of education is associated with better employment opportunities and higher incomes (Abdullah et al. 2015). Similarly, a low level of education is associated with poor employment opportunities and lower incomes. The household earning influences neighborhood selection. People with higher levels of education and higher incomes live in rich neighborhoods; people with lower levels of education and lower incomes live in poor neighborhoods (Bischoff

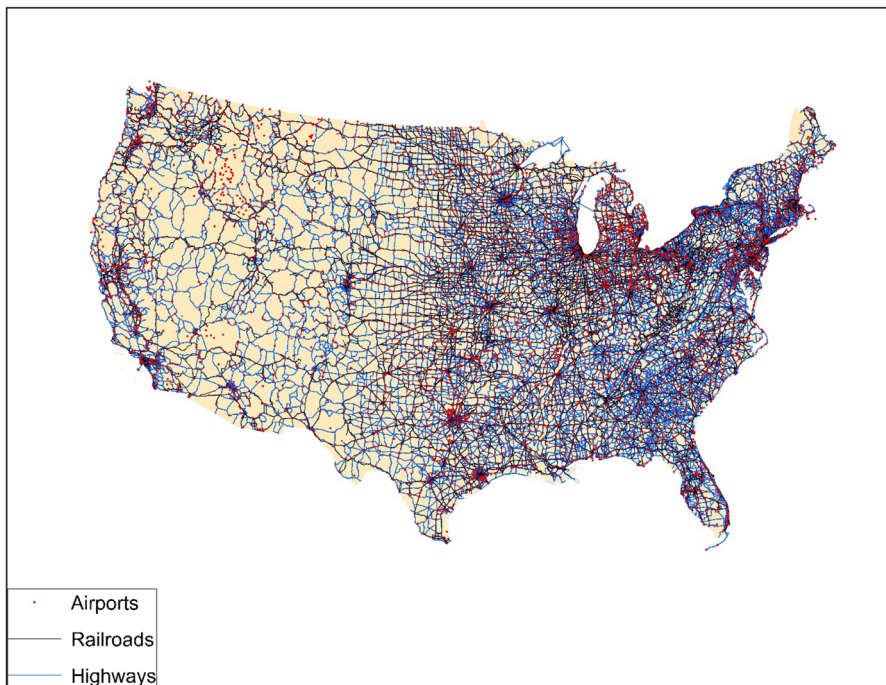


Fig. 1 Transportation infrastructures in the United States

and Reardon 2014). Education and income are important determinants of population composition and distribution. So are the transportation infrastructures such as railroads, highways, and airports. Since transportation infrastructures, education, and income have demographic and developmental consequences, it is important to understand their relationships. This understanding becomes essential now because railroads, highways, and airports are in the post-construction phase and they are competing with each other. In this context, our question is: how is each transportation infrastructure individually and collectively associated with education and income change? This study reveals the way in which transportation infrastructures affect education and income at the county level in the United States.

2 Literature Review

2.1 Prior Studies

Most literature on the associations between transportation and education and income is on travel behaviors. In general, household income affects the use of transportation modes (McDonald 2008). The use of the physical modes of transportation (walking and biking) to go to schools in children of low-income households is higher than in children of high-income households (McDonald 2008). Household income also influences trip purpose, duration of trip, and distance covered. The households with the highest income levels walk the longest distances, whereas the households with the lowest incomes walk the longest durations (Yang and Diez-Roux 2012). Similarly, the households with the highest incomes walk longer distances for recreation, and households with the lowest incomes walk longer distances for work.

The relationship between income and travel behavior is indirect. The household income influences the car ownership that determines the use of transportation mode. Having a car reduces the dependency on the public and non-motorized or physical modes of transportation, such as walking and biking. According to Pucher and Renne (2003), in the urban area, the use of public transit drops sharply when a household owns a car. Similarly, bike and taxi use also drop.

The interaction between income and geography also results in different travel behaviors. For example, in urban areas poor people walk twice as much as rich people; in rural areas both poor and rich walk the same distances (Besser and Dannenberg 2005; Pucher and Renne 2005). In urban areas, poor people live in the central cities where trip distances are shorter and walkable. They walk mostly to access public transportation. In rural areas, because of the absence of public transportation, practically everybody depends on cars for travel irrespective of their income.

Income does influence the type of public transit use (Pucher and Renne 2003). Increased income is inversely associated with public bus use and positively associated with suburban rail use. The use of the public bus by the poor is higher than that of the rich. On the other hand, the use of the suburban rail by the rich is higher than that of the poor. One of the reasons behind the use of the suburban rail by the affluent is its service from the high-income suburban areas to the metropolitan downtowns, where residents have their jobs. The suburban rail offers fast and comfortable

service. The suburban rail is dependable and provides stress-free travel at peak office hours. On the other hand, bus services are limited to the central cities. Also, bus services are slow, less comfortable, less dependable, and stressful. Bus transits serve only local trips. Such associations between income s and types of public transit can be found in major metropolitan areas such as New York City; Washington, DC; Boston; and Chicago.

Education influences income potential, which determines the ability to afford private vehicles (Guequierre 2003; Krovi and Barnes 2000). Education and income also have an impact on the selection of neighborhood, which can affect access to transit service. People with low education rely more on transit and carpooling. A high level of education has a strong positive relationship with walk trips (Agrawal and Schimek 2007), although the reason for the positive association of educational attainment with recreational walking is not known. People with higher education may have a greater awareness of the health benefits of walking. A high level of education has the inverse relationship with work-related walking time (Besser and Dannenberg 2005); people with the graduate level of education walk less than people with high school diplomas. A higher level of education among commuters is associated with the decline in carpooling, too (Ferguson 1997; Guequierre 2003). Even though there is some literature on the associations of education and income with travel behaviors, literature on the direct association of transportation infrastructures with education and income changes is few.

2.2 Transportation, Education and Income

Transportation infrastructures improve physical accessibility and reduces distance and travel time to public services, markets, and jobs (Chi et al. 2006). Iimi et al. (2015) found that the construction and maintenance of transportation infrastructures ensure year-round trafficability, address increased travel demand to schools, increase car ownership, increase use of public transportation and individual cars, increase the number of students attending schools and contributes to improving education (Iimi et al. 2015).

However, people do not take equal advantage of transportation infrastructures. Poor, minority and rural residents are considered transport disadvantaged groups (Owoeye and Yara 2011). Accessibility to transportation infrastructures, the distance between home and school, and the transportation cost determines students' travel time, which ultimately influences attendance and academic achievement. In general, poor accessibility, longer distance and higher transportation cost are associated with students' travel time (Gašparović 2014; Lin et al. 2013; Kamaruddin et al. 2009; Raychaudhuri et al. 2010). The greater distance to school from home provides fewer opportunities for participation in extracurricular activities and less available time for studying at home (Gašparović 2014). The level of services of public transportation such as frequency of vehicles and organization of transportation lines also influences travel time (Gašparović 2014). In general, academic success and the quality of public transportation are better in the central city than the city periphery and rural areas (Owoeye and Yara 2011).

Population responses vary with the availability of transportation services. Places like cities that have better transportation networks and services contribute to developing better connections among their citizens, attract new citizens, business, and offer agglomeration benefits including higher returns to education, which will ultimately increase household income in the long run (De La Roca and Diego 2017; Gerritse and Arribas-Bel 2017). In this way, influencing education and income transportation infrastructures also affect the population size and composition.

2.3 Theory

Literature on the economic impact of transportation systems is filled with accessibility theory, neoclassical growth theory, location theory, and growth pole theory explaining the associations of transportation infrastructures with population and employment (Chi 2012; Darwent 1969; Eberts 1990; Ratner and Goetz 2013). Accessibility theory focuses on how providing access to transportation infrastructures affects the economy (Ratner and Goetz 2013). Access to the transportation modes and their service frequencies generate and affect the local business competition (Atack and Margo 2011; Coffman and Gregson 1998; Decker and Flynn 2007; Duncan 2008; Israel and Cohen-Blankshtain 2010; Levinson 2008a, b). The influence of transportation infrastructures on local businesses is higher at proximity, and it gradually disappears as distance increases.

Neoclassical growth theory considers transportation infrastructures as production systems (Chi et al. 2006; Eberts 1990): transportation infrastructures behave like production systems because inputs influence outputs. The assumption of this theory is that high investment (input) in transportation infrastructures produces high economic growth (output). Location theory is about how business organizations make decisions to locate their offices, such as manufacturing units, head offices, retail spaces, and warehouses (Chi et al. 2006). Their decisions are based on the location's proximity to the transportation infrastructure and the associated transportation cost that affects the revenue generation. Similarly, growth pole theory is about the role of transportation infrastructures in causing demographic and socioeconomic changes in nearby areas (Chi 2010; Darwent 1969). Two aspects of growth pole theory are spread and backwash effects—the spread effect indicates simultaneous growth or decline of two areas, and backwash effect is about the growth of one area at the cost of another.

These theories are useful for explaining the relationships between transportation infrastructures and dependent variables of this study. The spread effect of growth pole theory can explain the positive spatial lag effect of the infrastructure on both education and income. The findings of this study show that the growth in education and income of a county is affected by the growth of education and income in the surrounding counties. Similarly, location theory can explain the facilitative role of highways in both education and income change: highways help to facilitate movement of people of any education and income during the study periods. Accessibility theory is useful to explain the relationship between airports and education. Airports have a positive association with education and behave like a growth force. Access

to airports influences economic growth that may affect growth in education and income.

On the other hand, we have used neoclassical growth theory to explain the relationship between railroads and education and income. Railroads have a negative association with education and income. The negative association indicates that railroads help to decline the density of education and income and behave like a distributive force. We assume that the deviation of the association of railroads from a positive to a negative is because of the competition of three modes of transportation: railroads, highways, and airports. These three modes of transportation are competing and complementing to provide accessibility. Because of the diversity of the roles they play, the use of multiple theories can explain the associations of transportation infrastructures with education and income.

3 Data and Methods

3.1 Data

This national-level study explores the association of transportation infrastructures with education and income change from 1970 to 2010. The unit of analysis is the county because many governmental programs run at the county level and because of the accessibility of public data at this level. This study used data from diverse sources. Data for transportation infrastructures came from the National Transportation Atlas Database (NTAD), which is a big geospatial database made available by the Bureau of Transportation Statistics (BTS) of the United States Department of Transportation (USDOT). Data for the railroads, highways, and airports came from the Railway Network database, the National Highway Planning Network database (NHPN), and the Airports database, respectively. These databases are subsets of the NTAD. The data for demographic and socioeconomic variables were obtained from the Bureau of Labor Statistics; National Historical Geographic Information System (NHGIS); decennial censuses of 1970, 1980, 1990, 2000, and 2010; Cartographic Boundary Shapefiles; and Land Developability Index (Chi and Ho 2014).

3.2 Variables

This study has two categories of dependent variables: education and income. High school, Bachelor's degree, and graduate degree represent education, and income stands for median household income. Dependent variables are expressed in the natural log of current over past values. For example, the dependent variable high school represent the natural log of current over past values of populations with high school graduate. The main reason to consider the natural log is its contribution to achieving a bell-shaped distribution and better linearity with the independent variables. Transportation infrastructures such as railroads, highways, and airports are independent variables. Railroads is represented by railroad terminal density, which is measured by dividing the number of rail terminals in a county by the square root of the county area. Highways

is represented by highway density, which is calculated by dividing the total length of the highways in miles by the square root of the county area. The total number of public airport terminals available within a county boundary represents airports. It is important to bring these three modes of transportation into the analytical model because they are competing and linked with demographic change (Irwin and Kasarda 1991). Bringing them into a model separates the influence of each mode of transportation. Table 1 provides a description of the measurements and sources for all dependent, independent, and control variables.

This study controls for several variables. Age is a demographic control variable and it is represented by young and old. Young is measured by the percentage of the young population between the ages of 15 and 19 years. For this study, old represents people of 65 years of age or above in the population. Socioeconomic control variables are related to race and ethnicity, education, employment, and income. Race and ethnicity control variables are Whites, Blacks and Hispanics, which represent the percentages of non-Hispanic White, non-Hispanic Black, and Hispanic populations. Education control variables are high school, Bachelor's degree and graduate degree, which represent percentage of populations with the respective education levels. Similarly, employment represents the percentage of the population employed. This study also has two categories of geographical control variables: metro and region. Metro includes those counties that have at least one metropolitan area with 50,000 or more residents. West, Midwest, and Northeast are regional control variables. South is the reference variable. The variable Land Developability Index is used to control for the influence of the land use and development, which is one of the influencers of population dynamics (Chi 2010). The Land Developability Index shows the potential for land development and conversion in a geographical area.

3.3 Analytical Strategy

The analysis of the data was done in three distinct stages: standard regression, exploratory spatial data analysis (ESDA), and spatial regression. In the beginning, we applied descriptive statistics and standard regression. We used a full ordinary least squares (OLS) regression to explore the relationships between the three transportation variables and education and income changes. In the next step, the OLS regression was refined by the application of ESDA, which helped us to identify the spatial autocorrelation or spatial dependence. The issue of spatial dependence is important from the methodological perspective (Chi and Ventura 2011; Chi and Zhu 2008) because statistical inferences without considering spatial dependence could lead to unreliable conclusions. This study addresses the issue of spatial dependence by the application of spatial models such as spatial lag, spatial error, and spatial error model with lag dependence.

Statistical equations for the models (Ordinary least squares, spatial lag model, spatial error model, and spatial error model with lag dependence) used in this study are shown as following:

Ordinary least squares (OLS) regression model:

$$\ln\left(\frac{Dt + 10}{Dt}\right) = \alpha + \beta X_t + \epsilon \quad (1)$$

Table 1 Variable names, descriptions, and data sources

Variable names	Descriptions	Data sources
<i>Dependent variables</i>		
High school	Natural log of recent population with high school graduation over previous population with high school graduation	U.S. Census Bureau, NHGIS
Bachelor's degree	Natural log of recent population with bachelor's degree over previous population with bachelor's degree	U.S. Census Bureau, NHGIS
Graduate degree	Natural log of recent population with graduate degree over previous population with graduate degree	U.S. Census Bureau, NHGIS
Income	Natural log of recent median household income over previous median household income	U.S. Census Bureau
<i>Independent variables</i>		
Railroads	Total number of rail terminals divided by square root of county area	NTAD (the Railway Network database)
Highways	Total length of highways in miles divided by square root of county area	NTAD (the National Highway Planning Network database)
Airports	Total number of public airport terminals within a county	NTAD (the Airports database)
<i>Control variables</i>		
Prev. high school	Previous decade change rate of population with high school graduation	U.S. Census Bureau, NHGIS
Prev. bachelor's degree	Previous decade change rate of population with bachelor's degree	U.S. Census Bureau, NHGIS
Prev. graduate degree	Previous decade change rate of population with graduate degree	U.S. Census Bureau, NHGIS
Prev. income	Previous decade change rate of median household income	U.S. Census Bureau
Employment	Percentage employed	U.S. Census Bureau, NHGIS
Young	Percentage young (aged between 15 and 19 years)	U.S. Census Bureau, NHGIS
Old	Percentage old (aged ≥ 65)	U.S. Census Bureau, NHGIS
Whites	Percentage non-Hispanic Whites	U.S. Census Bureau, NHGIS
Blacks	Percentage non-Hispanic Blacks	U.S. Census Bureau, NHGIS
Hispanics	Percentage Hispanics	U.S. Census Bureau
High school percent	Percentage of population with high school graduation	U.S. Census Bureau, NHGIS

Table 1 (continued)

Variable names	Descriptions	Data sources
Bachelor's degree percent	Percentage of population with bachelor's degree	U.S. Census Bureau, NHGIS
Graduate degree percent	Percentage of population with graduate degree	U.S. Census Bureau, NHGIS
Income level	Median household income	U.S. Census Bureau
Metro	Counties with at least one metropolitan area with population $\geq 50,000$	U.S. Census Bureau
West	Counties in the West region	U.S. Census Bureau
Midwest	Counties in the Midwest region	U.S. Census Bureau
Northeast	Counties in the Northeast region	U.S. Census Bureau
South (reference)	Counties in the South region	U.S. Census Bureau
Land Developability Index	Percentage of land in a county that can be developed	Land developability http://www.landdevelopability.org/

NHGIS National Historical Geographic Information System, *NTAD* National Transportation Atlas Database

Spatial lag model (SLM):

$$Ln\left(\frac{Dt+10}{Dt}\right) = \alpha + \beta X_t + \rho W1 Ln\left(\frac{Dt+10}{Dt}\right) + \varepsilon \quad (2)$$

Spatial error model (SEM):

$$Ln\left(\frac{Dt+10}{Dt}\right) = \alpha + \beta X_t + \varepsilon, \varepsilon = \lambda W2\varepsilon + \xi \quad (3)$$

Spatial error model with lag dependence (SEMLD):

$$Ln\left(\frac{Dt+10}{Dt}\right) = \alpha + \beta X_t + \rho W1 Ln\left(\frac{Dt+10}{Dt}\right) + \varepsilon, \varepsilon = \lambda W2\varepsilon + \xi \quad (4)$$

where Ln represents natural log, Dt stands for dependent variable in year t , $Dt+10$ is dependent variable in year $t+10$, α characterizes intercept, X_t is a matrix of independent and control variables in year t , β represents a vector of coefficients of X_t , ρ denotes a spatial-lag parameter, λ stands for a spatial error parameter, $W1$ represents a spatial weight matrix for the lag term, and $W2$ denotes a spatial weight matrix for the error term.

Moran's I statistic, the most common method, is used to identify spatial correlation (Figs. 6, 7, 8, 9). Moran's I assesses the linear association or linearity between a variable at a location and the weighted average of the variable at its surrounding locations (Chi and Zhu 2008). To do so, the analysis process requires designing and discovering the best-fit spatial weight matrix. Only the weight matrix that has the highest level of spatial dependence and statistical significance should be used in the analysis (Anselin 1988). For the polygon shapefiles, the most common spatial weight matrices in use are Queen's and Rook's contiguity weight matrices (Anselin 1990; GeoDa User's Guide 2003). Hence, we decided to use the first- and second-order Queen's and Rook's spatial weight matrices. Out of many first- and second-order Queen's and Rook's weight matrices, only those which have high coefficient values of spatial autocorrelation and statistical significance are selected (Voss and Chi 2006).

After the spatial weight matrices were specified, we identified the spatial clustering patterns that exist in the data. We conducted ESDA, which helps to verify, identify, and visualize the spatial patterns and spatial clusters. By running the local Moran's I or local indicators of spatial autocorrelation (LISA) statistic, we identified the visual spatial clusters in the data (Figs. 2, 3, 4, 5). Two types of spatial clustering could exist: positive and negative. In a positive spatial clustering pattern, counties with high and low values group together with the counties that have respective values; in a negative spatial clustering pattern, counties with high values lump with the counties that have low values.

In the next step, the diagnostic test or Lagrange multiplier test statistic was applied to identify the hidden spatial patterns. The diagnostic test also helps to identify the suitable spatial regression model to be used in the analysis. This test suggests

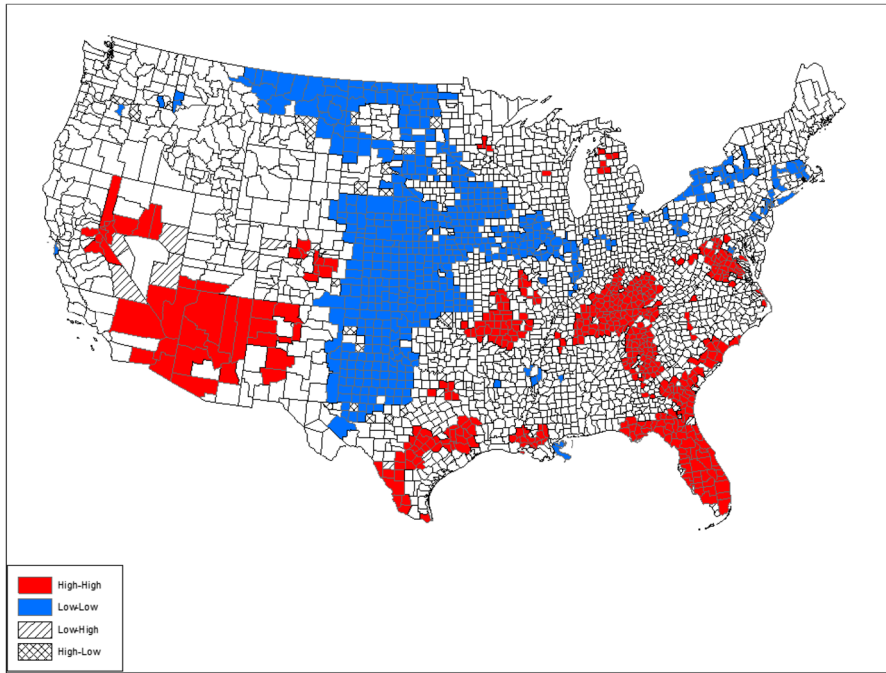


Fig. 2 LISA cluster map of high school graduate change from 1970 to 2010 at the county level in the continental United States

a better model out of two, spatial lag and spatial error. This study also applied an additional model called spatial error model with lag dependence. Since there are four models (ordinary least squares, spatial lag, spatial error, and spatial error with lag dependence), the best-fit model is identified based on the values of overall fitness, including the log-likelihood, Akaike information criterion (AIC), and Schwarz Bayesian information criterion (BIC). To identify the best-fit model, we looked for the highest value of the log-likelihood and the lowest value of the Akaike's information criterion (AIC), and Schwarz's Bayesian information criterion (BIC). The spatial error model with lag dependence turned out to be the best-fit model. All four regression models are calculated using the software called *GeoDa* for the decade as well as for the entire study period.

4 Findings

Since the spatial error model with lag dependence is the best-fit model, the findings presented here are based on the results of this model only. There are four tables, one for each dependent variable. Table 2 presents the results for the high school for all periods (1970–1980, 1980–1990, 1990–2000, 2000–2010, and 1970–2010). Railroads has a negative relationship with high school across all periods. The increase in railroad terminal density contributes to the declining high school graduate

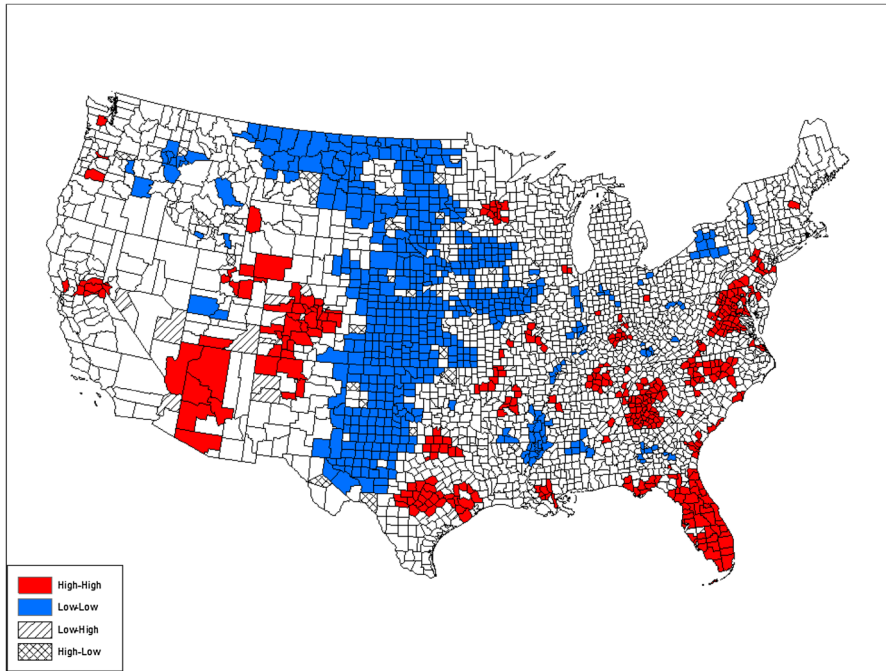


Fig. 3 LISA cluster map of change in bachelor's degree from 1970 to 2010 at the county level in the continental United States

population. The association of airports is comparatively stronger than highways. The association of highways is significant in only one period, whereas that of airports is significant in three out of five periods. The direction of the relationship is opposite, highways being negative and airports being positives.

Table 3 presents the results of the spatial error model with lag dependence for the relationships between transportation infrastructures and change in population with Bachelor's degree for all periods (the 1970s, 1980s, 1990s, 2000s, and 1970–2010). The association of railroads with Bachelor's degree is negative across all periods. The growth in railroad terminal density is associated with the decline in population with Bachelor's degree for the 1970s, 1980s, 1990s, 2000s, and the entire study period (1970–2010). Another transportation variable, airports, has a positive association with Bachelor's degree for the 1970s and 1980s and for the period of 1970–2010. The variable airports is stronger than the variable highways. The variable highways is not significant at all.

Table 4 shows the results of the spatial error model with lag dependence for graduate degree for the period of the 1970s, 1980s, 1990s, 2000s, and 1970–2010. The association of railroads with graduate degree is strong and negative for all periods. The variable highways is not significant at all. Airports is positive for the period of the 1970s and the entire study period (1970–2010).

Table 5 represents the results of the spatial error model with lag dependence for income for the periods of the 1970s, 1980s, 1990s, 2000s, and 1970–2010. The table

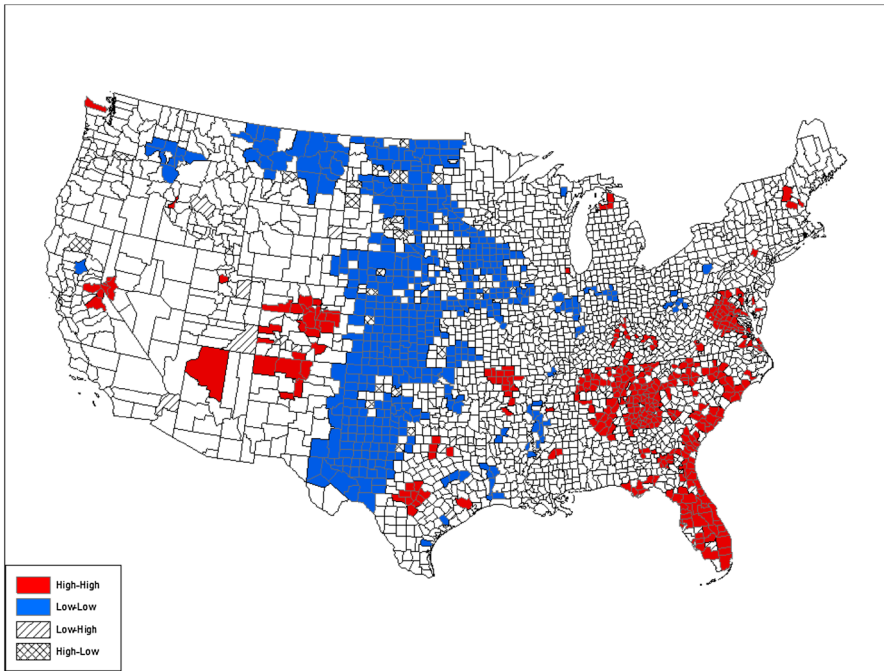


Fig. 4 LISA cluster map of change in graduate degree from 1970 to 2010 at the county level in the continental United States

shows railroads is negative in the 1970s, 1980s, and 1990s and positive in the 2000s. Highways is significant only from 1970 to 2010. Airports has a negative relationship with income in the 1980s and 2000s.

This study shows the direct impact of independent variables on dependent variables even after controlling for many socioeconomic variables. By controlling for the spatial effects, this study also exposes the indirect impact of dependent variables. Dependent variables are affected by own changes in different locations. Spatial lag effect in all models is statistically significant and positive, indicating that growth and decline in a county is influenced by the growth and decline in the surrounding counties. This is true for both education and income and can be explained by the spread effect of the growth pole theory.

5 Discussion and Conclusion

The findings of this study show that the associations of three transportation infrastructures, railroads, highways, and airports, with education and income are not uniform. Broadly, railroads have a negative and highways have no significant relationship with education and income change. The associations of airports with education and income change are mostly positive. This study contributes to the transportation literature by identifying the association that transportation infrastructures have with

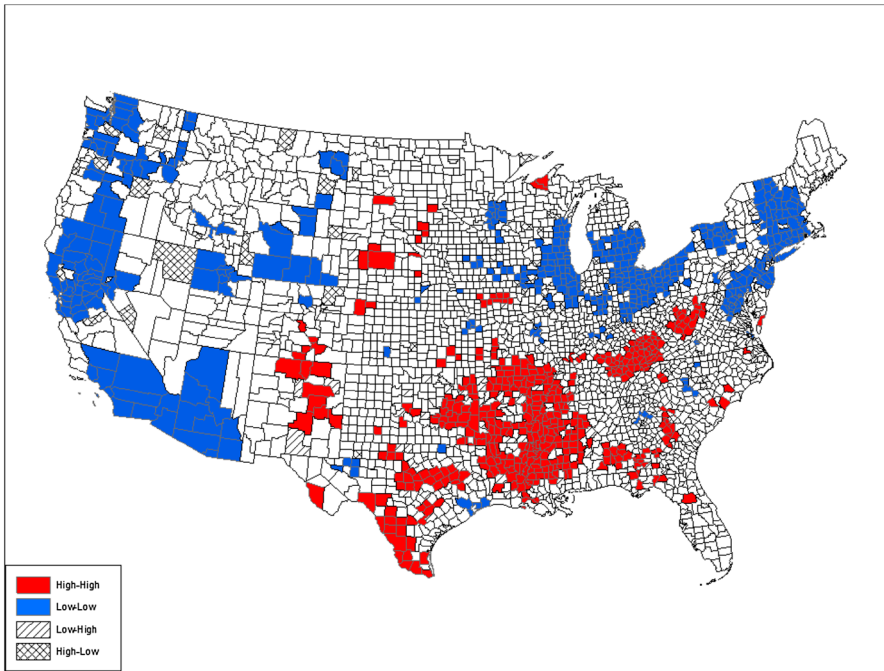


Fig. 5 LISA cluster map of income change from 1970 to 2010 at the county level in the continental United States

education and income distribution. To our best knowledge, this is the first study of this kind. In addition, this study examines three modes of transportation—railroads, highways and airports—collectively in association with education and income using spatial regression models.

5.1 Railroads as a Distributive Force

This study clearly shows railroads have a negative association with education and income irrespective of their levels. All three levels of education, high school, Bachelor's degree, and graduate degree, have a negative association with railroads even after controlling for the other modes of transportation and demographic, socio-economic, geographic, and land developability variables. What could be the possible reasons for the consistent negative association of railroads with education and income change? Railroad terminal density does not directly influence both travel time of students from home to school and the attendance at any educational level. The negative association probably indicates the indirect relationship of railroad terminal density with education and income.

A possible explanation for the negative relationship could be related to the reduced investment in transportation infrastructures (Business Roundtable 2015). According to a Business Roundtable report (2015), transportation infrastructures

Table 2 Results of the spatial error models with lag dependence (dependent variable = high school)

	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
<i>Independent variable</i>					
Railroads	– 0.009*** (0.001)	– 0.008*** (0.001)	– 0.004*** (0.001)	– 0.002** (0.001)	– 0.021*** (0.002)
Highways	– 0.002 (0.001)	– 3.91E–4 (0.001)	– 0.001* (0.001)	– 6.49E–5 (0.001)	– 0.004 (0.002)
Airports	0.006*** (0.001)	– 0.002 (0.001)	4.54E–4 (0.001)	0.002* (0.001)	0.009*** (0.003)
<i>Control variables</i>					
Prev. high school	–	– 0.002 (0.006)	0.003 (0.006)	0.046*** (0.010)	–
Young	– 0.002 (0.002)	– 0.004* (0.002)	2.78E–4 (0.001)	0.002 (0.001)	0.005 (0.004)
Old	– 0.005*** (0.001)	– 0.002* (0.001)	– 0.001** (4.73E–4)	– 0.002*** (4.26E–4)	– 0.002 (0.002)
Bachelor's degree percent	– 0.006*** (0.001)	0.007*** (0.001)	4.35E–4 (0.001)	0.002*** (4.96E–4)	– 0.003** (0.001)
Graduate degree percent	0.002 (0.002)	– 0.006*** (0.001)	– 0.004*** (0.001)	– 0.002*** (0.001)	– 0.010*** (0.003)
Whites	– 0.001*** (4.19E–4)	0.001*** (2.50E–4)	– 0.001** (2.05E–4)	4.61E–5 (1.83E–4)	– 0.002* (0.001)
Blacks	– 0.002*** (4.32E–4)	0.001*** (2.47E–4)	– 0.001** (2.12E–4)	– 2.53E–4 (1.86E–4)	– 0.002** (0.001)
Hispanics	–	–	– 0.001** (2.18E–4)	– 6.19E–5 (1.93E–4)	–
Income level	– 1.18E–5*** (2.51E–6)	5.83E–6*** (8.53E–7)	1.27E–6*** (3.60E–7)	1.69E–8 (2.57E–7)	– 2.52E–6 (4.38E–6)
Employment	0.002*** (4.31E–4)	– 0.007*** (3.90E–4)	– 0.002*** (3.15E–4)	– 0.001*** (2.90E–4)	– 0.002** (0.001)

Table 2 (continued)

	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
Metro	0.037*** (0.005)	0.037*** (0.004)	0.013*** (0.003)	0.009** (0.003)	0.114*** (0.010)
West	0.025*** (0.007)	– 0.016** (0.006)	0.009* (0.004)	1.21E–4 (0.004)	0.039** (0.012)
Midwest	0.023*** (0.005)	– 0.004 (0.004)	0.011*** (0.003)	0.011*** (0.003)	0.085*** (0.014)
Northeast	0.038*** (0.008)	0.005 (0.006)	0.025*** (0.005)	0.014** (0.005)	0.038*** (0.009)
Land Developability Index	1.16E–4 (8.28E–5)	3.95E–4*** (7.32E–5)	1.99E–4*** (5.08E–5)	2.09E–4*** (5.05E–5)	0.001*** (1.57E–4)
Constant	0.249*** (0.050)	0.120** (0.041)	0.127*** (0.031)	0.024 (0.026)	0.271** (0.091)
Spatial lag effects	0.979*** (0.010)	1.005*** (0.010)	1.051*** (0.012)	1.012*** (0.020)	1.017*** (0.010)
Spatial error effects	– 0.782*** (0.029)	– 0.768*** (0.029)	– 0.937*** (0.026)	– 0.952*** (0.028)	– 0.823*** (0.028)
<i>Measures of fit</i>					
Log-likelihood	1492.20	2146.36	2873.29	2861.32	– 414.586
AIC	– 2948.40	– 4254.73	– 5706.58	– 5682.64	865.172
BIC	– 2839.64	– 4139.93	– 5585.74	– 5561.80	973.929
Spatial weight matrix	First-order Rook's	First-order Rook's	First-order Rook's	First-order Queen's	First-order Rook's

AIC Akaike's information criterion, BIC Schwartz's Bayesian Information Criterion

*Significant at $p \leq 0.05$ for a two-tail test; **significant at $p \leq 0.01$ for a two-tail test; ***significant at $p \leq 0.001$ for a two-tail test; standard errors in parentheses

Table 3 Results of the spatial error models with lag dependence (dependent variable = bachelor's degree)

<i>Independent variable</i>	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
<i>Railroads</i>	– 0.006*** (0.001)	– 0.004** (0.001)	– 0.007*** (0.001)	– 0.003** (0.001)	– 0.020*** (0.003)
<i>Highways</i>	2.72E–4 (0.001)	– 0.001 (0.001)	– 0.001 (0.001)	– 0.001 (0.001)	0.001 (0.002)
<i>Airports</i>	0.004* (0.002)	0.004* (0.002)	0.001 (0.001)	0.003 (0.002)	0.010** (0.004)
<i>Control variables</i>					
Prev. bachelor's degree	–	0.008 (0.005)	– 0.023* (0.012)	0.007 (0.008)	–
Young	– 0.006* (0.003)	0.008** (0.003)	– 0.003 (0.002)	0.001 (0.002)	0.002 (0.005)
Old	– 0.004*** (0.001)	– 0.002* (0.001)	– 0.002* (0.001)	– 0.001 (0.001)	– 0.009*** (0.002)
High school percent	0.001* (3.84E–4)	– 0.003*** (0.001)	4.55E–4 (4.23E–4)	1.74E–4 (4.72E–4)	0.003*** (0.001)
Graduate degree percent	– 0.008*** (0.002)	0.015*** (0.002)	– 0.002* (0.001)	– 0.003* (0.001)	0.002 (0.004)
Whites	– 0.001* (0.001)	0.002*** (3.67E–4)	– 4.71E–4 (3.46E–4)	4.84E–4 (3.32E–4)	0.001 (0.001)
Blacks	– 0.002*** (0.001)	0.001*** (3.65E–4)	– 0.001* (3.59E–4)	9.13E–6 (3.38E–4)	– 0.001 (0.001)
Hispanics	–	–	– 4.98E–4 (3.69E–4)	2.89E–4 (3.49E–4)	–
Income level	– 7.92E–6* (3.43E–6)	– 3.43E–6** (1.21E–6)	1.27E–6* (6.07E–7)	1.08E–6* (4.59E–7)	– 2.77E–5*** (6.63E–6)
Employment	0.001 (0.001)	– 0.001 (0.001)	– 0.001* (4.72E–4)	– 0.001* (4.67E–4)	– 0.001 (0.001)

Table 3 (continued)

	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
Metro	0.056*** (0.007)	0.034*** (0.007)	0.032*** (0.006)	0.026*** (0.006)	0.190*** (0.015)
West	– 0.002 (0.009)	– 0.037*** (0.008)	– 0.002 (0.006)	– 3.61E–4 (0.007)	– 0.013 (0.017)
Midwest	0.017* (0.007)	– 0.001 (0.006)	0.002 (0.005)	0.003 (0.006)	0.030 (0.020)
Northeast	0.014 (0.010)	– 0.031*** (0.009)	0.016* (0.008)	0.009 (0.009)	0.047*** (0.013)
Land Developability Index	1.64E–4 (1.10E–4)	2.52E–4* (1.04E–4)	1.61E–4 (8.41E–5)	1.07E–4 (9.14E–5)	3.24E–4 (2.17E–4)
Constant	0.190** (0.066)	– 0.116 (0.063)	0.083 (0.052)	– 0.010 (0.048)	0.039 (0.127)
Spatial lag effects	1.045*** (0.014)	1.018*** (0.014)	1.074*** (0.016)	1.021*** (0.022)	1.033*** (0.011)
Spatial error effects	– 0.986*** (0.025)	– 0.917*** (0.027)	– 0.982*** (0.026)	– 0.836*** (0.030)	– 0.905*** (0.027)
<i>Measures of fit</i>					
Log-likelihood	329.80	687.79	1170.29	1219.73	– 1595.83
AIC	– 623.60	– 1337.58	– 2300.57	– 2399.46	3227.65
BIC	– 514.85	– 1222.78	– 2179.73	– 2278.61	3336.41
Spatial weight matrix	First-order Rook's	First-order Rook's	First-order Rook's	First-order Queen's	First-order Rook's

AIC Akaike's information criterion, BIC Schwartz's Bayesian Information Criterion

*Significant at $p \leq 0.05$ for a two-tail test; **significant at $p \leq 0.01$ for a two-tail test; ***significant at $p \leq 0.001$ for a two-tail test; standard errors in parentheses

Table 4 Results of the spatial error models with lag dependence (dependent variable = graduate degree)

<i>Independent variable</i>	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
<i>Railroads</i>					
	– 0.007** (0.002)	– 0.005** (0.002)	– 0.009*** (0.001)	– 0.003* (0.002)	– 0.019*** (0.003)
<i>Highways</i>					
	– 0.002 (0.002)	1.36E–4 (0.001)	1.93E–4 (0.001)	– 0.002 (0.001)	– 0.001 (0.003)
<i>Airports</i>					
	0.007* (0.003)	– 0.002 (0.002)	0.001 (0.002)	0.003 (0.002)	0.010* (0.005)
<i>Control variables</i>					
Prev. graduate degree	–	– 0.012*** (0.003)	– 0.050*** (0.007)	– 0.044*** (0.008)	–
Young	– 0.021*** (0.004)	– 0.003 (0.003)	– 0.015*** (0.003)	– 0.006 (0.003)	– 0.033*** (0.006)
Old	– 0.005*** (0.002)	0.001 (0.001)	– 0.004*** (0.001)	– 0.003*** (0.001)	– 0.011*** (0.003)
High school percent	0.001 (0.001)	0.006*** (0.002)	0.002* (0.001)	0.001 (0.001)	0.004*** (0.001)
Bachelor's degree percent	– 0.002 (0.001)	0.013*** (0.002)	0.002 (0.001)	0.004** (0.001)	0.001 (0.002)
Whites	7.38E–5 (0.001)	0.001 (4.51E–4)	6.45E–6 (4.91E–4)	1.25E–4 (4.68E–4)	4.50E–4 (0.001)
Blacks	– 2.25E–4 (0.001)	1.81E–4 (4.50E–4)	– 2.23E–4 (0.001)	– 2.82E–4 (4.75E–4)	– 0.001 (0.001)
Hispanics	–	–	– 9.79E–6 (0.001)	2.23E–4 (4.98E–4)	–
Income level	– 1.33E–5* (5.30E–6)	2.89E–6 (1.48E–6)	2.99E–7 (8.18E–7)	– 3.35E–7 (6.40E–7)	– 3.25E–5*** (7.63E–6)
Employment	0.002 (0.001)	– 0.009*** (0.001)	– 0.002* (0.001)	2.36E–4 (0.001)	– 0.001 (0.001)

Table 4 (continued)

	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
Metro	0.055*** (0.012)	0.026** (0.008)	0.032*** (0.008)	0.020* (0.009)	0.160*** (0.017)
West	0.019 (0.015)	-0.010 (0.011)	-0.044*** (0.010)	-0.015 (0.010)	0.003 (0.021)
Midwest	0.025* (0.011)	-0.003 (0.007)	-0.013 (0.007)	-0.010 (0.008)	0.046 (0.023)
Northeast	0.030 (0.016)	-0.015 (0.011)	-0.005 (0.011)	-0.016 (0.012)	0.052*** (0.016)
Land Developability Index	1.86E-4 (1.79E-4)	2.85E-4* (1.28E-4)	-3.25E-5 (1.24E-4)	-3.42E-7 (1.30E-4)	2.57E-4 (2.68E-4)
Constant	0.202 (0.108)	-0.022 (0.079)	0.202** (0.073)	0.023 (0.066)	0.402** (0.154)
Spatial lag effects	1.041*** (0.019)	1.061*** (0.015)	1.071*** (0.019)	1.051*** (0.022)	1.031*** (0.012)
Spatial error effects	-0.914*** (0.027)	-0.942*** (0.026)	-0.910*** (0.027)	-0.860*** (0.028)	-0.968*** (0.026)
<i>Measures of fit</i>					
Log-likelihood	-1087.32	22.610	232.82	117.88	-2315.99
AIC	2210.64	-7.219	-425.63	-195.75	4667.98
BIC	2319.40	107.580	-304.79	-74.91	4776.74
Spatial weight matrix	First-order Rook's	First-order Rook's	First-order Rook's	First-order Rook's	First-order Rook's

AIC Akaike's information criterion, BIC Schwartz's Bayesian Information Criterion

*Significant at $p \leq 0.05$ for a two-tail test; **significant at $p \leq 0.01$ for a two-tail test; ***significant at $p \leq 0.001$ for a two-tail test; standard errors in parentheses

Table 5 Results of the spatial error models with lag dependence (dependent variable = income)

<i>Independent variable</i>	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
<i>Railroads</i>	– 0.003*** (0.001)	– 0.003*** (0.001)	– 0.002*** (4.04E–4)	0.004* (0.001)	– 0.003 (0.002)
<i>Highways</i>	– 0.001 (0.001)	3.58E–4 (4.34E–4)	– 6.66E–5 (3.33E–4)	– 0.001 (0.001)	– 0.003* (0.001)
<i>Airports</i>	0.001 (0.001)	– 0.002* (0.001)	– 0.001 (0.001)	– 0.005* (0.002)	– 0.004 (0.002)
<i>Control variables</i>					
<i>Prev. income</i>	–	– 0.034*** (0.004)	–	– 0.048* (0.024)	–
<i>Young</i>	– 0.001 (0.001)	– 0.003** (0.001)	– 0.002* (0.001)	0.009*** (0.003)	0.010* (0.003)
<i>Old</i>	0.002*** (4.07E–4)	– 3.74E–4 (4.24E–4)	3.37E–4 (2.95E–4)	0.006*** (0.001)	0.015*** (0.001)
<i>High school percent</i>	– 1.10E–4 (1.59E–4)	– 0.002** (0.001)	– 1.89E–4 (1.71E–4)	– 2.77E–4 (0.001)	– 0.004*** (4.85E–4)
<i>Bachelor's degree percent</i>	– 0.001* (3.58E–4)	– 0.001 (0.001)	– 0.001 (3.81E–4)	– 0.008*** (0.001)	– 0.004*** (0.001)
<i>Graduate degree percent</i>	– 0.004*** (0.001)	1.01E–4 (0.001)	3.27E–6 (0.001)	0.004* (0.002)	– 0.008** (0.003)
<i>Whites</i>	– 2.61E–4 (2.44E–4)	0.001*** (1.49E–4)	– 9.19E–5 (1.30E–4)	– 0.002*** (4.44E–4)	– 0.002*** (0.001)
<i>Blacks</i>	– 5.96E–5 (2.55E–4)	0.001*** (1.54E–4)	– 2.88E–5 (1.36E–4)	– 0.001* (4.50E–4)	– 0.001 (0.001)
<i>Hispanics</i>	–	–	– 1.10E–4 (1.39E–4)	– 0.002*** (4.68E–4)	–
<i>Employment</i>	– 4.97E–4* (2.42E–4)	4.35E–4 (0.001)	– 3.48E–4 (1.95E–4)	– 0.002* (0.001)	– 0.005*** (0.001)

Table 5 (continued)

	1970–1980	1980–1990	1990–2000	2000–2010	1970–2010
Metro	0.018*** (0.003)	0.011*** (0.003)	0.009*** (0.002)	– 0.026*** (0.008)	– 0.027*** (0.009)
West	0.021*** (0.004)	– 0.005 (0.004)	0.007*** (0.002)	0.018* (0.009)	0.035*** (0.012)
Midwest	0.008*** (0.003)	– 0.004 (0.002)	0.004 (0.002)	0.005 (0.007)	0.026* (0.013)
Northeast	0.023*** (0.005)	– 0.006 (0.004)	0.016*** (0.003)	0.016 (0.011)	– 0.020* (0.008)
Land Developability Index	5.49E–5 (4.79E–5)	1.13E–4** (4.29E–5)	3.45E–6 (3.15E–5)	– 1.64E–4 (1.20E–4)	2.17E–5 (1.39E–4)
Constant	0.065* (0.031)	0.068* (0.028)	0.032 (0.020)	0.246*** (0.066)	0.999*** (0.095)
Spatial lag effects	0.987*** (0.014)	0.980*** (0.011)	1.048*** (0.012)	0.922*** (0.016)	0.711*** (0.018)
Spatial error effects	– 0.885*** (0.029)	– 0.808*** (0.028)	– 0.991*** (0.025)	– 0.970*** (0.026)	– 0.726*** (0.029)
<i>Measures of fit</i>					
Log-likelihood	2995.88	3606.69	4169.44	71.29	– 66.19
AIC	– 5955.77	– 7175.39	– 8298.88	– 102.58	168.38
BIC	– 5847.01	– 7060.59	– 8178.04	18.26	277.14
Spatial weight matrix	First-order Queen's	First-order Rook's	First-order Rook's	First-order Rook's	First-order Rook's

AIC Akaike's information criterion, BIC Schwartz's Bayesian Information Criterion

*Significant at $p \leq 0.05$ for a two-tail test; **significant at $p \leq 0.01$ for a two-tail test; ***significant at $p \leq 0.001$ for a two-tail test; standard errors in parentheses

in the United States are underinvested. Now, the rate of public investment in transportation infrastructures is lower than it was in the 1960s. The underfunded system is not sufficient to properly maintain and improve the quality of the transportation infrastructures. The underinvestment is also responsible for not creating enough short-term and long-term jobs or jobs for all education and income levels.

Another probable reason for the negative association is the decline in the manufacturing and extractive sectors and their associated employments during the study period. In the United States, employments in the manufacturing and extractive sectors declined continuously for 50 years, from 1960 to 2010 (Baily and Bosworth 2014). Railroads in the United States are mainly used for freight transportation to carry raw and finished goods, and therefore railroads are closely associated with the manufacturing and extractive industries. The golden days of the railroad, when it used to be a growth force, are long gone. Now, it cannot help the areas it passes through prosper. This also could be a reason for the negative association of railroads with education and income. Neoclassical growth theory takes transportation infrastructures as a production system where output depends on input. Decline in input such as investment naturally wane output such as socioeconomic growth that is indicated by education and income decline.

5.2 Highways as a Facilitator

Availability of roads can directly influence travel time of students from home to school and their attendance by affecting the transport accessibility of public and private vehicles, the frequency of vehicles and organization of transportation line (Chi et al. 2006; Iimi et al. 2015). However, this study shows the association of highways with education and income is not statistically significant. Highways could have played a facilitator role across the study period, as other studies have reported (Chi 2010; Thompson and Bawden 1992). Probably, highways provide location advantages and act as means to facilitate the flow of finished and unfinished materials as well as the general population as advocated by location theory. Highways have a very complex network of connectivity at the regional and national level that help in facilitating and addressing the demand and supply sides of the economy. In this way, highways help people to have seamless access to goods, services, and opportunities. According to the location theory, the position of a reliable transportation infrastructure is one of the determinants of neighborhood selection and firm location. Besides, advancement in telecommunication and vehicle technology is supportive in determining the location (Auimrac 2005; Mejia-Dorantes et al. 2012).

Transportation infrastructure helps people on traveling for business and personal purpose. Based on their socioeconomic statuses, people may travel in private vehicles or use public transit. The construction of new infrastructure or the improvement of the existing one, both help people on their mobility. We infer that populations with all educational and income use the highways for their movement during the

study time. The change in the economy of the country does not seem to alter the facilitative role the highways play. This may be true because highways now compete with the other two modes of transportation, railroads, and airports. Being additional mode of transportation, highways are helpful in reduction of traffic congestion that provides comfort to the millions of people of all education and income levels.

5.3 Airports as a Growth Force

In this study, airports have a positive association with all three levels of education. However, airports are not statistically significant with income. Probably the positive association of airports with education is indirect because the number of airports does not directly influence travel time of students from home to school and their attendance. Many studies show a positive association of airports with economic growth and development (Appold and Kasarda 2013; Goetz 1992; Goetz and Sutton 1997; Irwin and Kasarda 1991). According to the accessibility theory, the economic growth results from the increased access provided by transportation infrastructures (Ratner and Goetz 2013). Economic growth of an area is closely associated with the available improved transportation technology. A newer form of transportation technology always incorporates higher speed and greater convenience. With high speed and great convenience, air services connect urban areas nationally and internationally and increase land values and land use intensity. In doing so, airports help the flow of people and resources that result in the economic growth of the connected areas.

On the other hand, economic growth is possible by attracting high-technology industries that heavily rely on air services. Our common-sense knowledge believes that education has a positive correlation with economic growth and development. The positive association of airports with education may be because of the positive association of economic growth with both airports and education. The positive association of airports is limited to education only—the findings of this study do not show a statistically significant association of airports with income. Airports may create economic growth, but the growth may not be enough to be statistically significant for income.

5.4 Policy Implications

In the literature on transportation systems, education and income are mostly associated with travel behaviors. For the first time, this study shows which transportation infrastructure has what kind of associations with education and income change. As stated previously, the direction of the associations of railroads and highways is clear. Railroads have a negative association and acts as a distributive force. Highways have

no statistically significant association and acts as a facilitator for educational and income changes. Airports is different from railroads and highways; it has a positive relationship with education. Airports is clearly a growth force for education, but it has no statistically significant association with income. Planners and policy makers should be aware of these facts that the relationships between transportation modes and education income are different. This study clearly shows that the complexity (in terms of the relationship) increases when we analyze the associations in specific sectors, such as education and income. Planners and policymakers should prepare for in-depth analyses when they plan for different development sectors.

6 Limitations of the Study

This study explores the impact of transportation infrastructures systematically by the application of strong statistical analysis. The data came from reliable sources, variables were carefully chosen based on the existing literature, hidden spatial associations were identified, and robust spatial analytical models were applied. Despite much strength, this study suffers from some weaknesses. The unavailability of transportation and Hispanics data for all time periods are the major limitations of the study. Changes in boundaries of some counties between 1970 and 2010 are another factor that may affect the analysis. These limitations are beyond our control. In addition, the significant spatial error effects indicate that the analytical models are incomplete. Important variables are still out there that can be included to improve the models. We did our best to make the analytical models consistent for all periods.

7 Future Research Direction

Some interesting findings of this research are worth exploring in the future. For example, the Land Developability Index is positive with high school level education change only. Why are Bachelor's and graduate degrees not significant with land developability? Potential areas for land development should be significant with any education level and income. Future studies should explore at what level land development exerts an impact on education and income. Similarly, graduate degree is not significant with Whites or Blacks in any period. It would be interesting to further explore the relationships between graduate degree and race and ethnicity. At the regional level, West is significant with income, and Midwest and Northeast are significant with high school. West is not significant with education; Midwest and Northeast are not significant with Bachelor's and graduate degrees. How are these regions different than the South? Future transportation research should consider

these issues seriously. Understanding these issues will help to clarify the complex relationships of transportation infrastructures with different development sectors at different geographic levels. It will ultimately contribute to filling the literature gap and improving our holistic understanding of transportation infrastructures when all three modes are competing. In addition, it is relevant because the new administration is planning for a vast investment in transportation infrastructures.

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Compliance with Ethical Standards

Conflict of interest We declare that we have no conflict of interest.

Appendix

See Figs. 6, 7, 8 and 9.

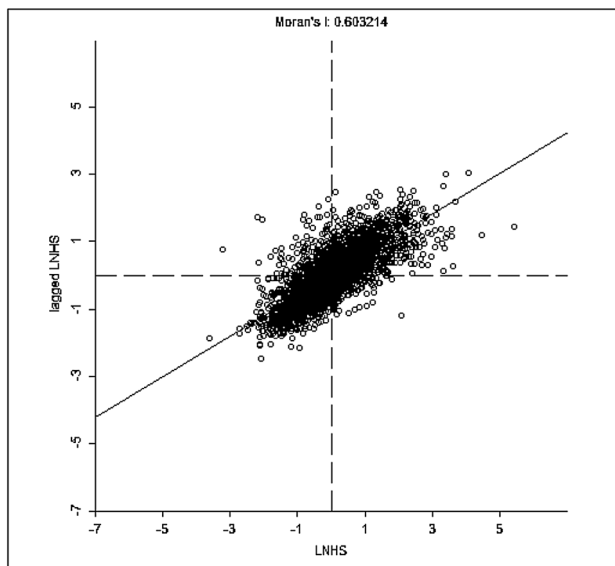


Fig. 6 Moran's I for 1970–2010 change in high school graduate. LNHS = natural log of change in high school graduate. The first-order Rook's contiguity weight matrix is used

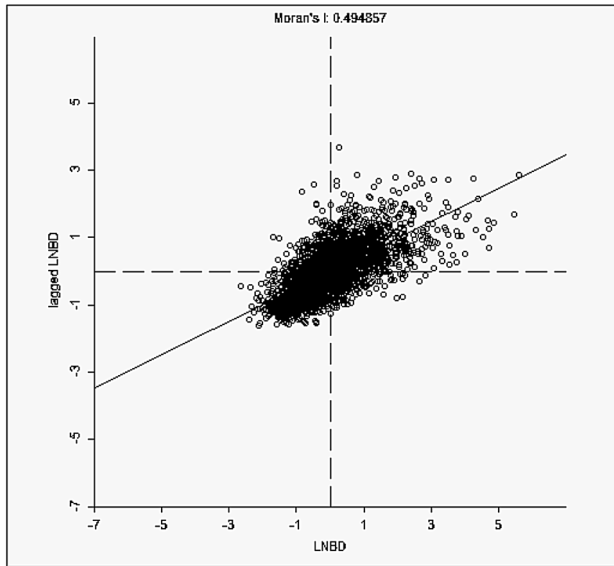


Fig. 7 Moran's I for 1970–2010 change bachelor degree. LNBD = natural log of change in bachelor's degree. The first-order Rook's contiguity weight matrix is used

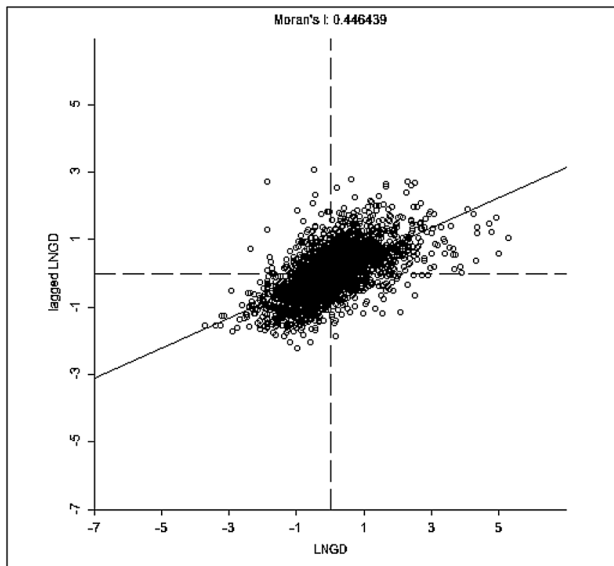


Fig. 8 Moran's I for 1970–2010 change in graduate degree. LNGD = natural log of change in graduate degree. The first-order Rook's contiguity weight matrix is used

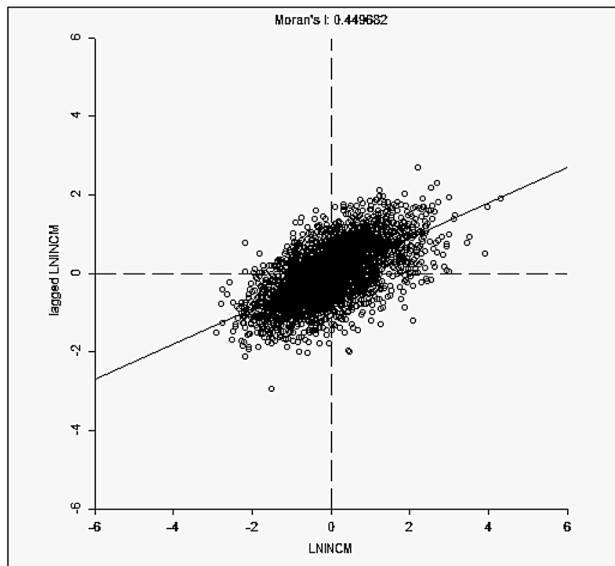


Fig. 9 Moran's I for 1970–2010 income change. LNINCM = natural log of income change. The first-order Rook's contiguity weight matrix is used

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